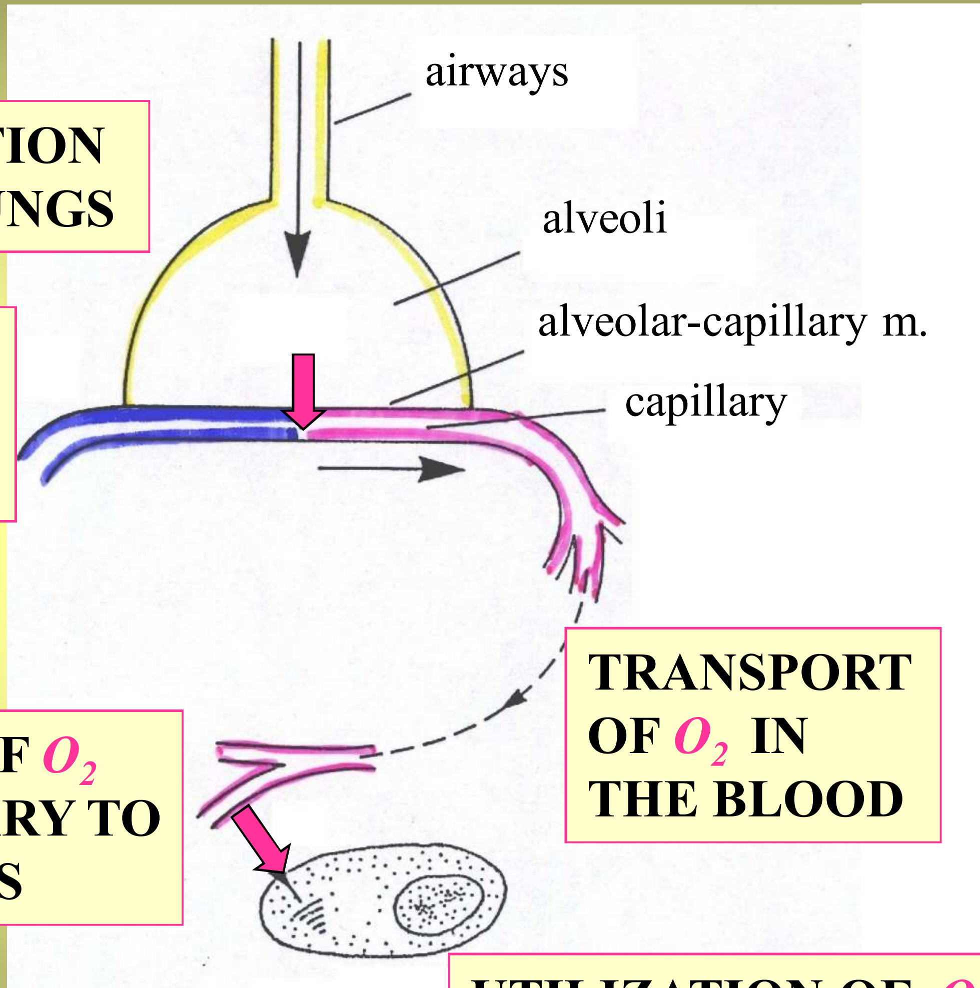
RESPIRATORY SYSTEM

RESPIRATORY FUNCTIONS
MECHANICS OF RESPIRATORY SYSTEM
GAS TRANSPORT

STOMATOLOGY

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

INTERNAL RESPIRATION

AT REST

O_2 UPTAKE ~300 ml / min

CO_2 OUTPUT ~250 ml / min

- I PHYSIOLOGY OF AIR PASSAGES
- II BASIC MEASURABLE PARAMETERS
- III ACTIVE AND PASSIVE FORCES
- IV COMPOSITION OF ALVEOLAR AIR
- V ALVEOLAR-CAPILLARY MEMBRANE
- VI TRANSPORT OF O_2 AND CO_2 IN THE BLOOD

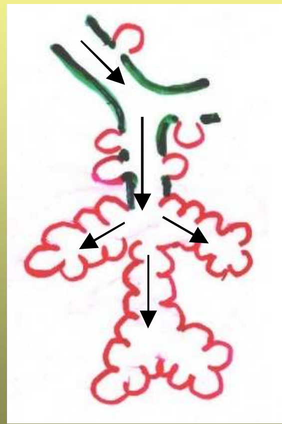
AIR PASSAGES

ANATOMICAL DEAD SPACE –CONDUCTING ZONE

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

Other physiological functions:

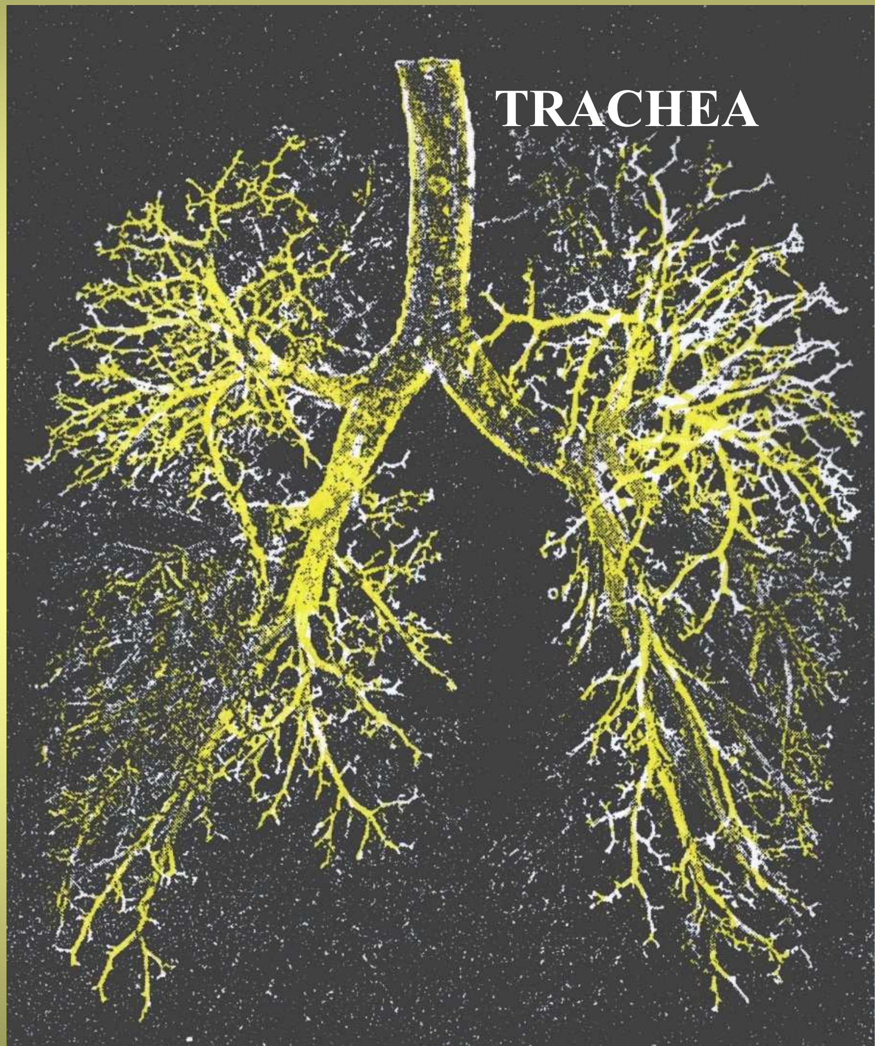
- air is warmed, cleaned and takes up water vapour
- respiratory reflex responses to the irritants
- speech and singing (function of larynx)



RESPIRATORY ZONE
(GAS EXCHANGE)

Total alveolar area ~100 m^2

CAST OF HUMAN AIR PASSAGES



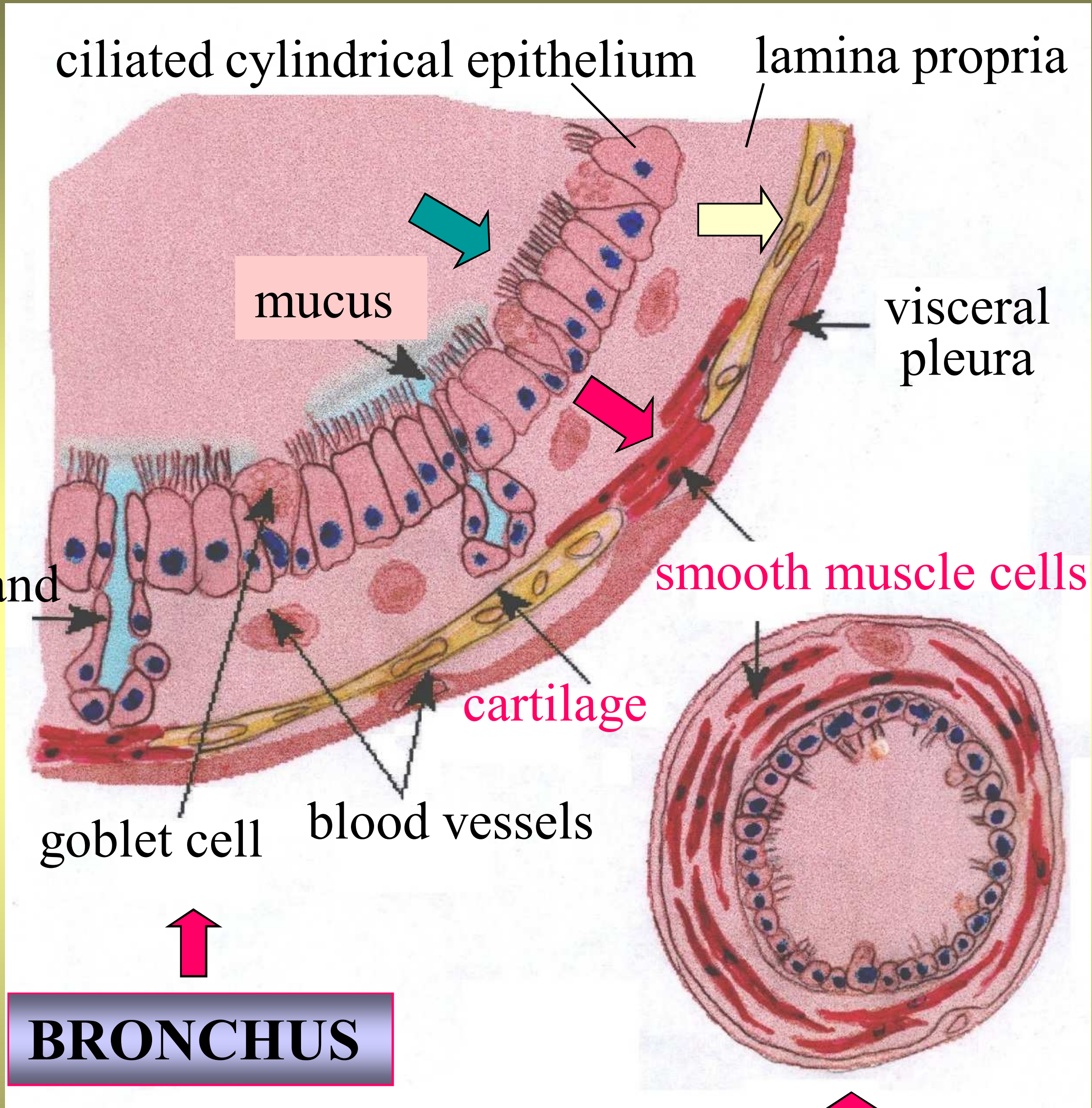
BRONCHI

BRONCHIOLES

TERMINAL BRONCHIOLES

AERODYNAMIC RESISTENCE

AUTONOMIC INNERVATION of smooth muscle cells



Muscarinic receptors:
Acetylcholine activates
bronchoconstriction

β-adrenergic receptors:
Noradrenaline activates
bronchodilatation

BRONCHUS

TERMINAL BRONCHIOLE

$\varnothing < 1$ mm

I AIR PASSAGES

II MEASURABLE PARAMETERS

- DEAD SPACE
- LUNG VOLUMES
- FUNCTIONAL INVESTIGATION
- CHARACTERISTIC PRESSURES

III ACTIVE AND PASSIVE FORCES

- RESPIRATORY MUSCLES
- LUNGS ELASTICITY
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- WORK OF BREATHING

IV COMPOSITION OF ALVEOLAR AIR

V ALVEOLAR-CAPILLARY MEMBRANE

VI TRANSPORT OF GASSES (O_2 and CO_2)

V_T tidal volume ~ **500 ml**

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

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

$$V_T = V_A + V_D$$

f = 12/min

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

PULMONARY MINUTE VENTILATION

6 l/min

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

ALVEOLAR VENTILATION

4.2 l/min

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

DEAD SPACE VENTILATION

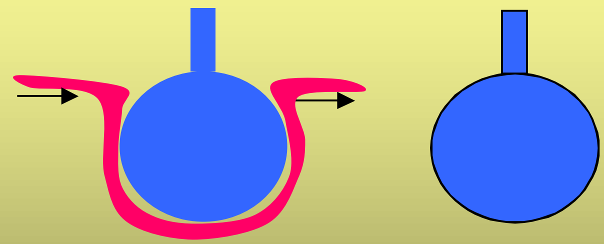
1.8 l/min

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

I AIR PASSAGES

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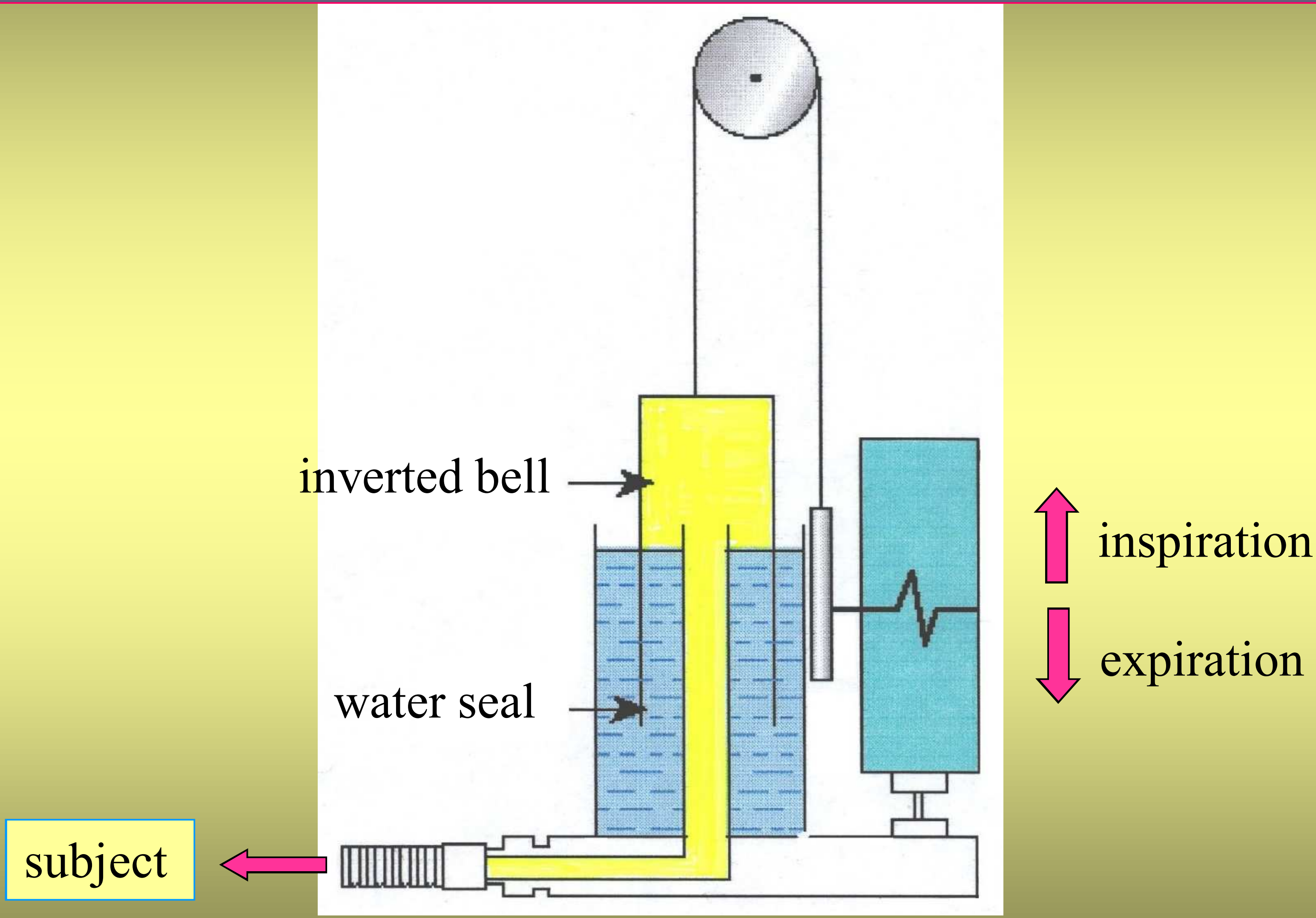
VI TRANSPORT OF GASSES (O_2 and CO_2)

SPIROMETRY

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



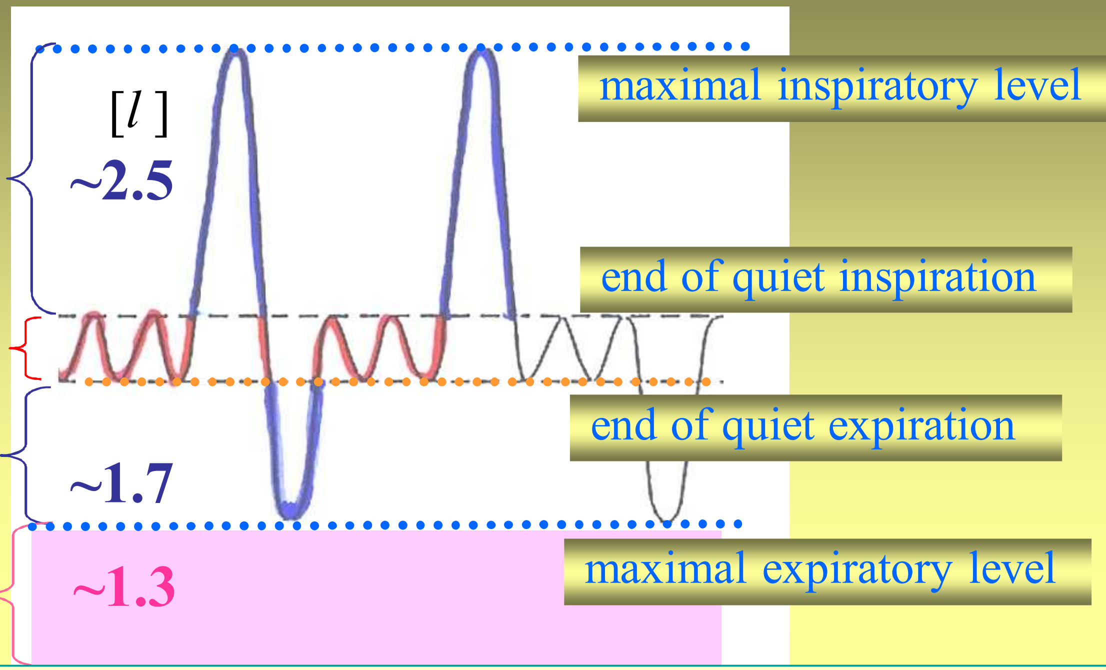
LUNG VOLUMES

INSPIRATORY RESERVE VOLUME *IRV*

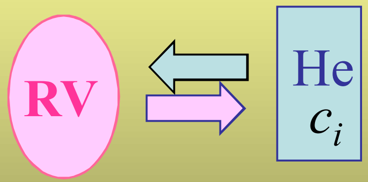
TIDAL VOLUME V_T

EXPIRATORY RESERVE VOLUME *ERV*

RESIDUAL VOLUME *RV*



DILUTION METHOD
He

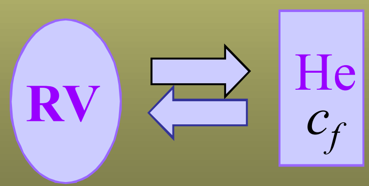


reservoir (V_r)

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)

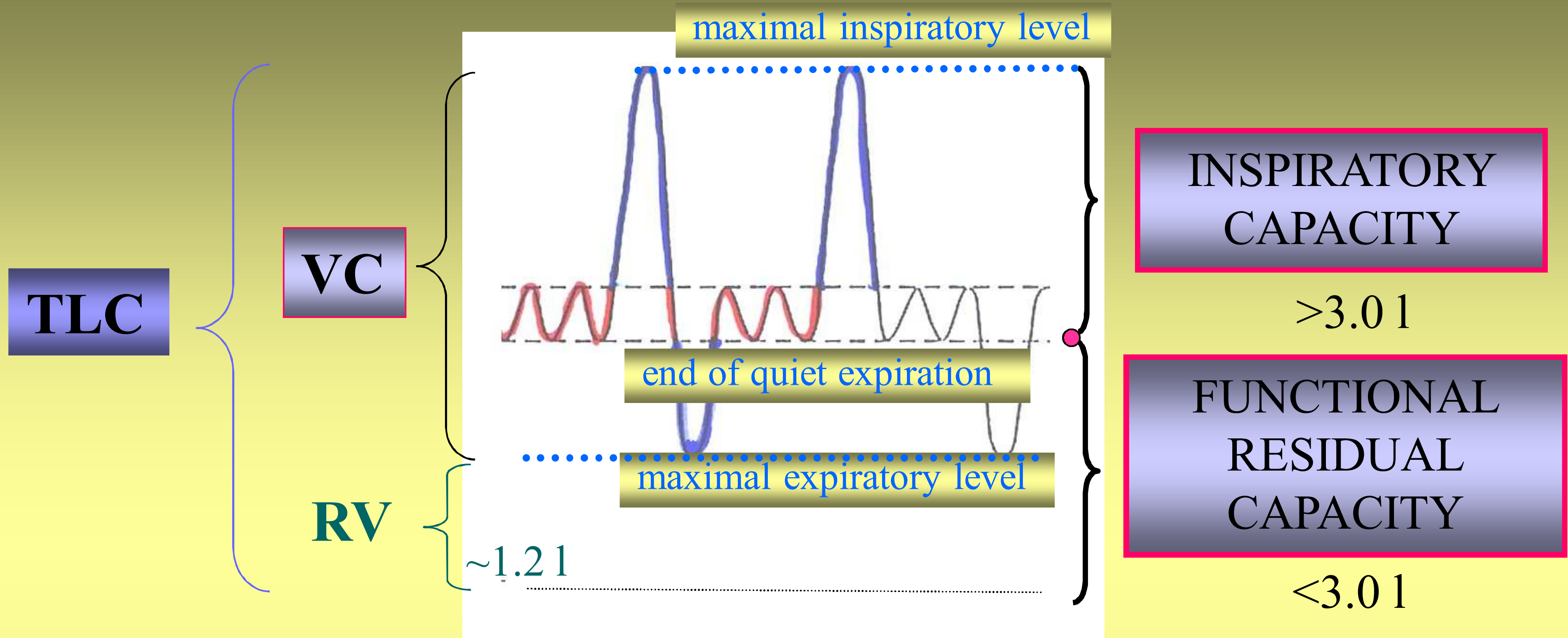
⇒ Equilibration of the air in the residual volume and reservoir

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



reservoir (V)

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



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

I AIR PASSAGES

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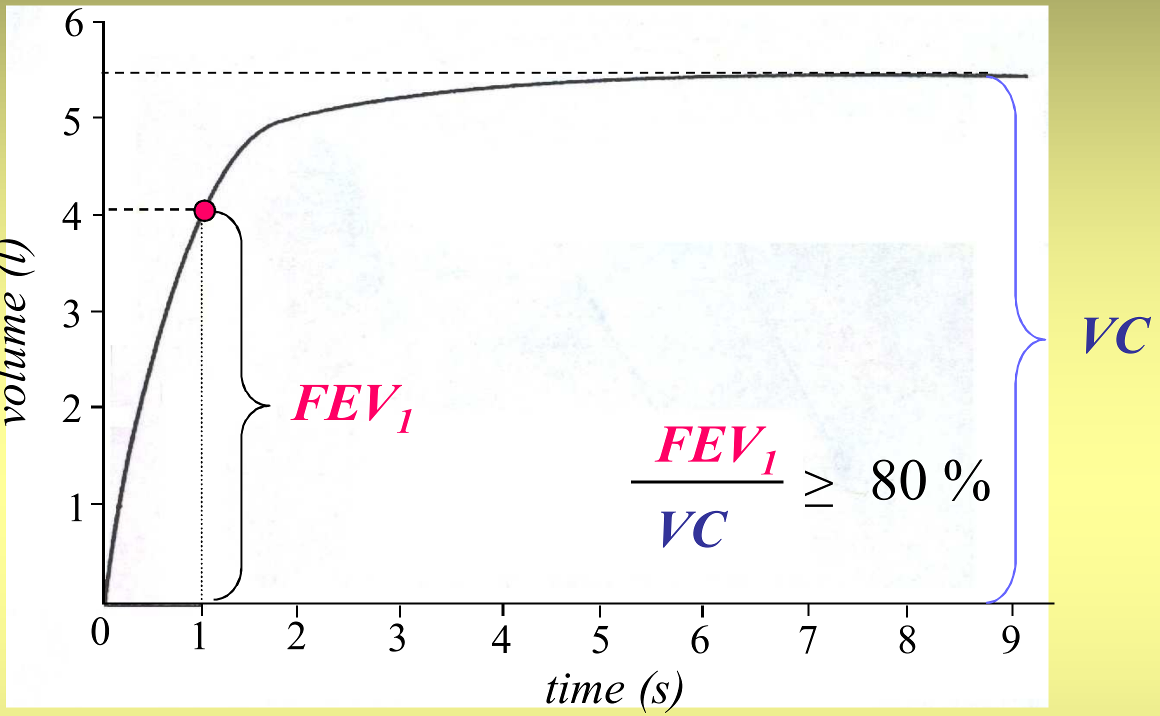
FUNCTIONAL INVESTIGATION OF THE LUNGS

- **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)

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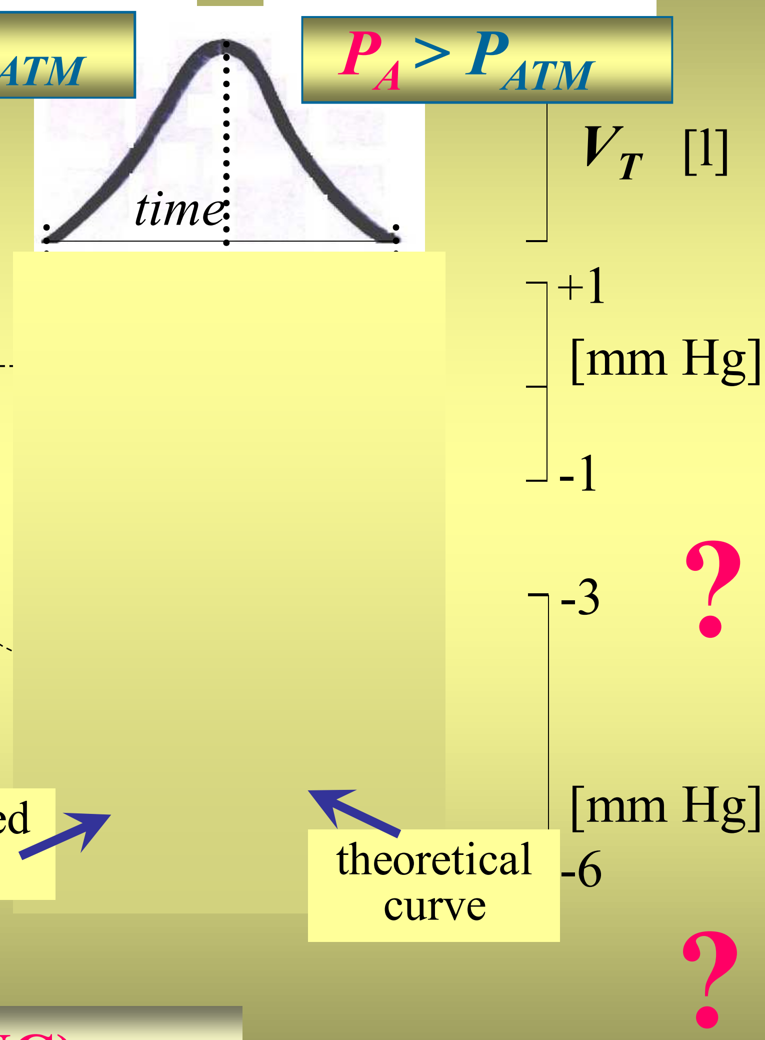
$P.V = const \Rightarrow P = \frac{const}{V}$

TIME COURSE OF PRESSURES AT QUIET RESPIRATION

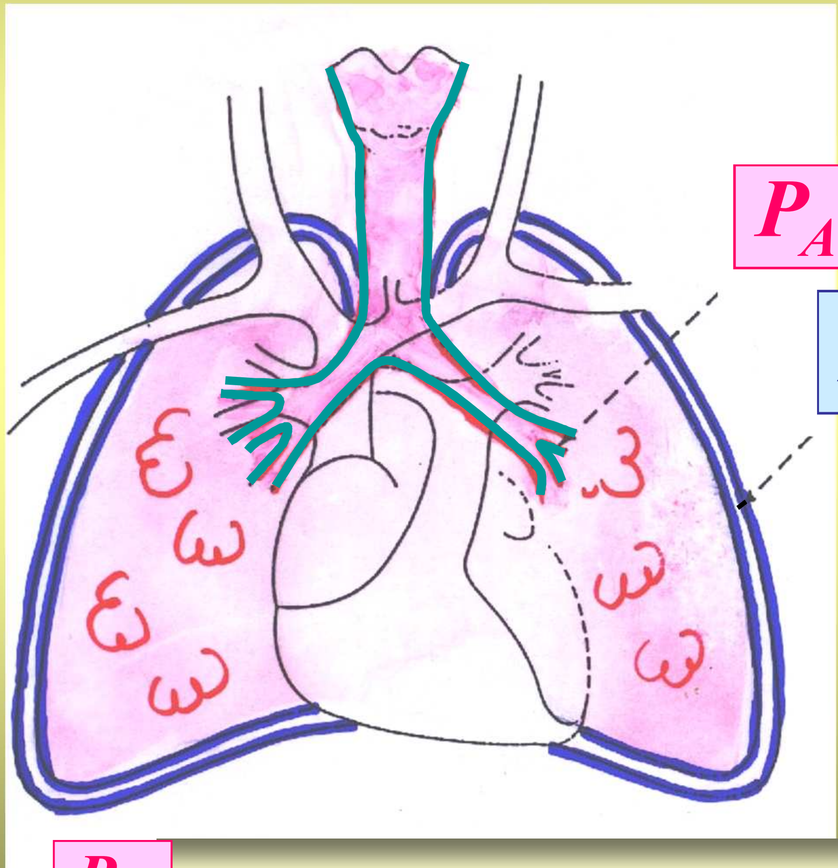
INSPIRATION $P_A < P_{ATM}$

EXPIRATION $P_A > P_{ATM}$



P_A

P_{PL}



P_A **ALVEOLAR (INTRAPULMONARY, LUNG)**

P_{PL} **INTRAPLEURAL (INTRATHORACIC)**

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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

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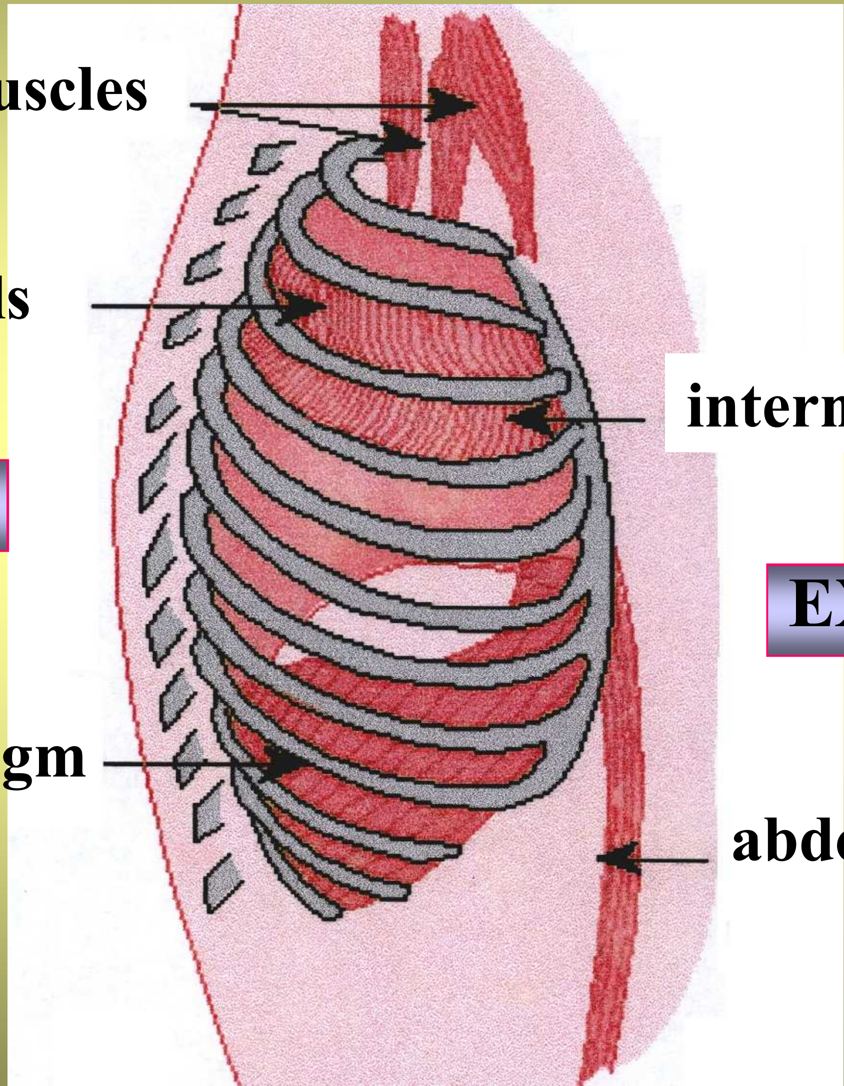
RESPIRATORY MUSCLES



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, …)

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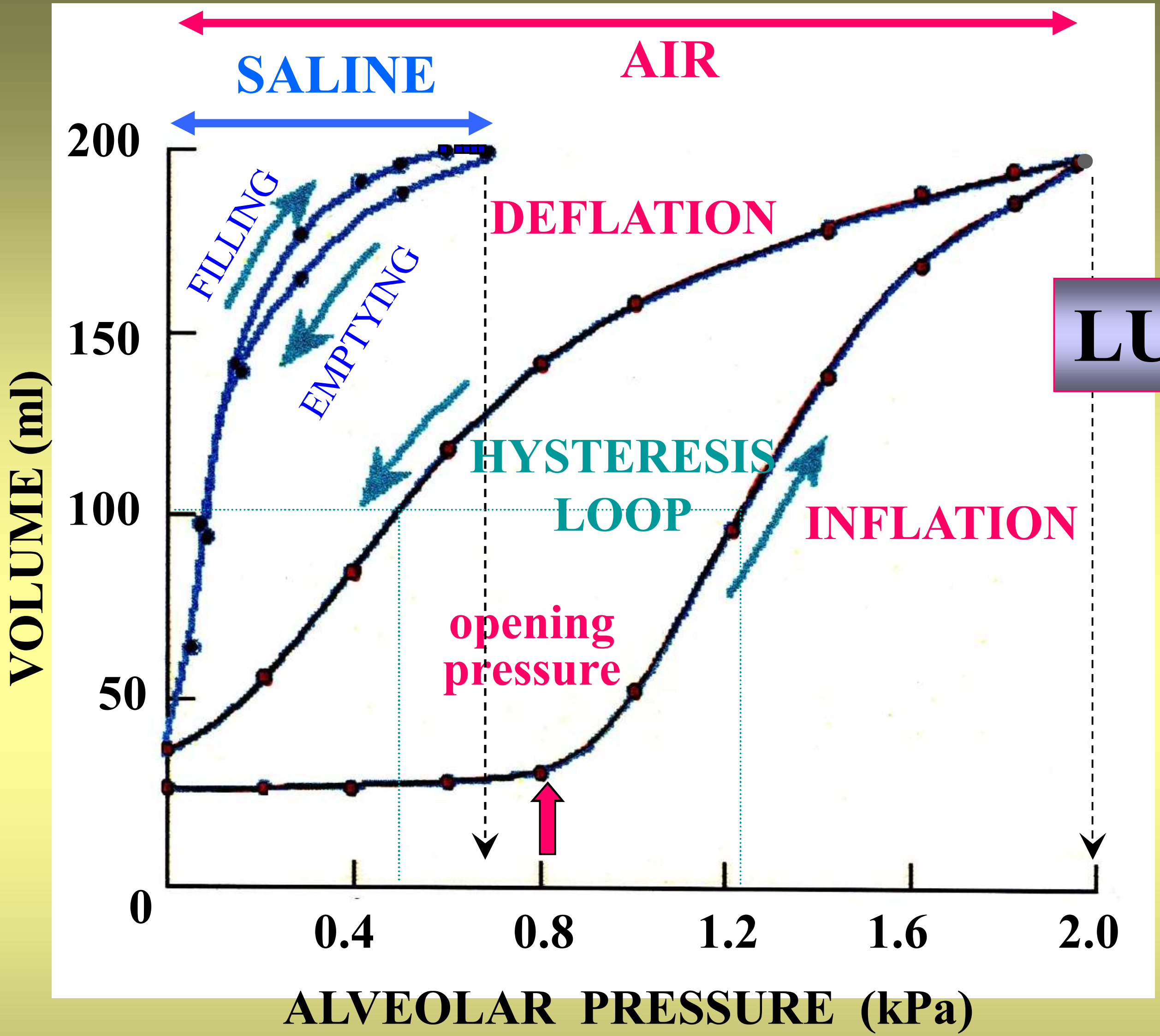


LUNGS ELASTICITY

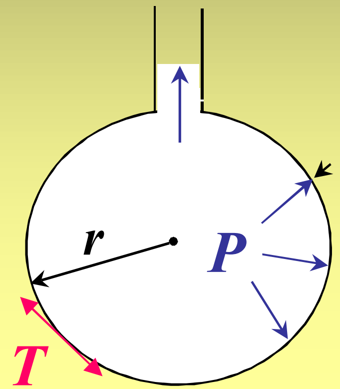
1 *kPa* = 7.5 *mm Hg*

LUNGS ELASTICITY

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

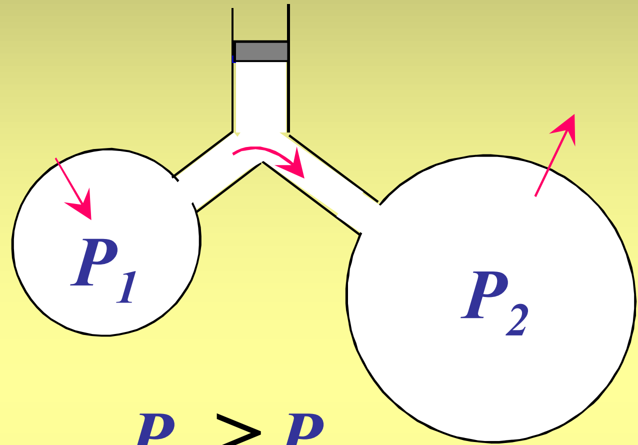
LAW OF LAPLACE

spherical structures



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

?



$P_1 > P_2$

- P pressure (transmural ΔP)
- r radius
- T surface tension

PATHOLOGY

- **COLLAPSE OF ALVEOLI - ATELECTASIS**
- **EXPANSION OF ALVEOLI**

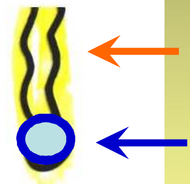
SURFACTANT

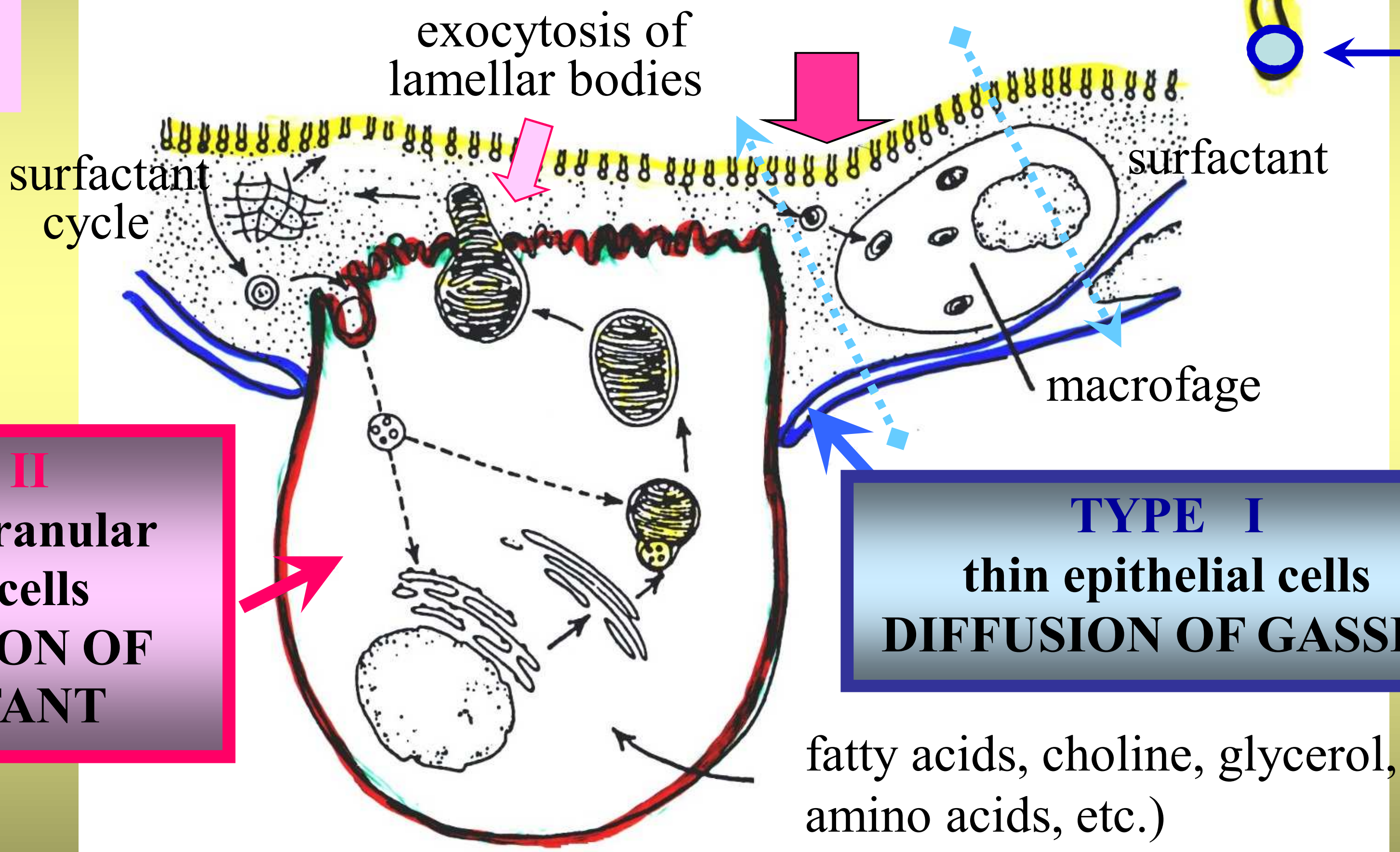
SURFACE TENSION LOWERING AGENT

EFFECT MAINLY IN THE EXPIRED POSITION

PHOSPHOLIPID
dipalmitoyl
fosfatidyl cholin

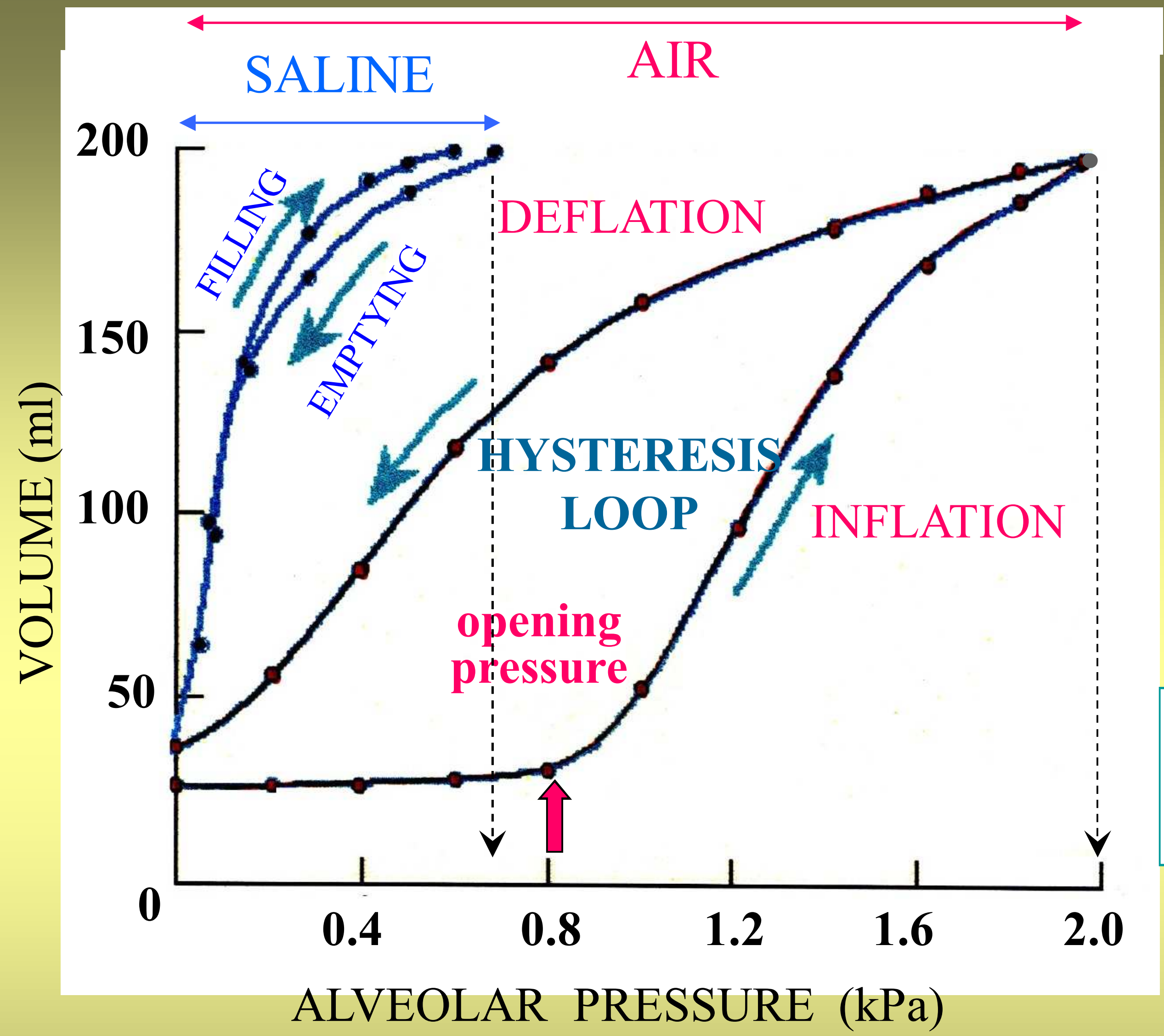
ALVEOLAR EPITHELIAL CELLS





TYPE II
specialized granular epithelial cells
PRODUCTION OF SURFACTANT

TYPE I
thin epithelial cells
DIFFUSION OF GASSES



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**

I AIR PASSAGES

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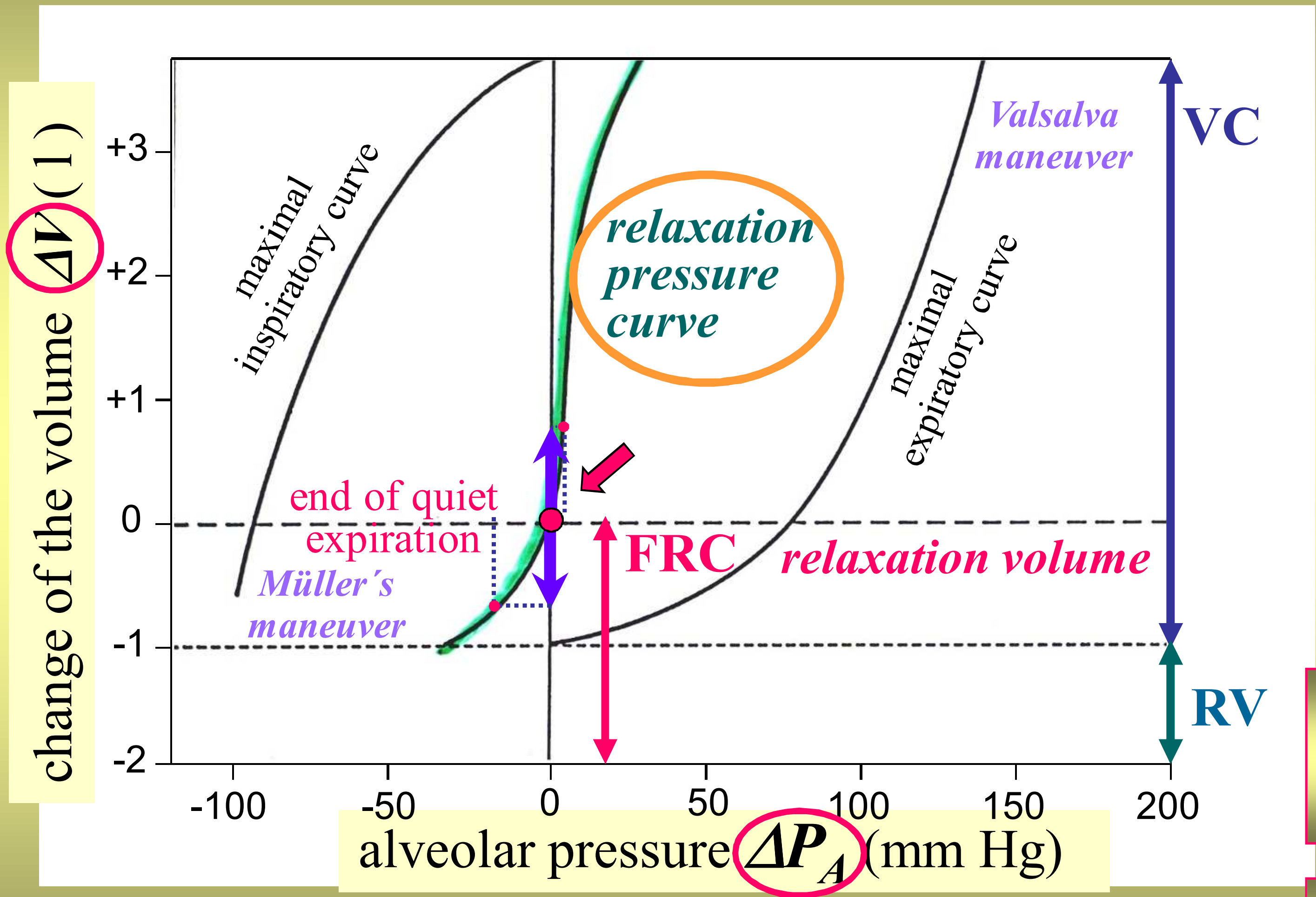
V ALVEOLAR-CAPILLARY MEMBRANE

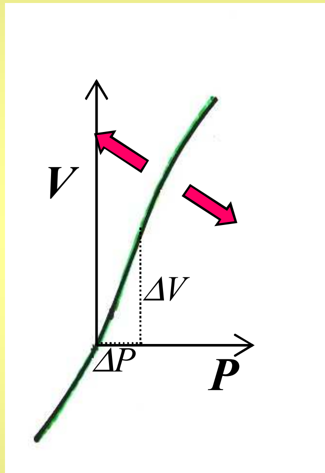
VI TRANSPORT OF GASSES (O_2 and CO_2)

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)

I AIR PASSAGES

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VI TRANSPORT OF GASSES (O_2 and CO_2)

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%)

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➡ **IV COMPOSITION OF ALVEOLAR AIR**

V ALVEOLAR-CAPILLARY MEMBRANE

VI TRANSPORT OF GASSES (O_2 and CO_2)

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

INSPIRED AIR

O_2	158.8
CO_2	0.3
N_2	601.0
…	

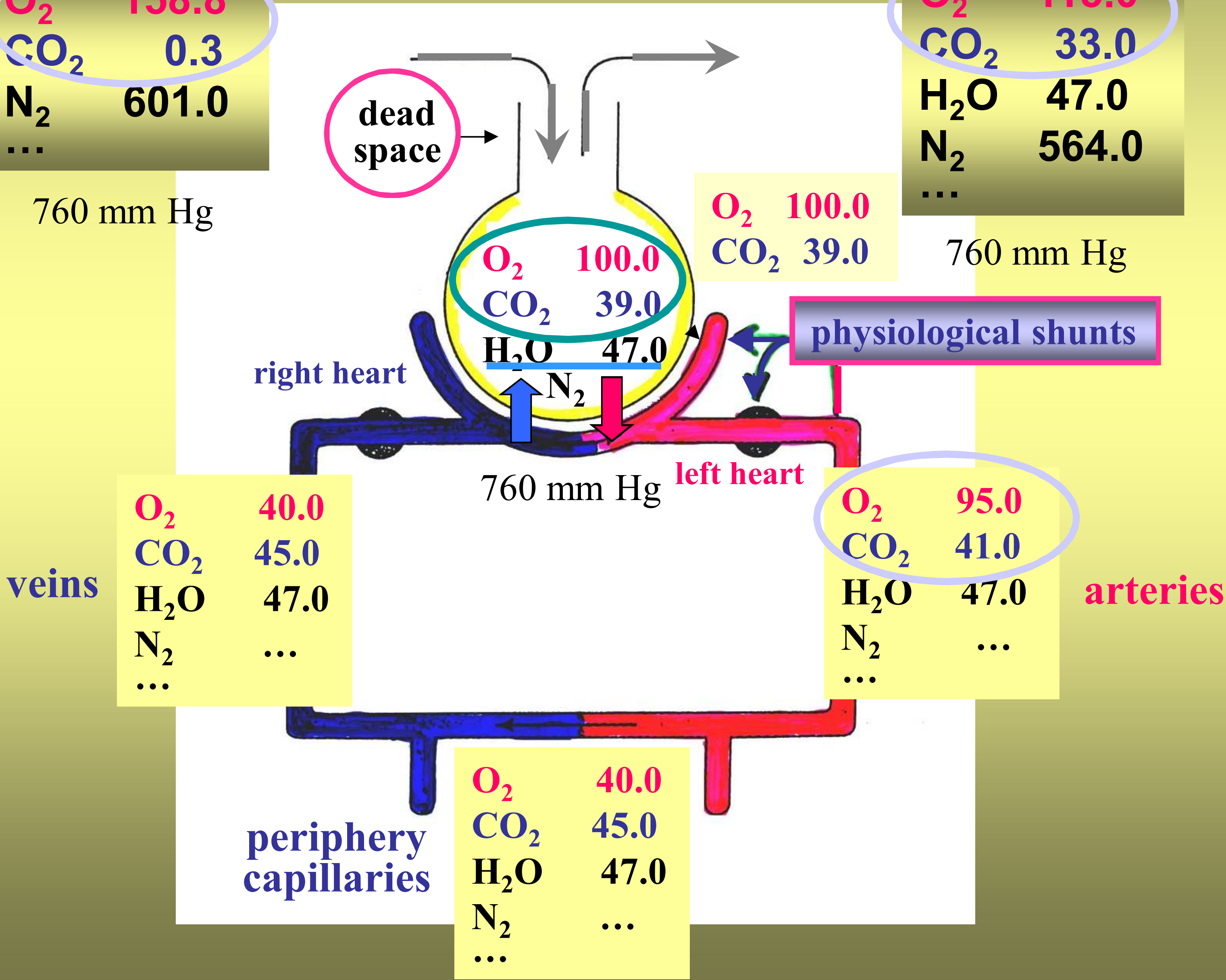
760 mm Hg

EXPIRED AIR

O_2	115.0
CO_2	33.0
H_2O	47.0
N_2	564.0
…	

760 mm Hg

?



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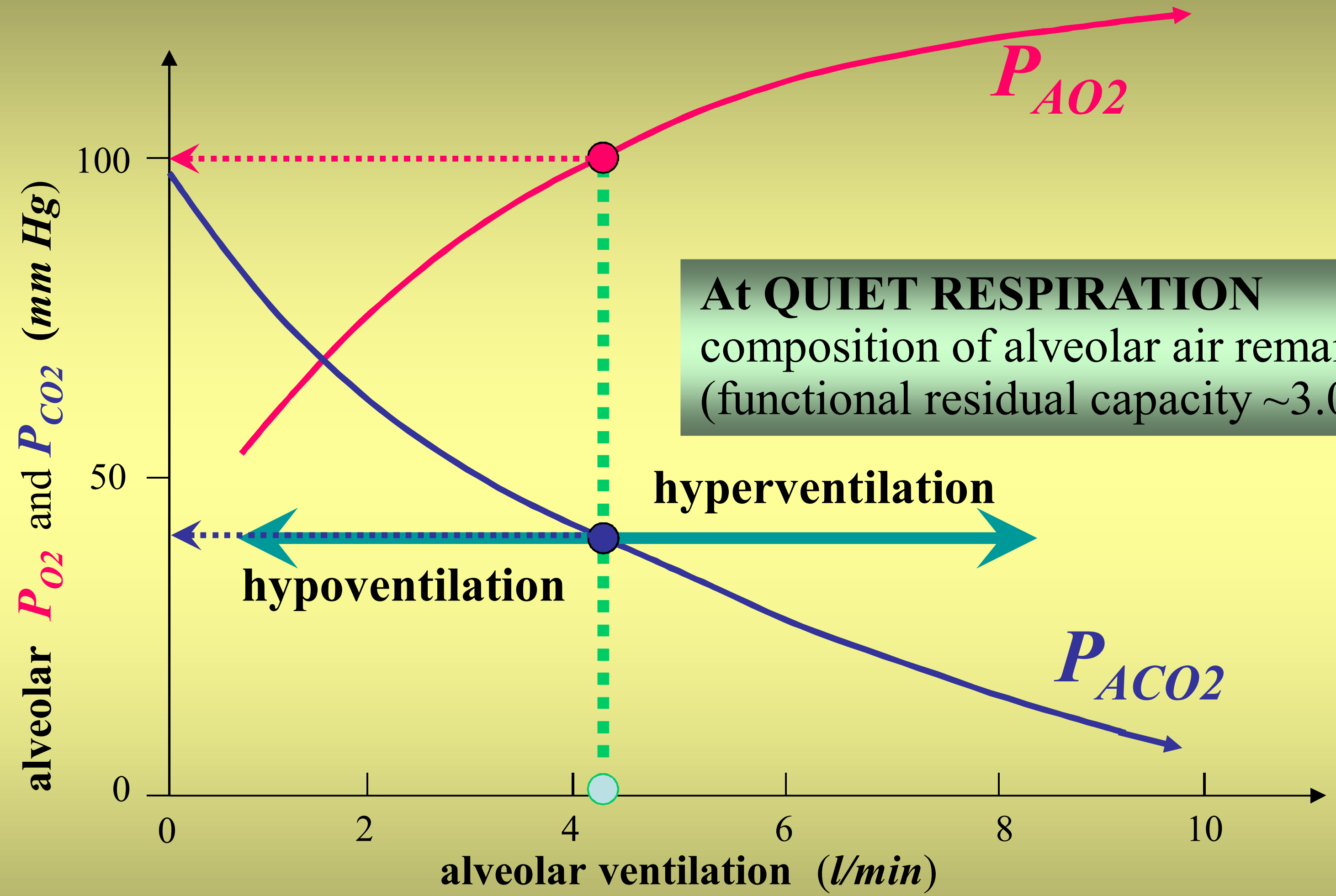
Alveolar P_{O2} and P_{CO2} at voluntary hypo- and hyperventilation



hyperventilation → hypocapnia → respiratory alkalosis

hypoventilation → hypercapnia → respiratory acidosis

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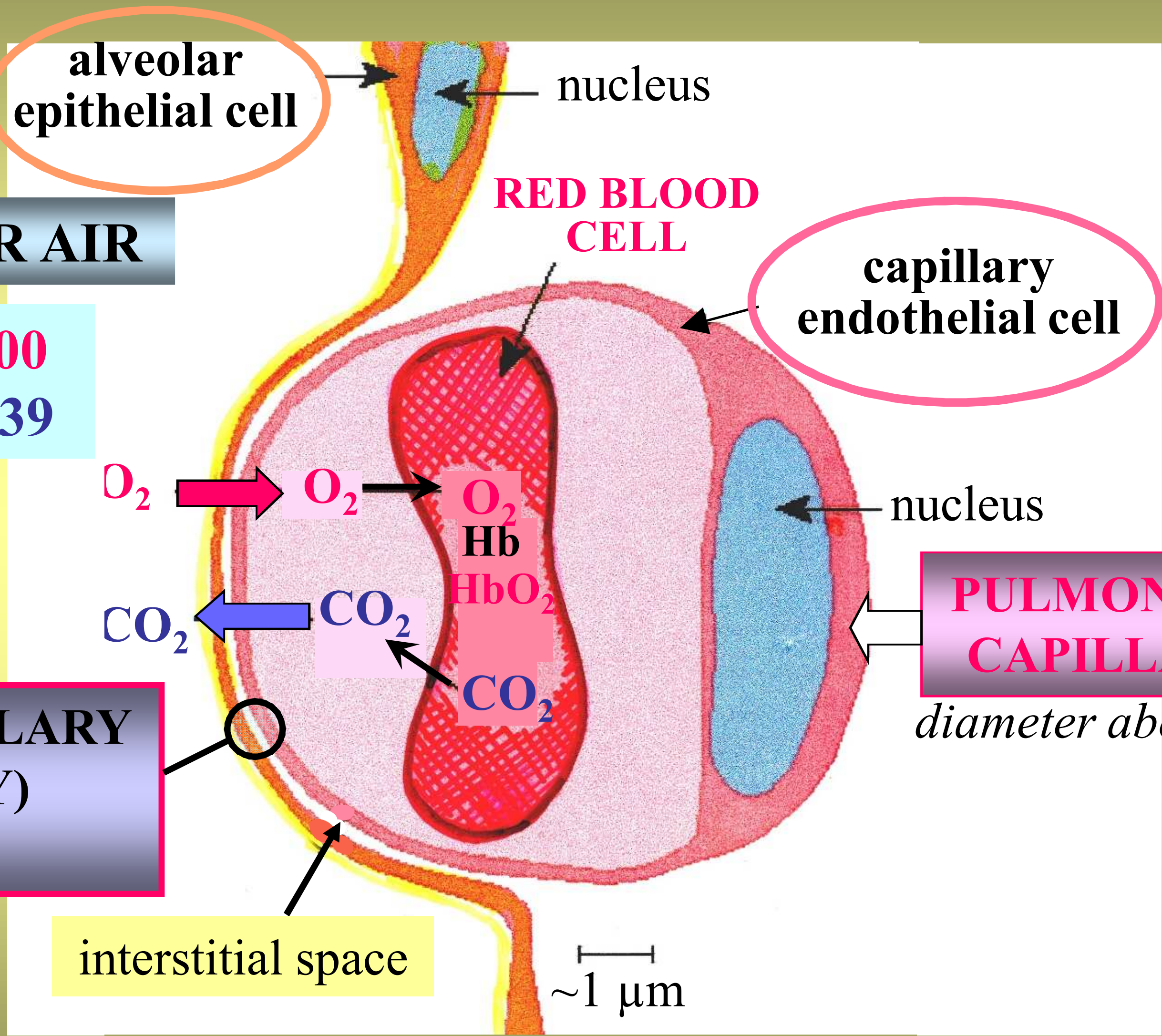
ALVEOLAR-CAPILLARY (RESPIRATORY) MEMBRANE

DIFFUSION OF GASES

ALVEOLAR AIR

P_{O2} = 100
P_{CO2} = 39
(mm Hg)



ALVEOLAR-CAPILLARY (RESPIRATORY) MEMBRANE

PULMONARY CAPILLARY

diameter about 5 µm

0.75 s

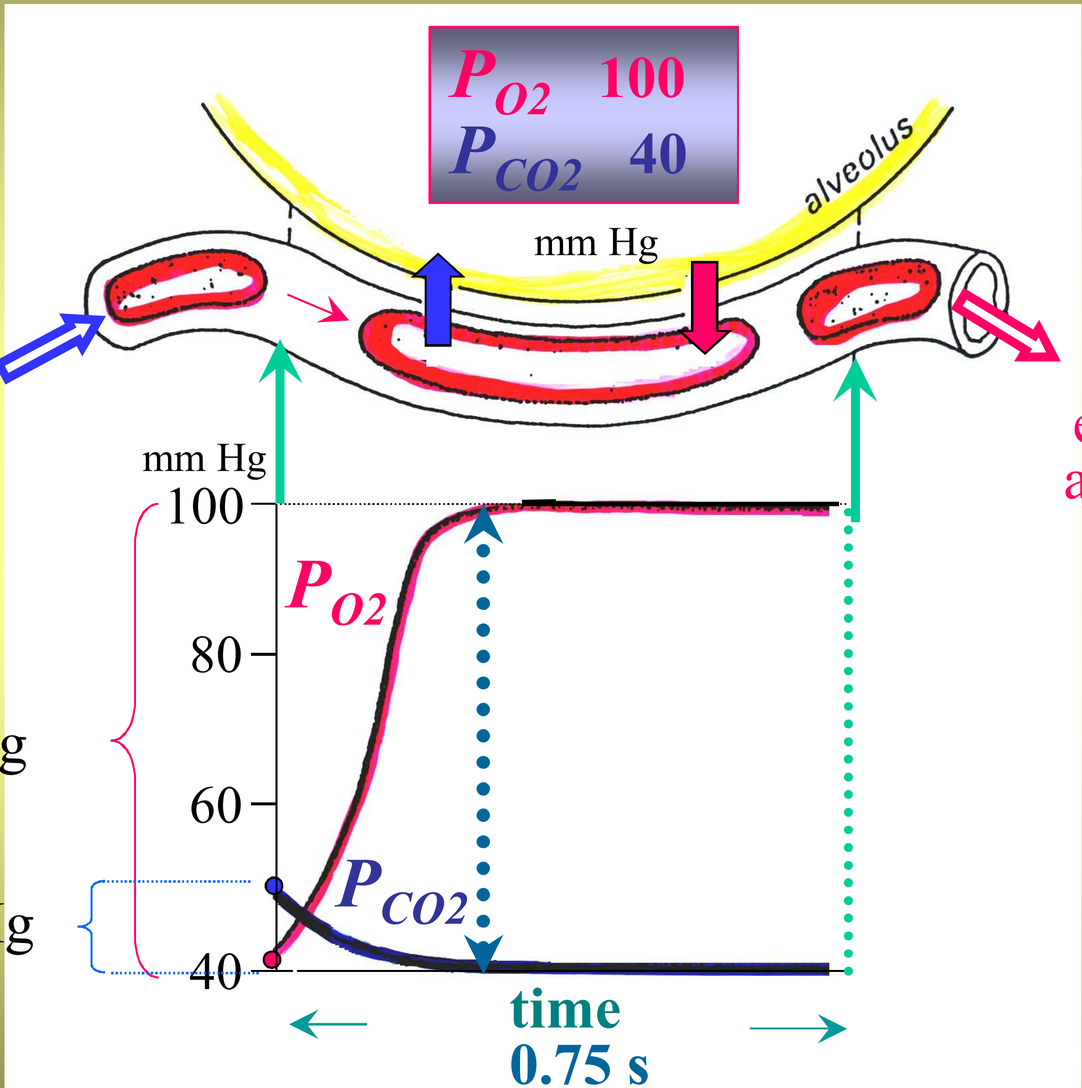
time interval of erythrocyte contact with respiratory membrane at rest

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



P_{O2} 100
P_{CO2} 40

mm Hg

equalization with alveolar pressures

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

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

time interval of contact of erythrocyte with respiratory membrane at rest

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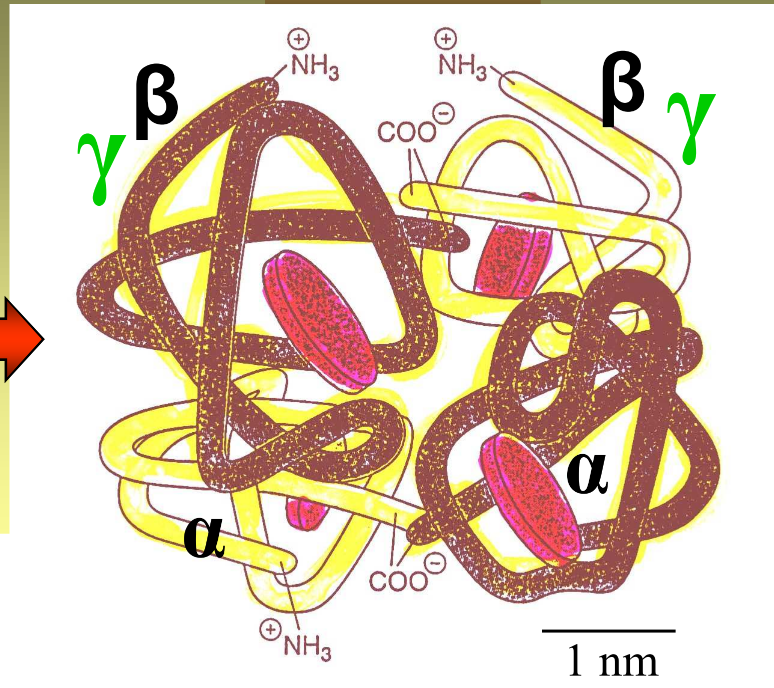
➡ **VI TRANSPORT OF GASSES (O_2 and CO_2)**

HAEMOGLOBIN

$Hb_4 + 4\ O_2 \leftrightarrow Hb_4O_8$

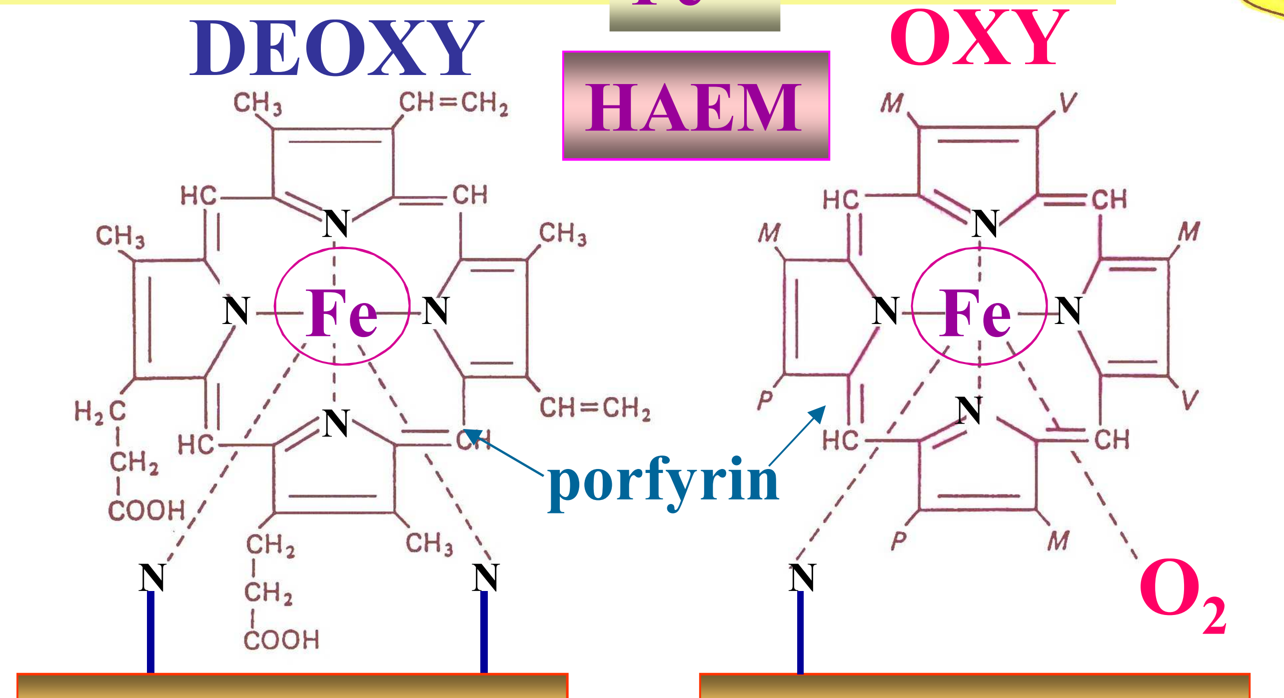
oxygenation

tetramer



Fe^{2+}

HAEM



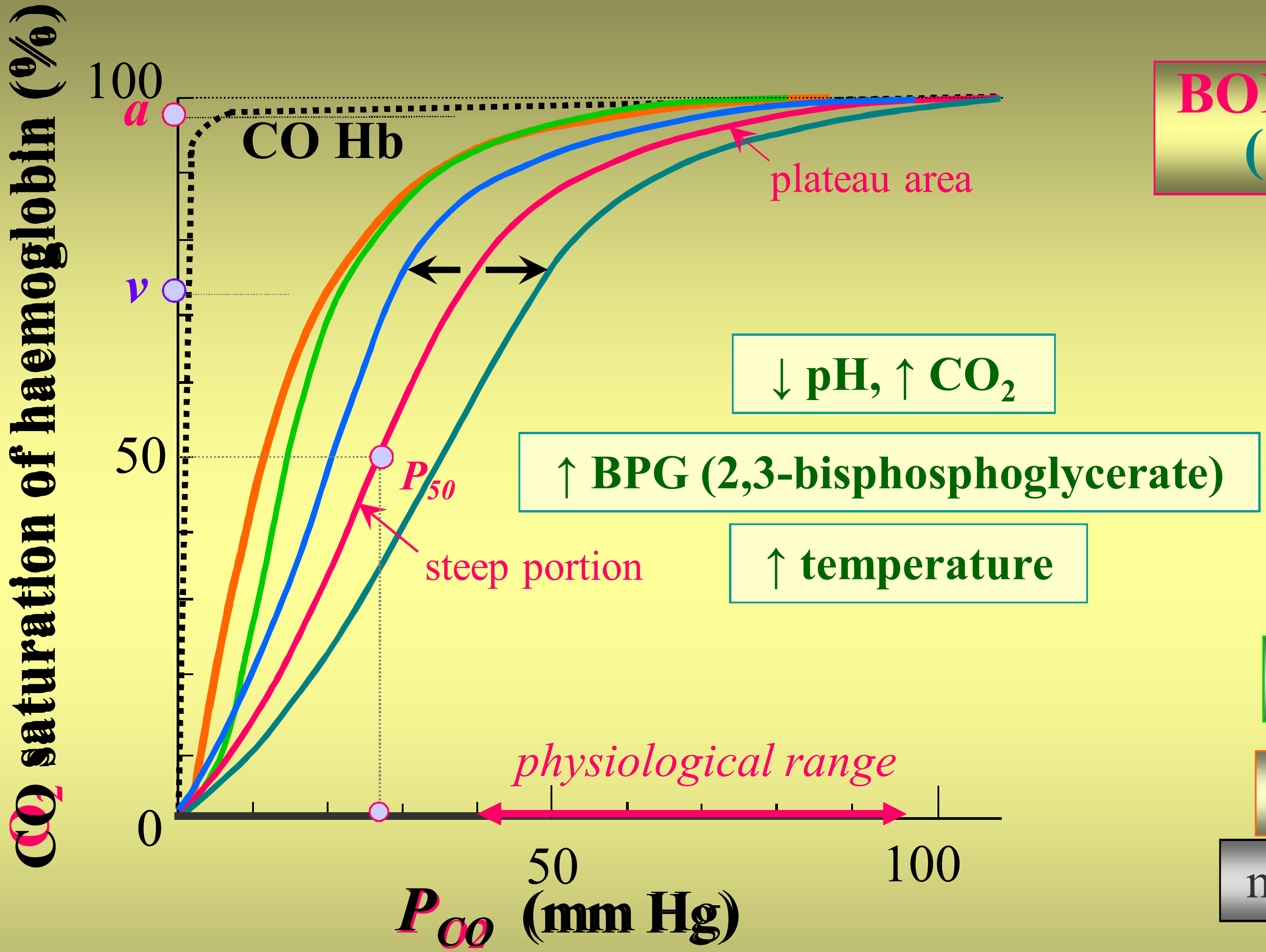
polypeptide chain

polypeptide chain

fetal Hb

Fe^{3+} (methaemoglobin)
oxidation

O_2–HAEMOGLOBIN DISSOCIATION CURVE



BOHR´S EFFECT
(↓ pH, ↑CO_2)

fetal Hb

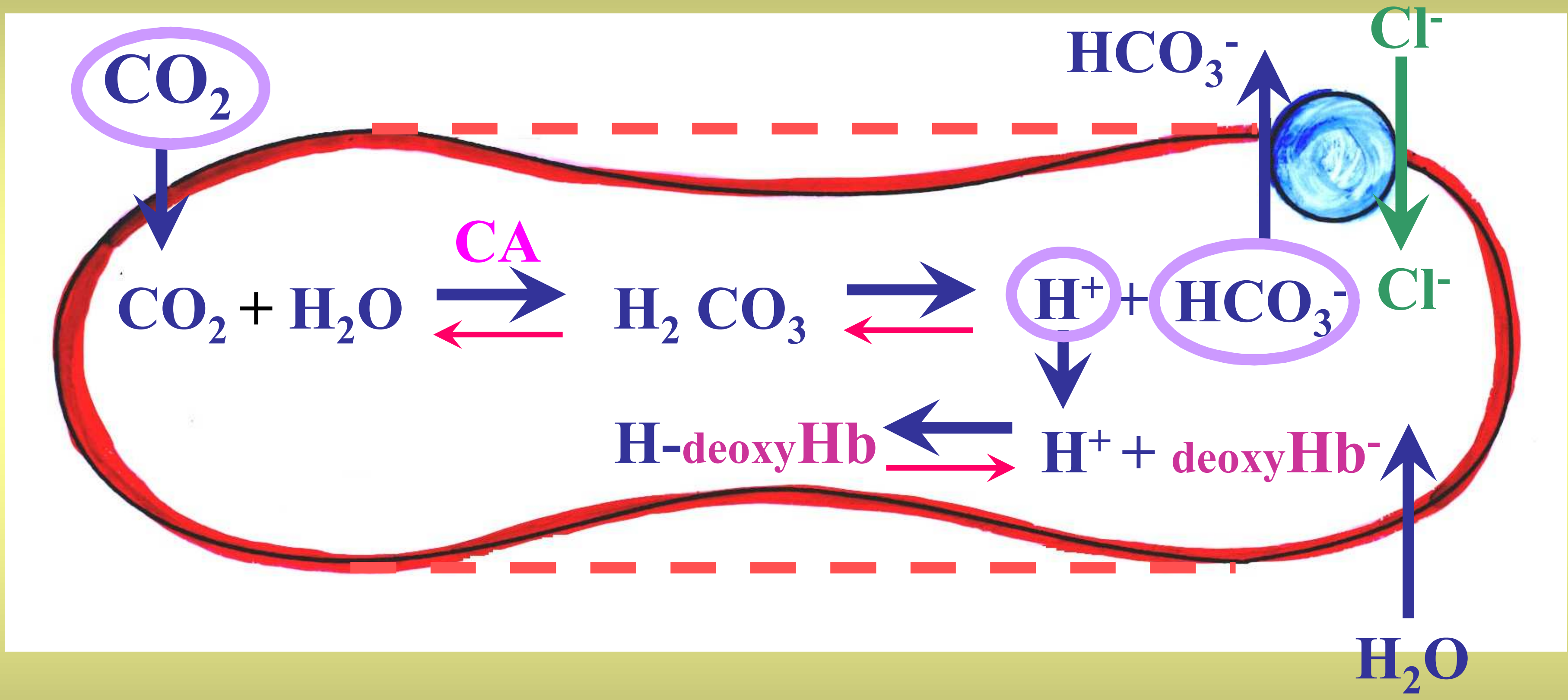
myoglobin

methaemoglobin

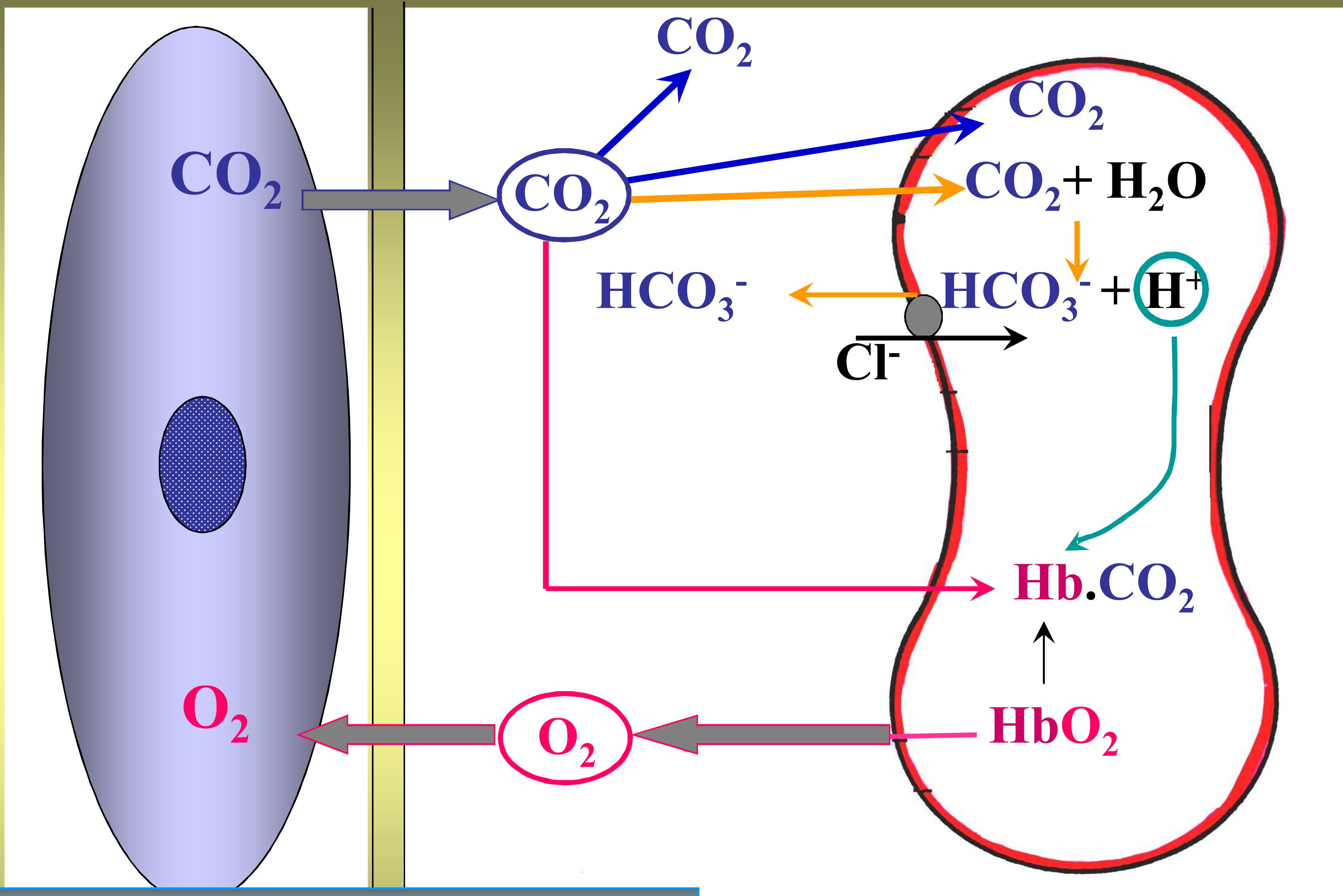
physically dissolved O_2 (1.4%)

TRANSPORT OF CO_2

HAMBURGER CHLORIDE SHIFT



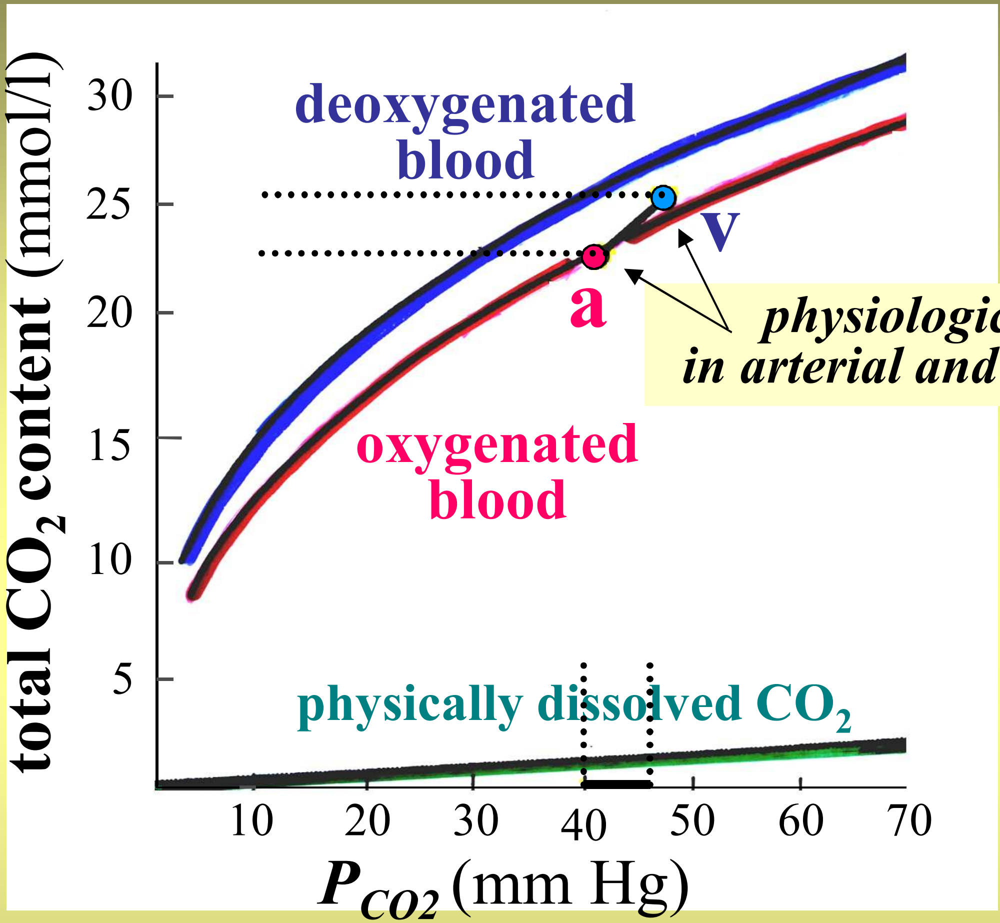
CA – carbonic anhydrase



- 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%)

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

END