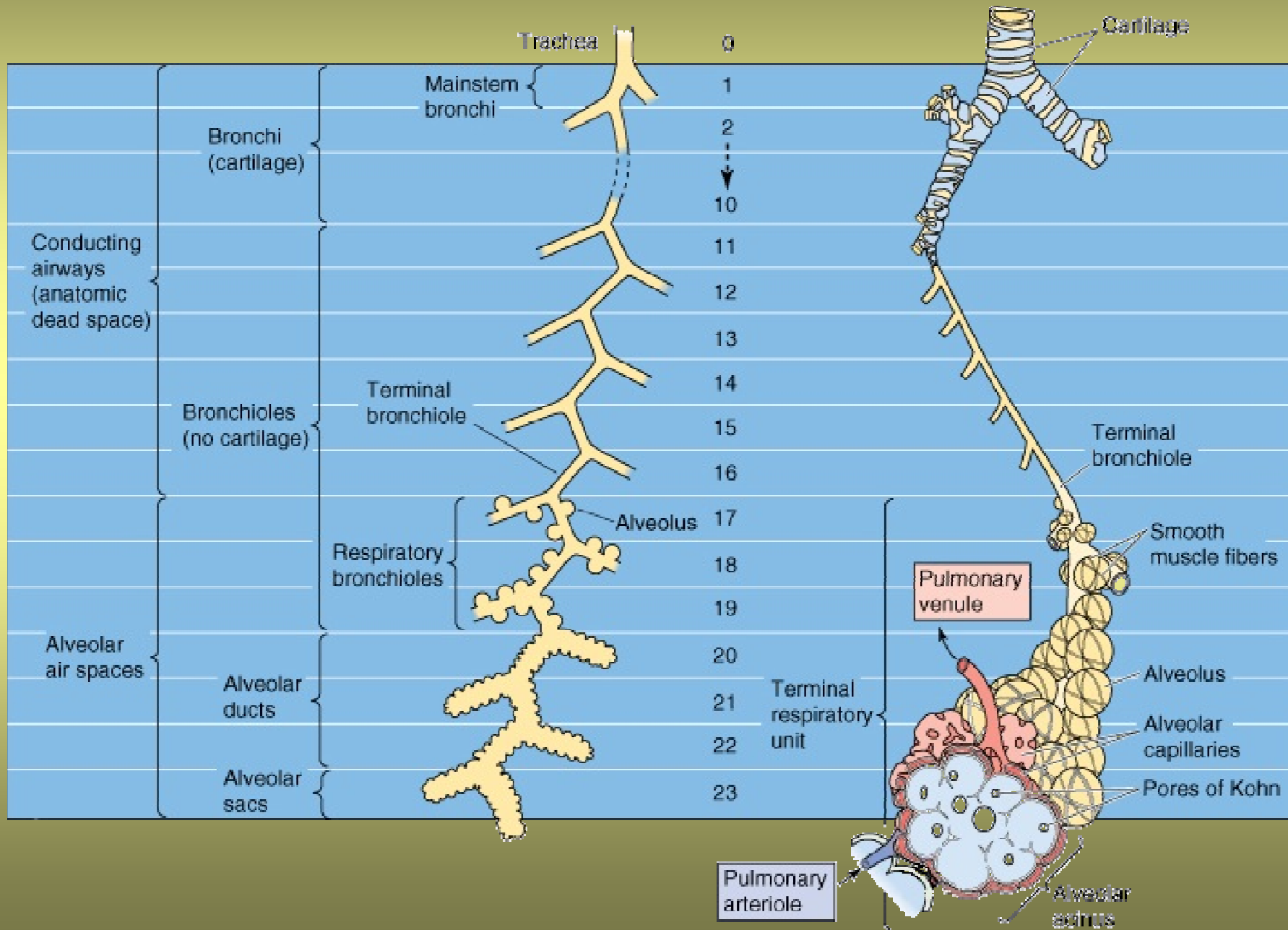


RESPIRATORY SYSTEM

**RESPIRATORY FUNCTIONS
MECHANICS OF RESPIRATORY SYSTEM
GAS TRANSPORT**

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



STEPS IN THE DELIVERY OF O_2 TO THE CELLS

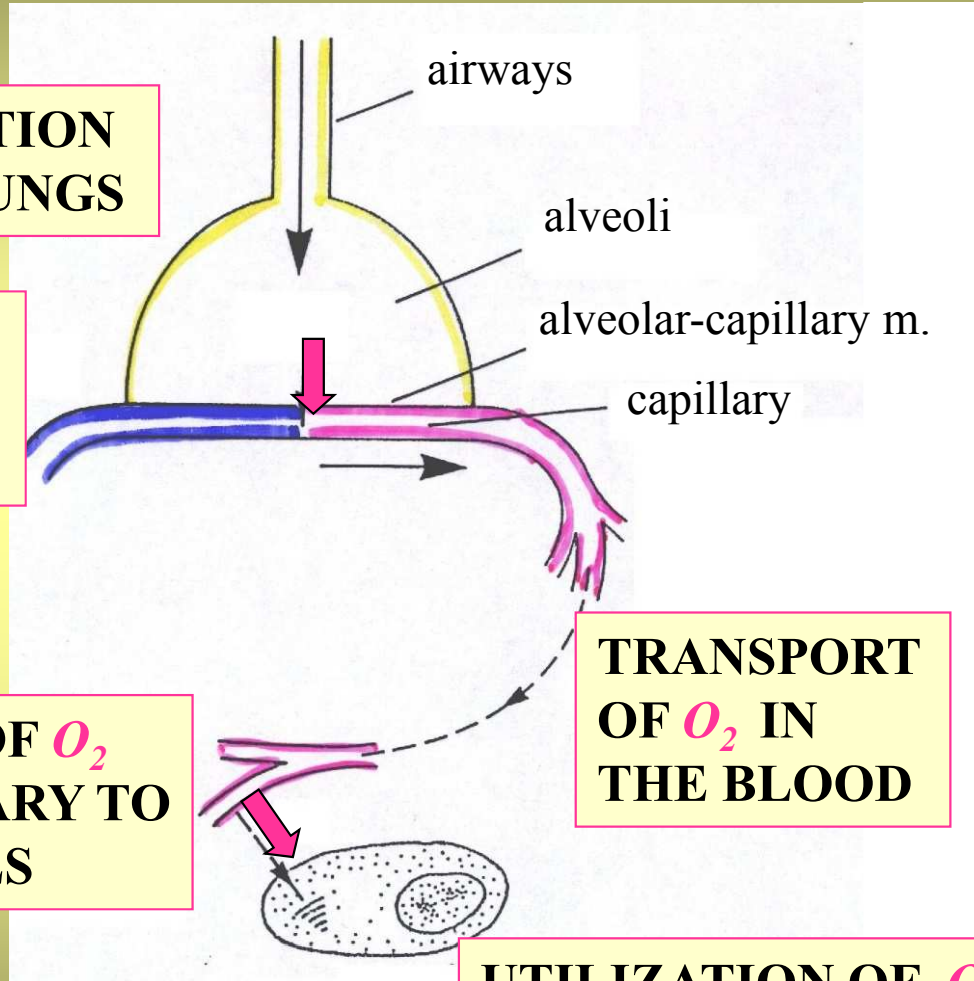
DIFFUSION OF O_2 ACROSS
ALVEOLAR-CAPILLARY
MEMBRANE

VENTILATION
OF THE LUNGS

DIFFUSION OF O_2
FROM CAPILLARY TO
THE CELLS

TRANSPORT
OF O_2 IN
THE BLOOD

UTILIZATION OF O_2
BY MITOCHONDRIA



AT REST

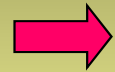
O_2 UPTAKE ~ 300 ml / min

CO_2 OUTPUT ~ 250 ml / min

INTERNAL RESPIRATION

AIR PASSAGES

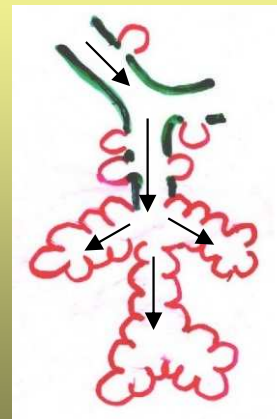
ANATOMICAL DEAD SPACE – **CONDUCTING ZONE**



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

Other physiological functions:

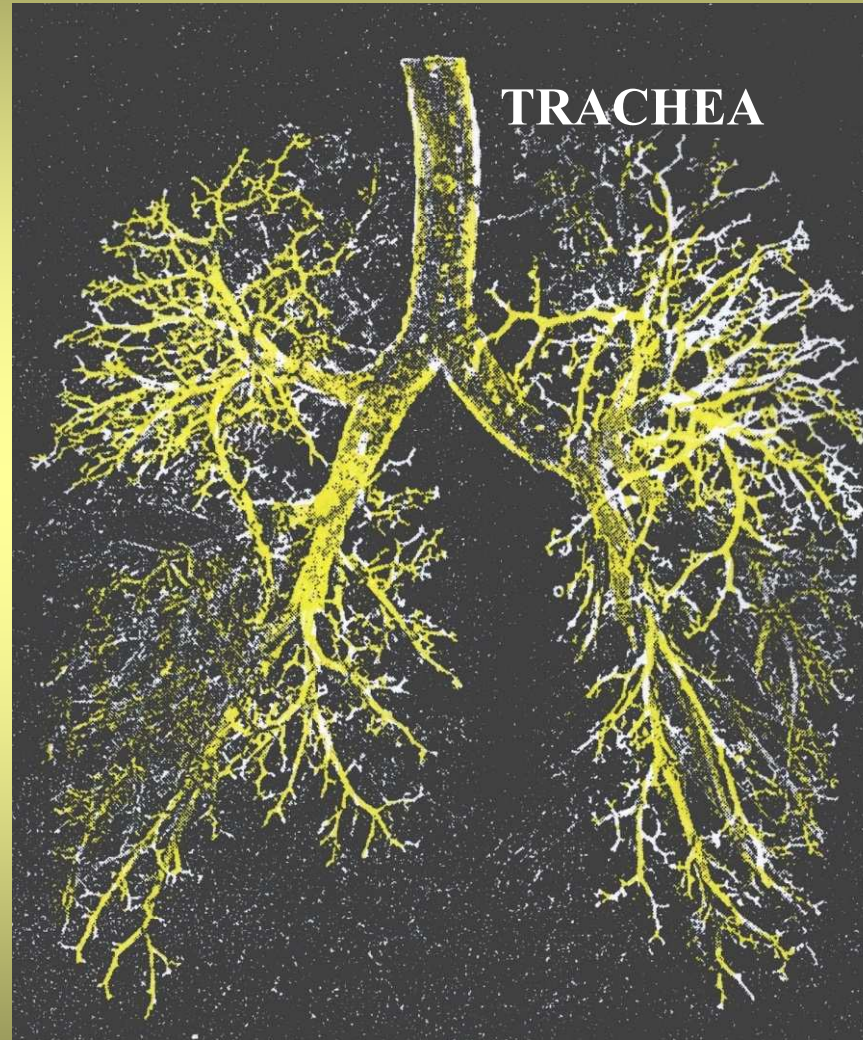
- air is warmed, cleaned and takes up water vapour
- respiratory reflex responses to the irritants
- speech and singing (function of larynx)



RESPIRATORY ZONE (GAS EXCHANGE)

Total alveolar area $\sim 100 \text{ m}^2$

CAST OF HUMAN AIR PASSAGES



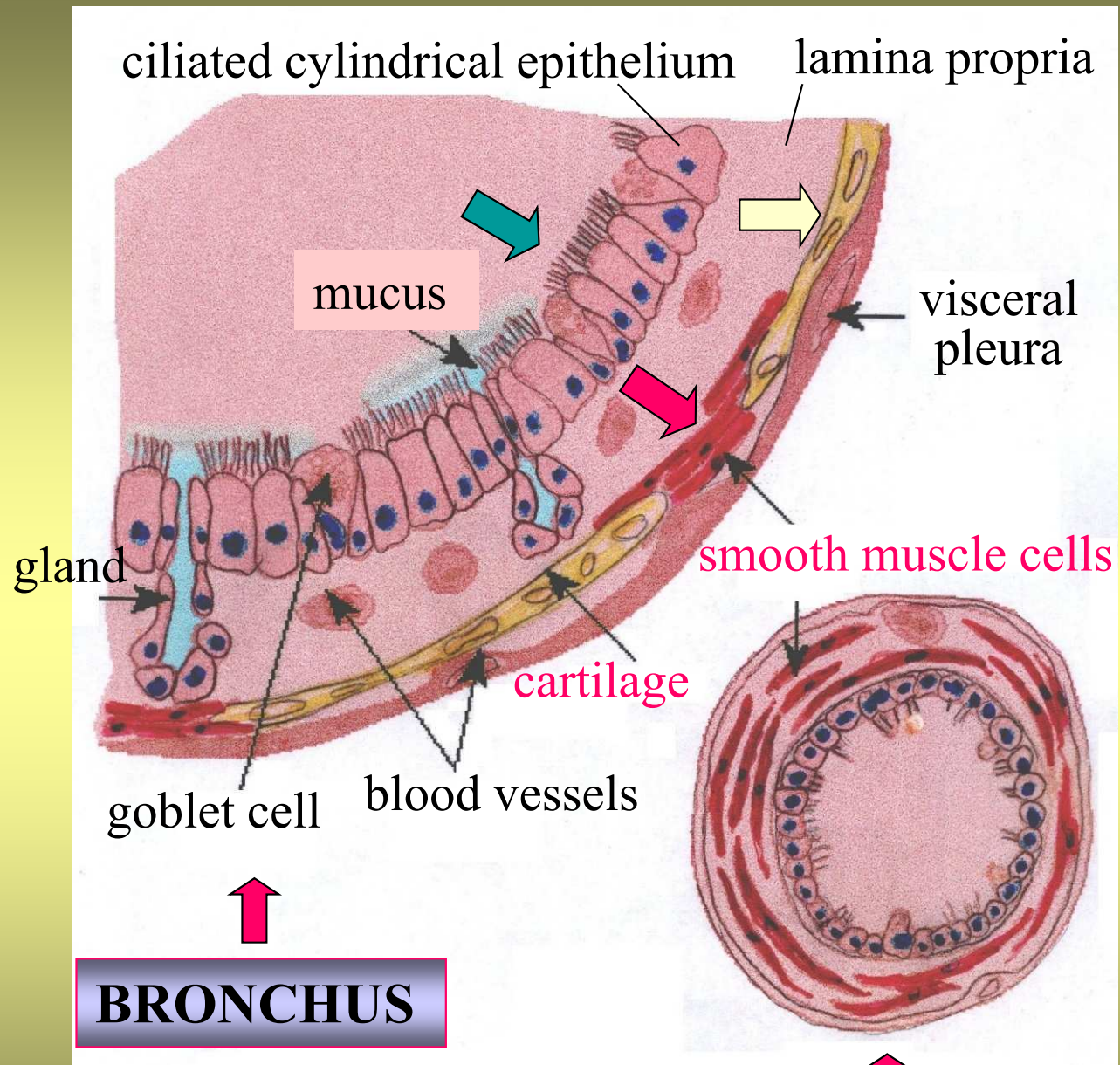
TRACHEA

BRONCHI

BRONCHIOLES

TERMINAL
BRONCHIOLES

AERODYNAMIC RESISTANCE



**AUTONOMIC
INNERVATION of
smooth muscle cells**

Muscarinic receptors:
Acetylcholine activates
bronchoconstriction

β-adrenergic receptors:
Noradrenaline activates
bronchodilatation

TERMINAL BRONCHIOLE

Ø < 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

$f = 12/\text{min}$

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

**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

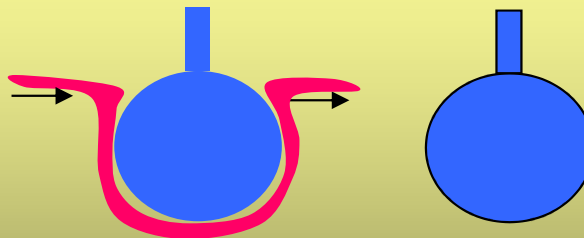
1.8 l/min

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

II MEASURABLE PARAMETERS

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

III ACTIVE AND PASSIVE FORCES

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

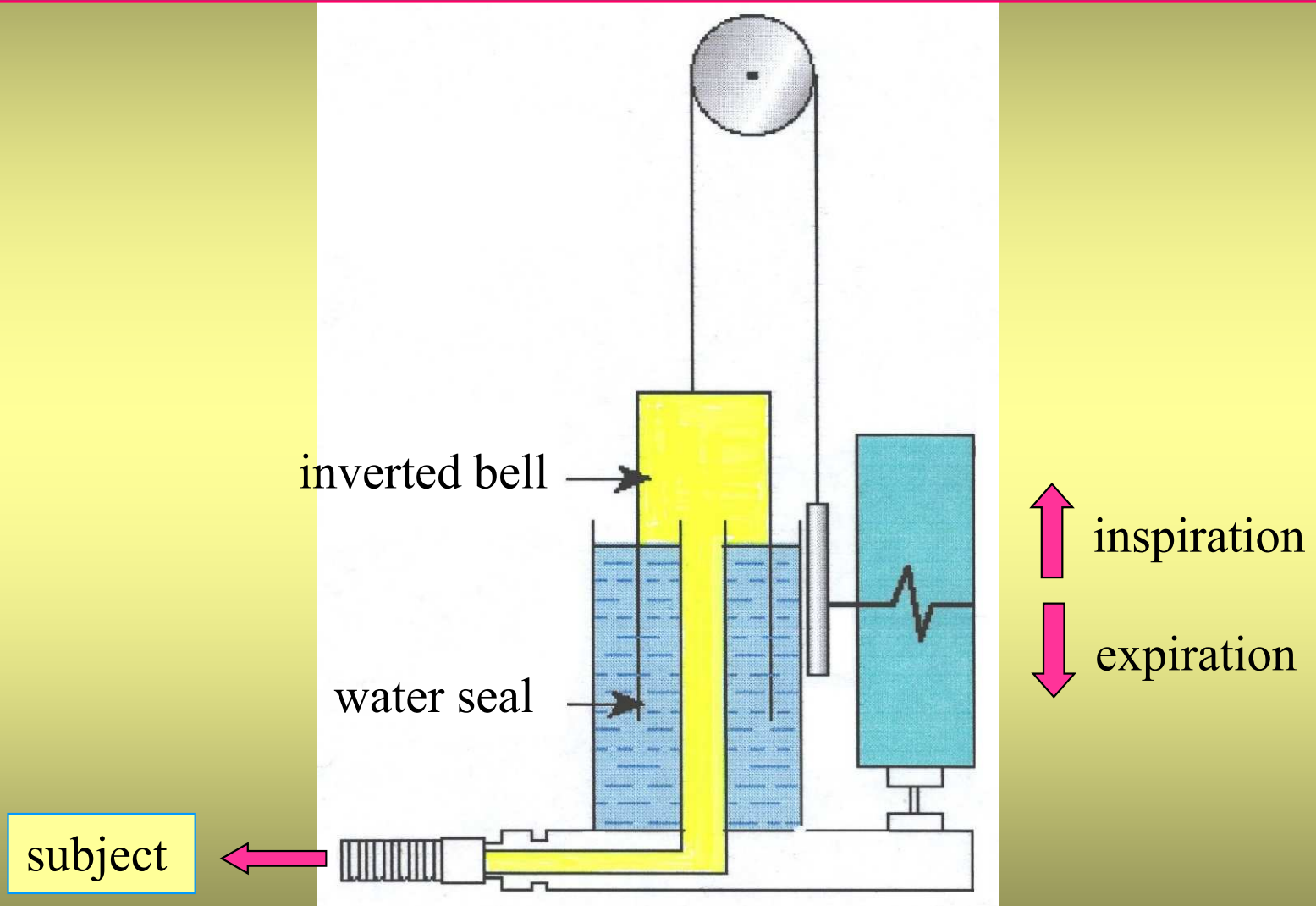
IV COMPOSITION OF ALVEOLAR AIR

V ALVEOLAR-CAPILLARY MEMBRANE

VI TRANSPORT OF GASSES (O_2 and CO_2)

SPIROMETRY

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



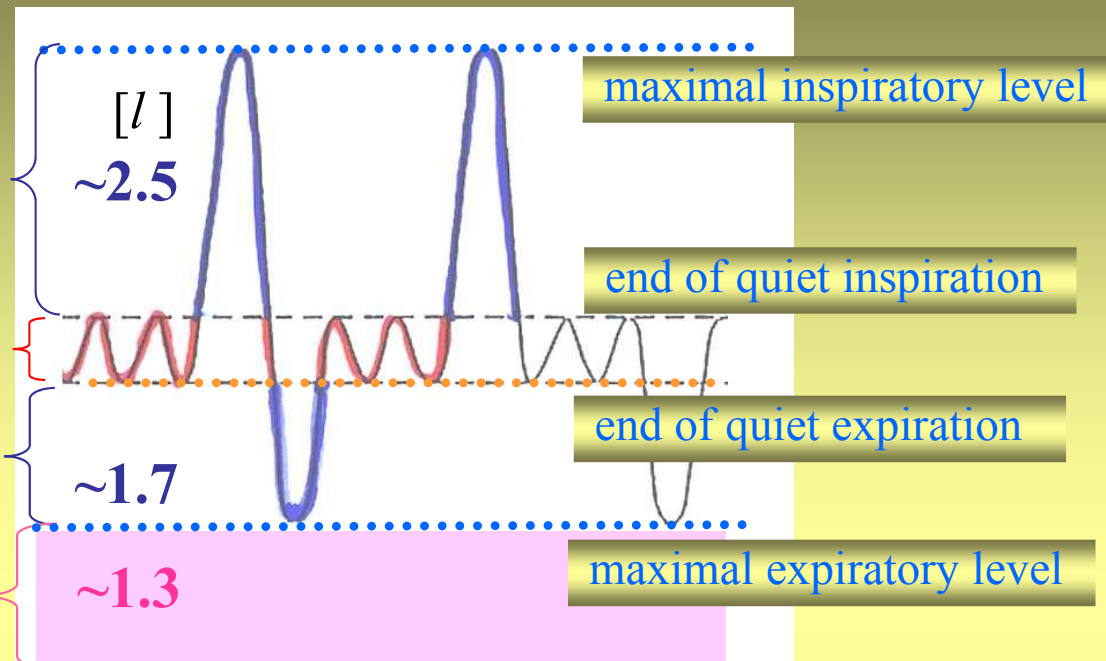
LUNG VOLUMES

INSPIRATORY
RESERVE VOLUME IRV

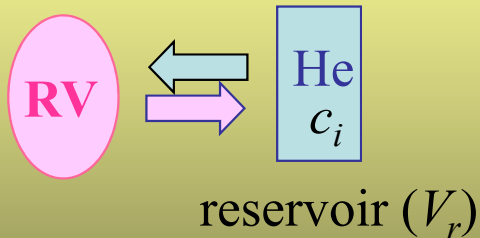
TIDAL VOLUME V_T

EXPIRATORY
RESERVE VOLUME ERV

RESIDUAL VOLUME RV



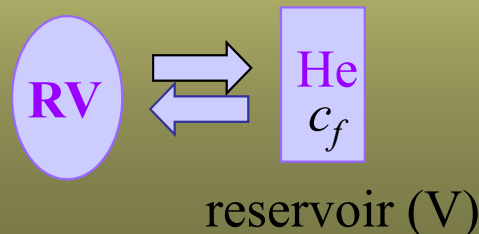
DILUTION METHOD
 He



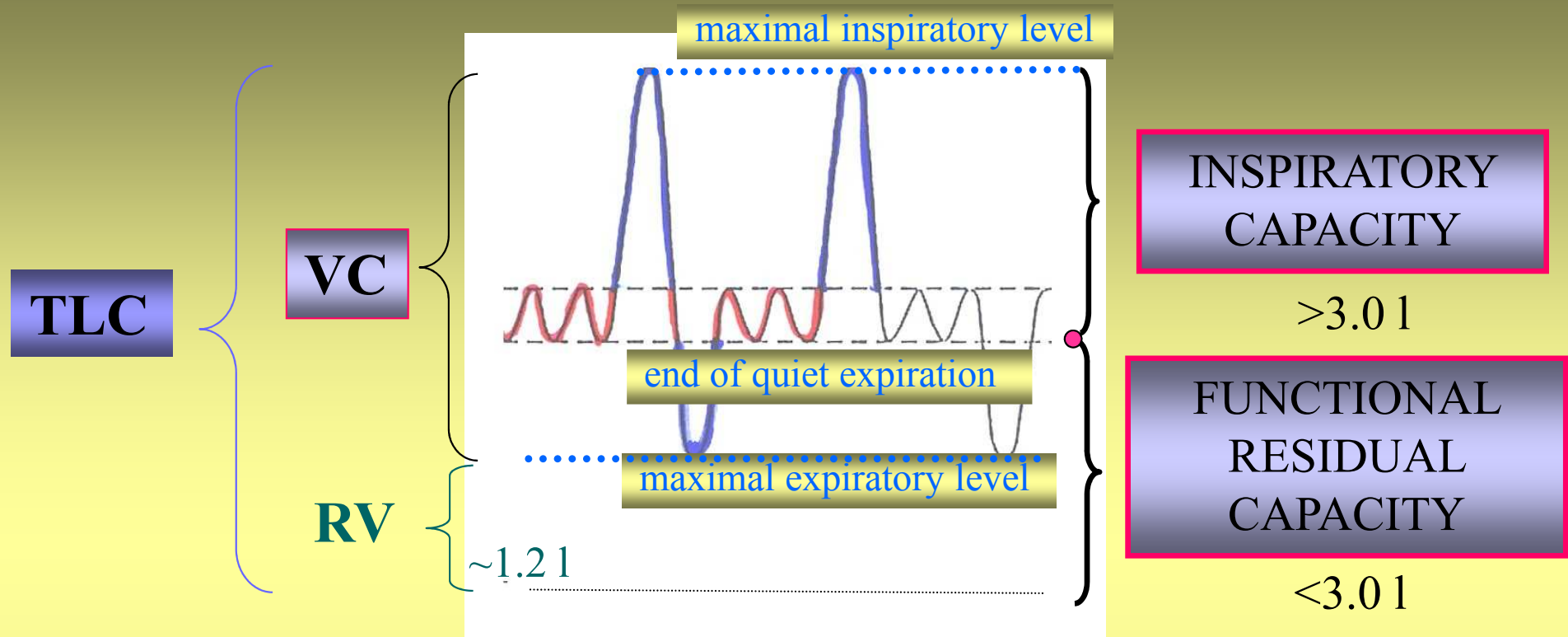
Principle of method: **1** Maximal expiration, **2** Repeated inspiration from and expiration into a reservoir (known volume V_r) with inert gas He (known concentration c_i)

⇒ 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).



$$RV = V_r \frac{c_{iHe} - c_{fHe}}{c_{fHe}}$$



VC **VITAL CAPACITY = $V_T + IRV + ERV$** $\sim 4.7\text{ l}$

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

TLC **TOTAL LUNG CAPACITY = $VC + RV$** $\sim 6.0\text{ l}$

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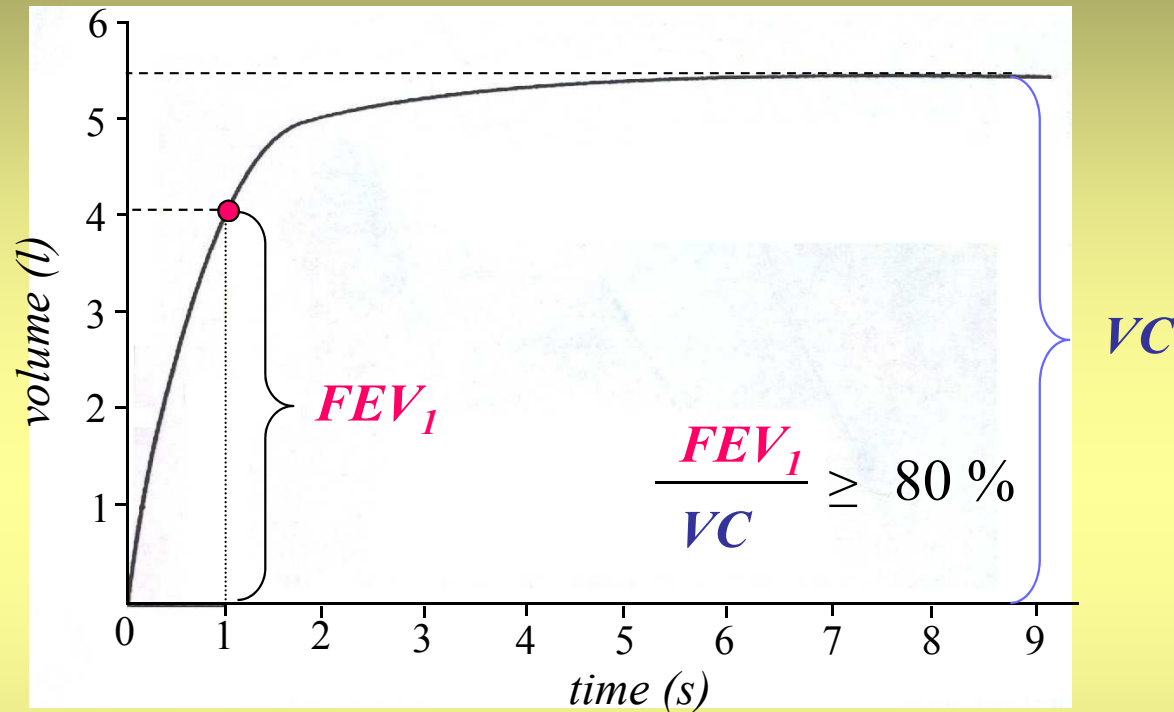
IV COMPOSITION OF ALVEOLAR AIR

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VI TRANSPORT OF GASSES (O_2 and CO_2)

FUNCTIONAL INVESTIGATION OF THE LUNGS

- **TIMED VITAL CAPACITY (FEV_1 - forced expiratory volume per 1 s)**

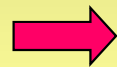


- **PULMONARY MINUTE VENTILATION RMV (respiratory minute volume) at rest** ($0.5 \text{ l} \times 12 \text{ breathes/min} = 6 \text{ l/min}$)
- **MAXIMAL VOLUNTARY VENTILATION (MVV)** (125-170 l/min)
- **PEAK EXPIRATORY FLOW RATE ($PEFR$)** ($\sim 10 \text{ l/s}$)

I AIR PASSAGES

II MEASURABLE PARAMETERS

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- LUNG VOLUMES
- FUNCTIONAL INVESTIGATION



- CHARACTERISTIC PRESSURES

III ACTIVE AND PASSIVE FORCES

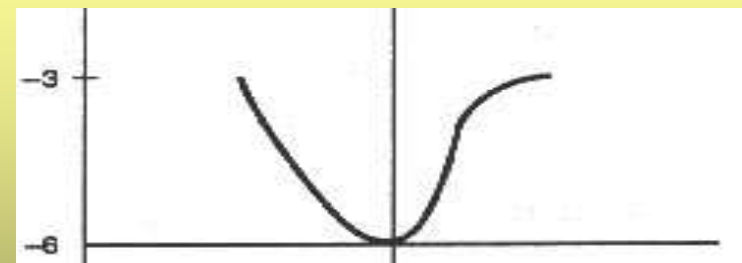
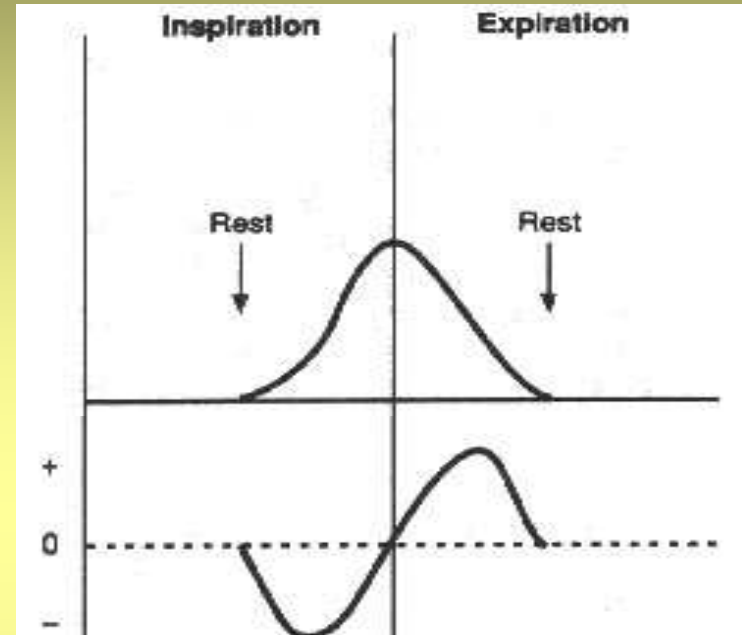
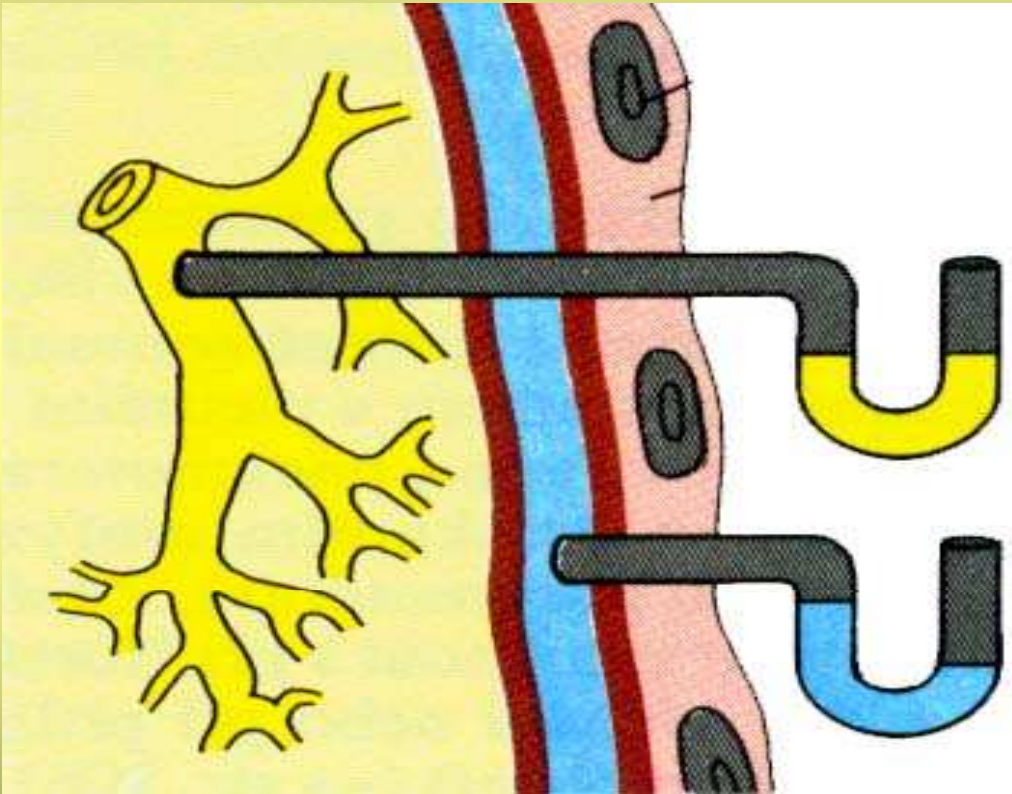
- RESPIRATORY MUSCLES
- LUNGS ELASTICITY
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IV COMPOSITION OF ALVEOLAR AIR

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VI TRANSPORT OF GASSES (O_2 and CO_2)

PLEURA
pulmonalis parietalis



FORCES PARTICIPATING IN RESPIRATION

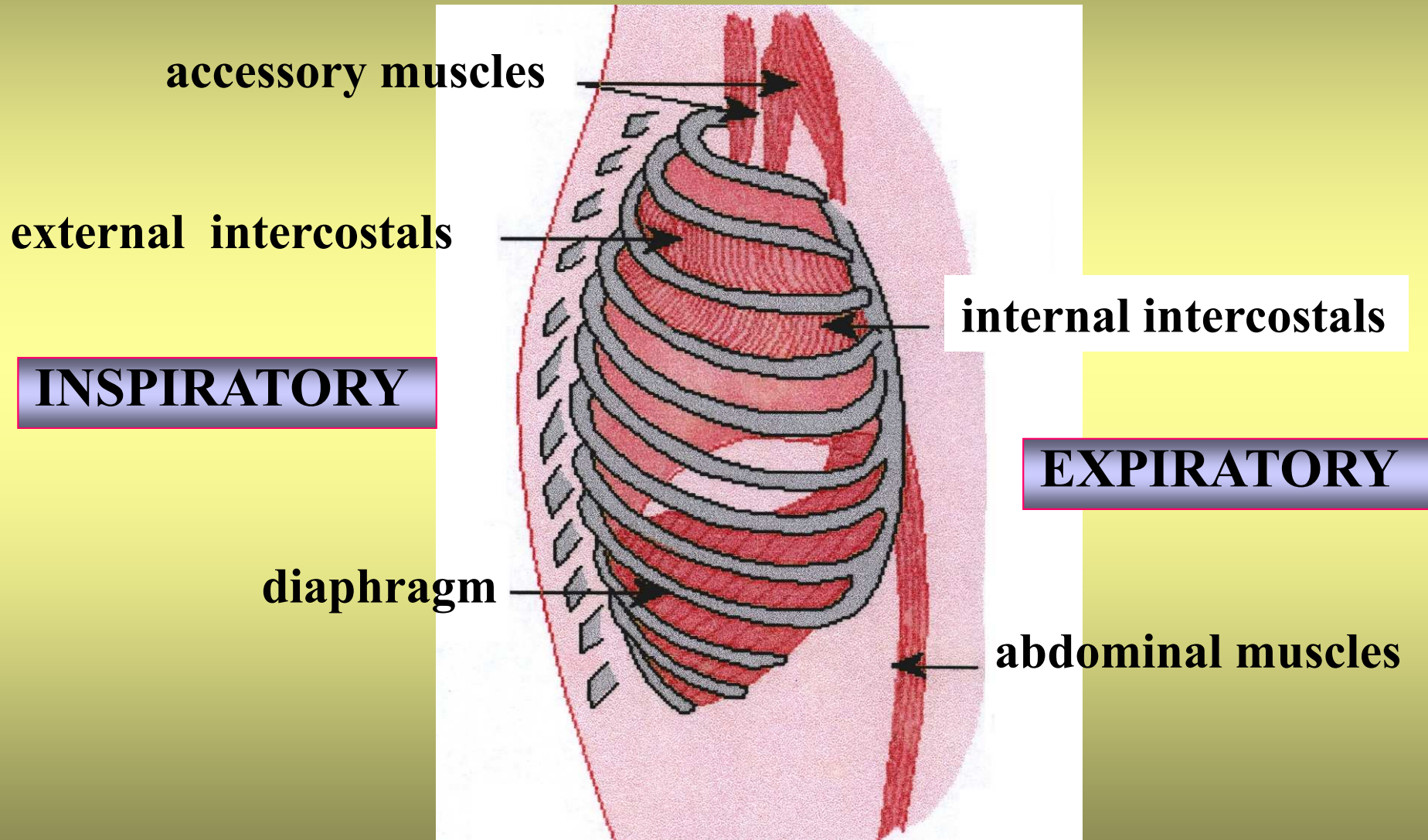
- **ACTIVE FORCES** performed by respiratory muscles
- **PASSIVE FORCES** represented by:
 - lungs elasticity
 - chest elasticity

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

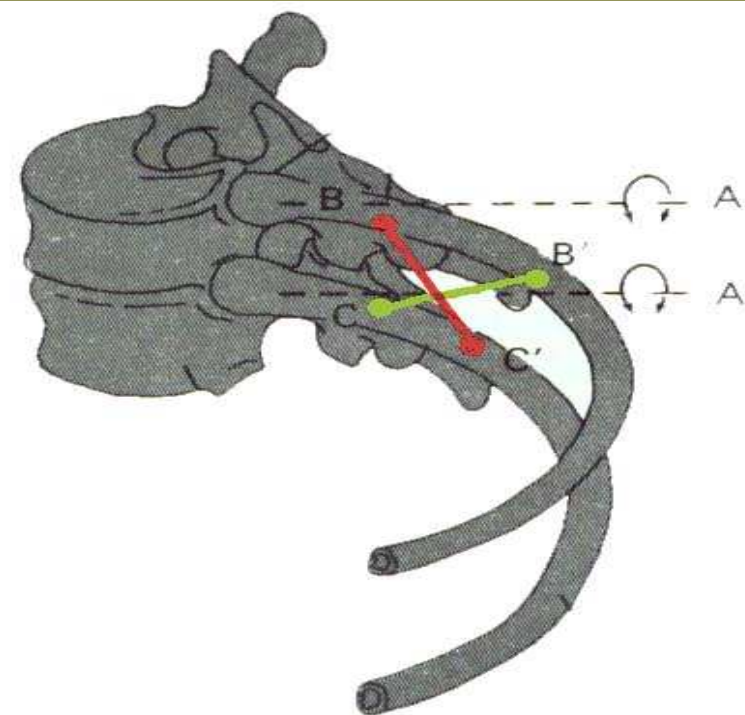
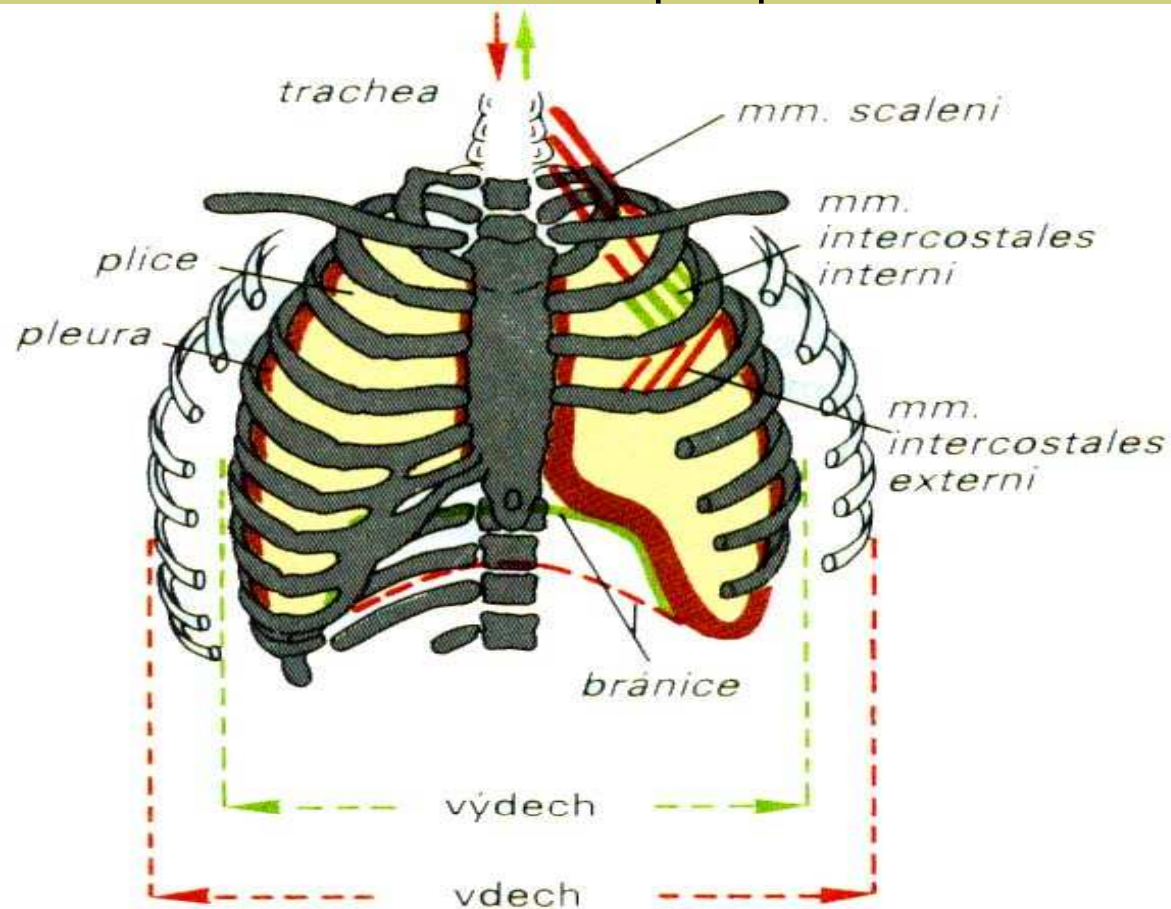
- *accessory inspiratory muscles* (mm. scalene)

EXPIRATORY muscles

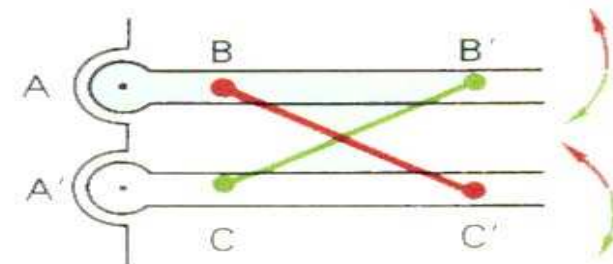
Only at FORCED breathing

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

Bucket-handle and water-pump handle effects



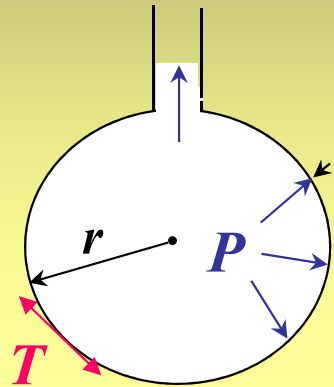
páka $A - B < A' - C' \rightarrow$ zvedání žeber



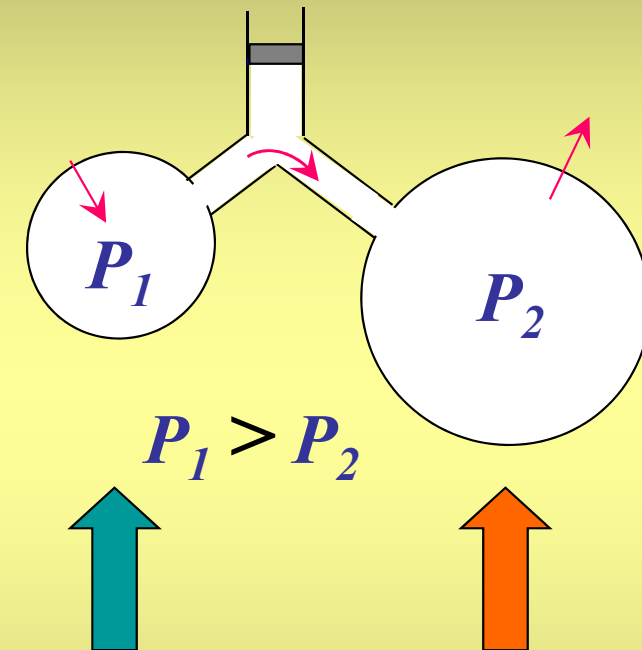
páka $A - B' > A' - C \rightarrow$ klesání žeber

LAW OF LAPLACE

spherical structures



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



P pressure

r radius

T surface tension

PATHOLOGY

- COLLAPSE OF ALVEOLI - ATELECTASIS
- EXPANSION OF ALVEOLI

SURFACTANT

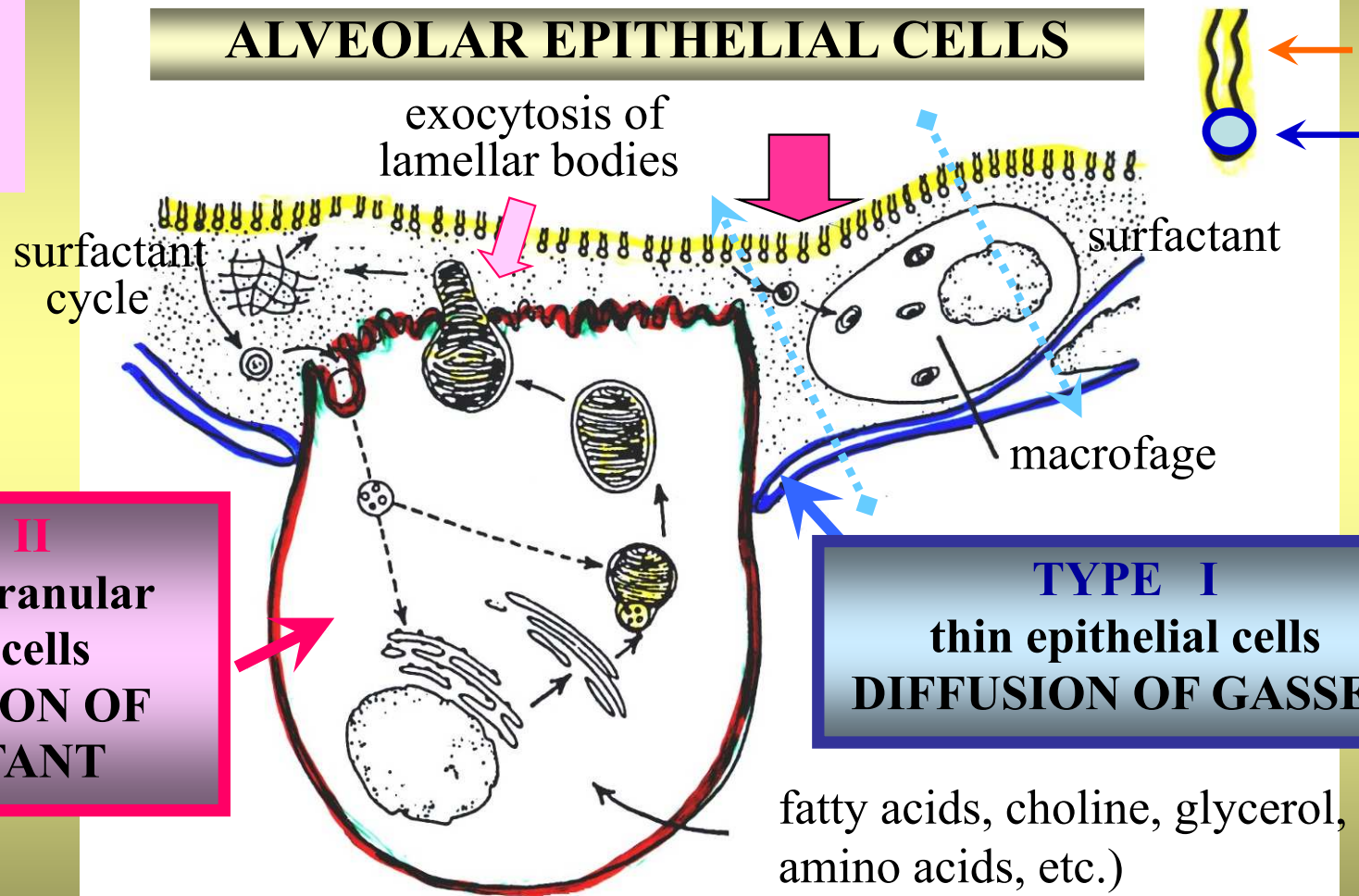
SURFACE TENSION LOWERING AGENT

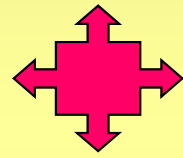
EFFECT MAINLY IN THE EXPIRED POSITION

PHOSPHOLIPID

dipalmitoyl
fosfatidyl cholin

ALVEOLAR EPITHELIAL CELLS





COMPOSITION OF DRY ATMOSPHERIC AIR

O₂ 20.98 %

N₂ 78.06 %

CO₂ 0.04 %

Other constituents

F_{O₂} ≅ 0.21

F_{N₂} ≅ 0.78

F_{CO₂} = 0.0004

BAROMETRIC (ATMOSPHERIC) PRESSURE AT SEA LEVEL

1 atmosphere = 760 mm Hg

PARTIAL PRESSURES OF GASSES IN DRY AIR AT SEA LEVEL

$$P_{O_2} = 760 \times 0.21 = \sim 160 \text{ mm Hg}$$

$$P_{N_2} = 760 \times 0.78 = \sim 593 \text{ mm Hg}$$

$$P_{CO_2} = 760 \times 0.0004 = \sim 0.3 \text{ mm Hg}$$

$$1 \text{ kPa} = 7.5 \text{ mm Hg (torr)}$$

COMPOSITION OF ALVEOLAR AIR

partial pressures in mm Hg

INSPIRED AIR

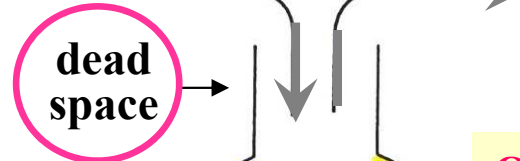
O ₂	158.8
CO ₂	0.3
N ₂	601.0
...	

760 mm Hg

EXPIRED AIR

O ₂	115.0
CO ₂	33.0
H ₂ O	47.0
N ₂	564.0
...	

760 mm Hg



O ₂	100.0
CO ₂	39.0
H ₂ O	47.0
N ₂	...

O ₂	100.0
CO ₂	39.0

physiological shunts

right heart

760 mm Hg

left heart

veins

O ₂	40.0
CO ₂	45.0
H ₂ O	47.0
N ₂	...
...	

arteries

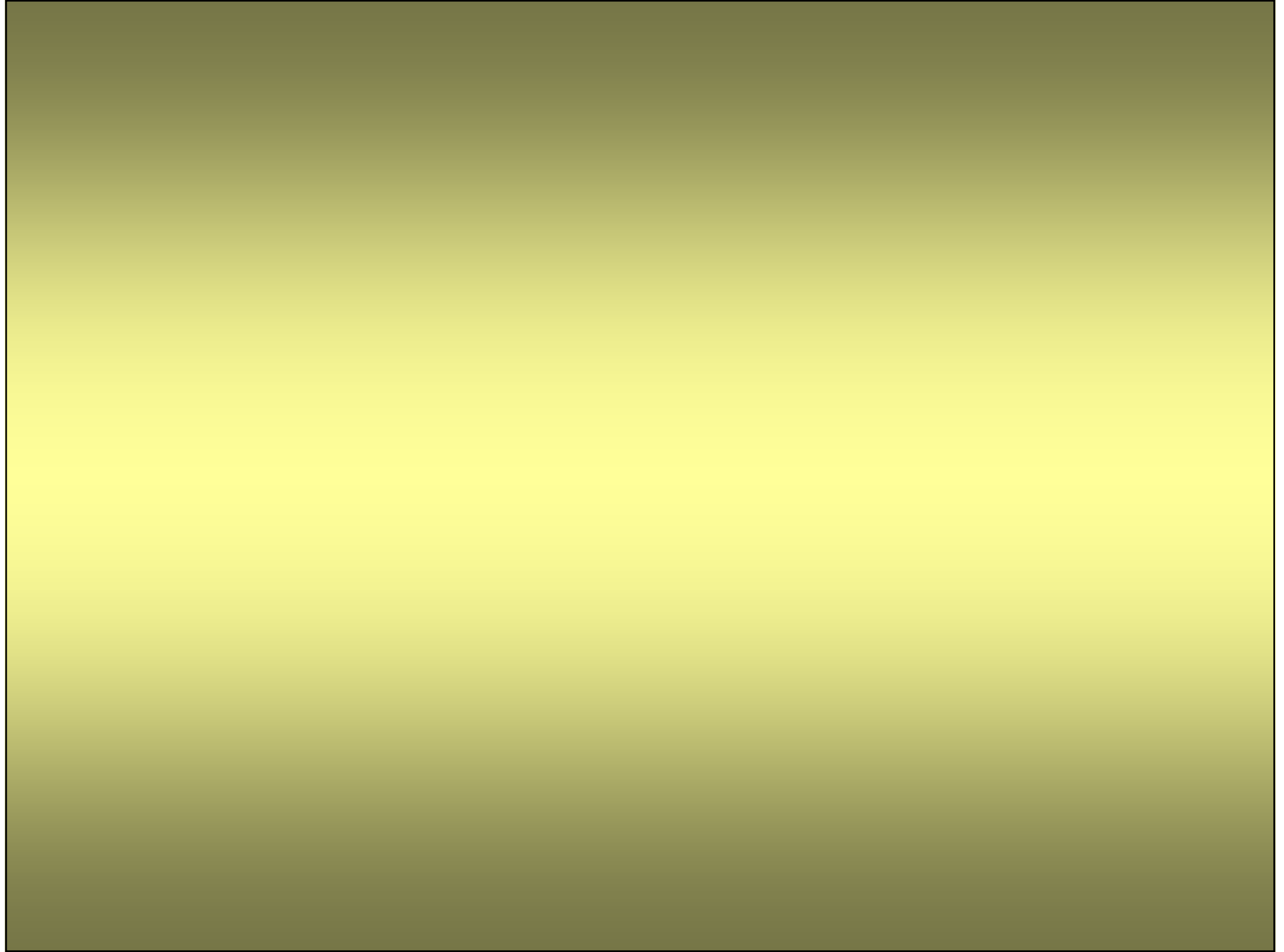
O ₂	95.0
CO ₂	41.0
H ₂ O	47.0
N ₂	...
...	

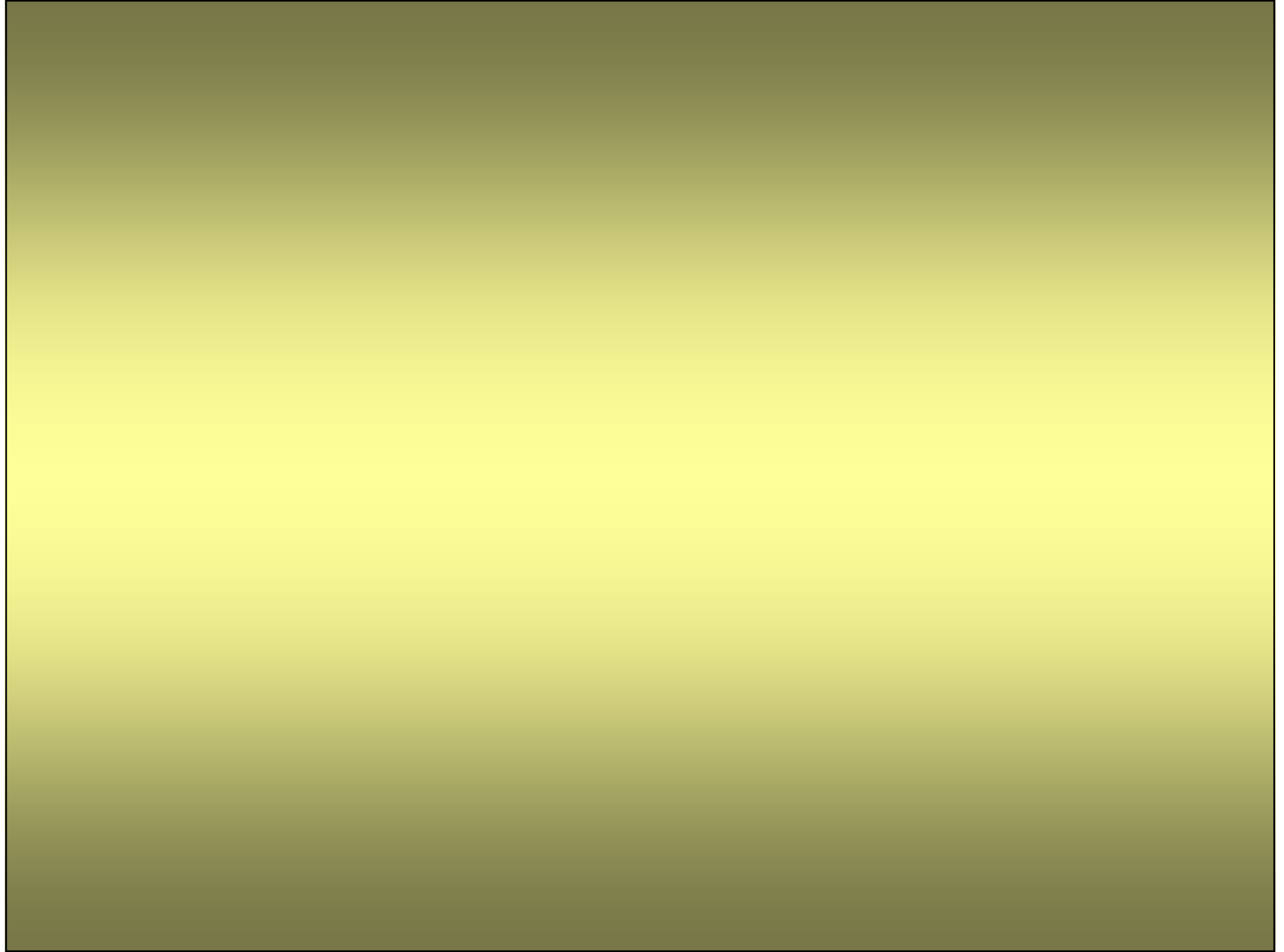
periphery capillaries

O ₂	40.0
CO ₂	45.0
H ₂ O	47.0
N ₂	...
...	

?

?





I AIR PASSAGES

II MEASURABLE PARAMETERS

- DEAD SPACE
- LUNG VOLUMES
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- CHARACTERISTIC PRESSURES

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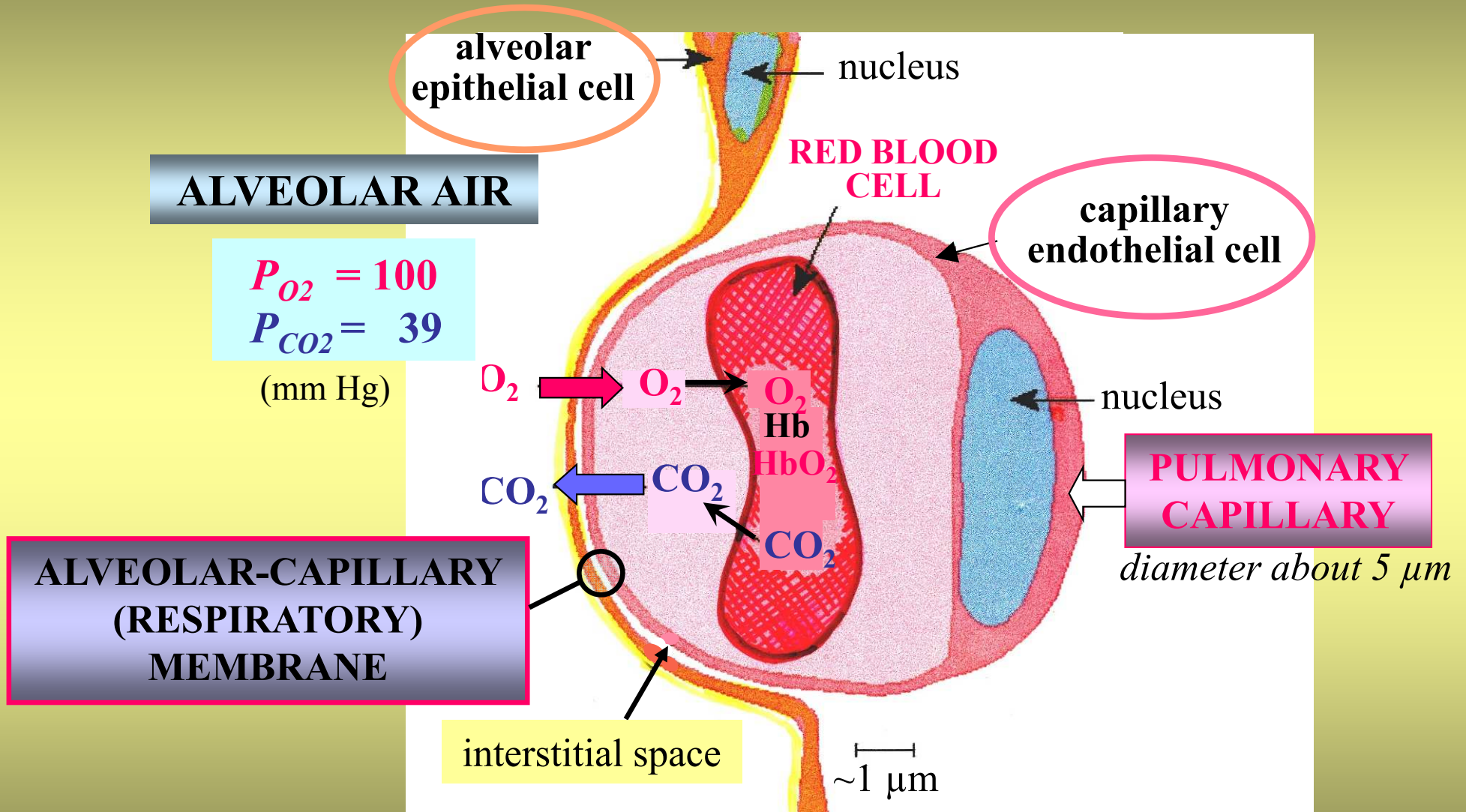
IV COMPOSITION OF ALVEOLAR AIR

V ALVEOLAR-CAPILLARY MEMBRANE

VI TRANSPORT OF GASSES (O_2 and CO_2)

ALVEOLAR-CAPILLARY (RESPIRATORY) MEMBRANE

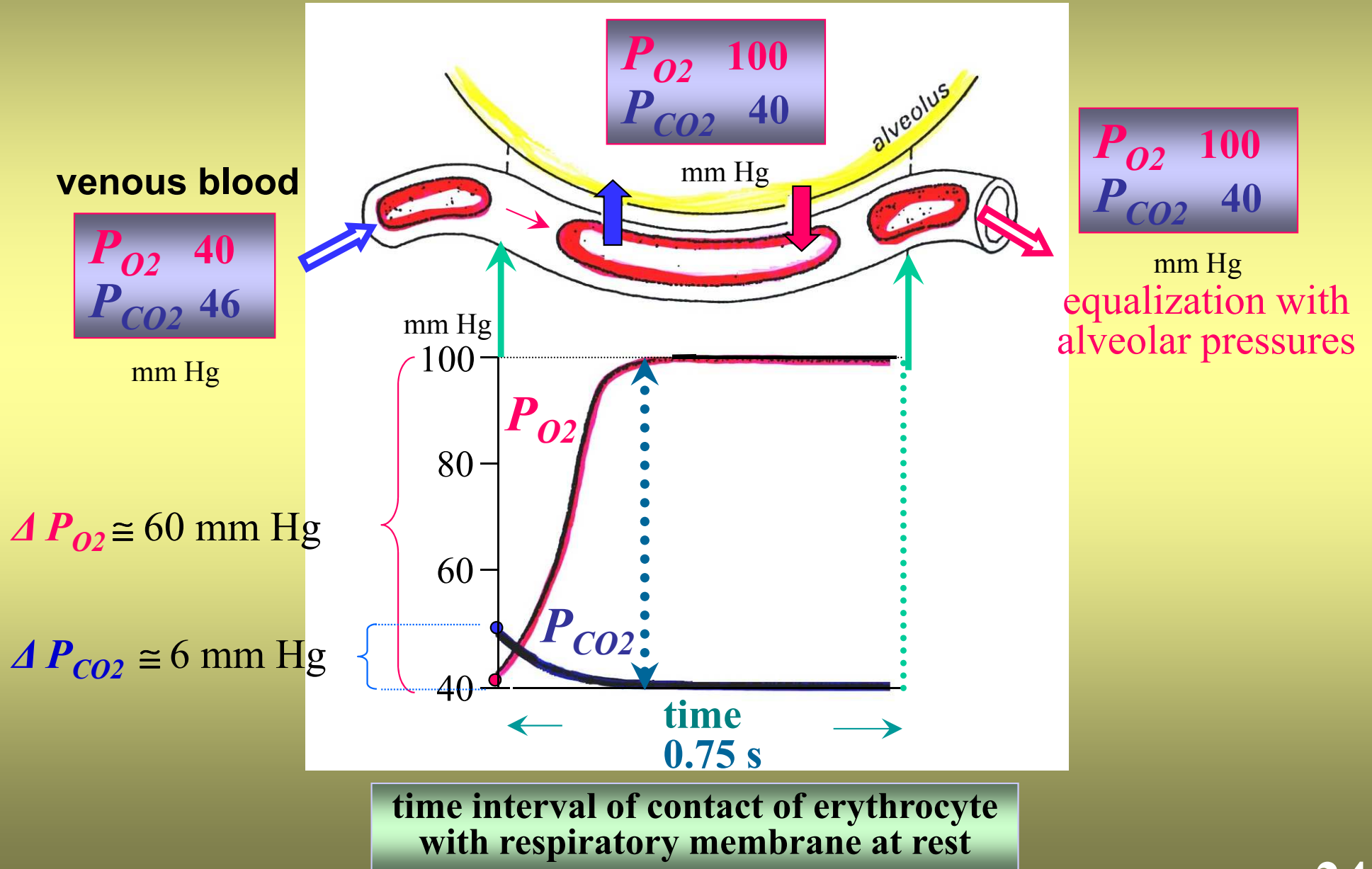
DIFFUSION OF GASES



0.75 s

time interval of erythrocyte contact with respiratory membrane at rest

TIME COURSE OF CAPILLARY P_{O_2} AND P_{CO_2} DURING GRADUAL EQUILIBRATION WITH ALVEOLAR AIR



I AIR PASSAGES

II MEASURABLE PARAMETERS

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III ACTIVE AND PASSIVE FORCES

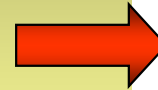
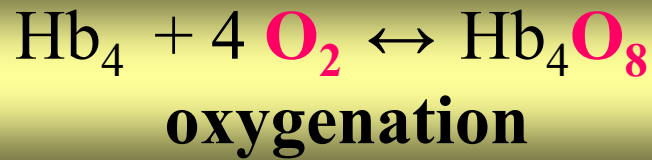
- RESPIRATORY MUSCLES
- LUNGS ELASTICITY
- COMPLIANCE
- WORK OF BREATHING

IV COMPOSITION OF ALVEOLAR AIR

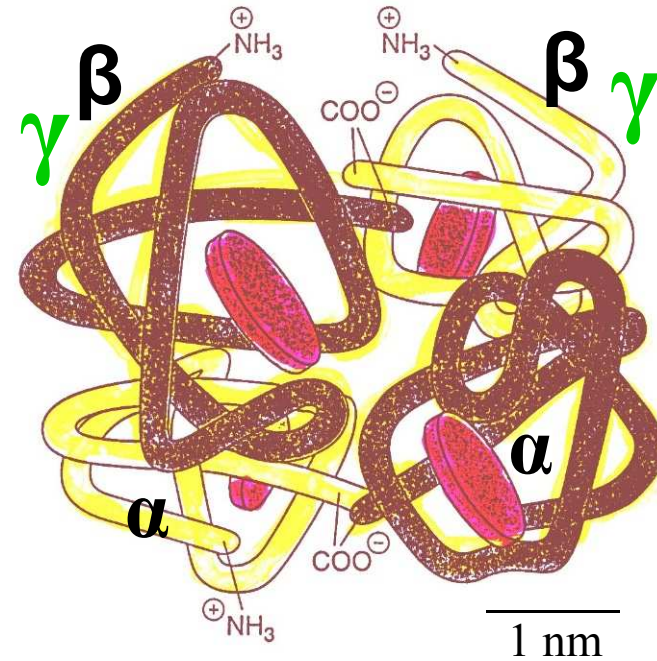
V ALVEOLAR-CAPILLARY MEMBRANE

➔ VI TRANSPORT OF GASSES (O_2 and CO_2)

HAEMOGLOBIN



tetramer

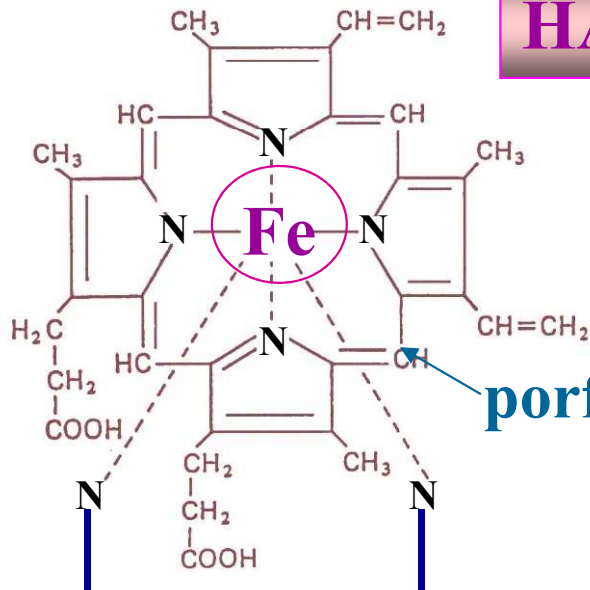


Fe^{2+}

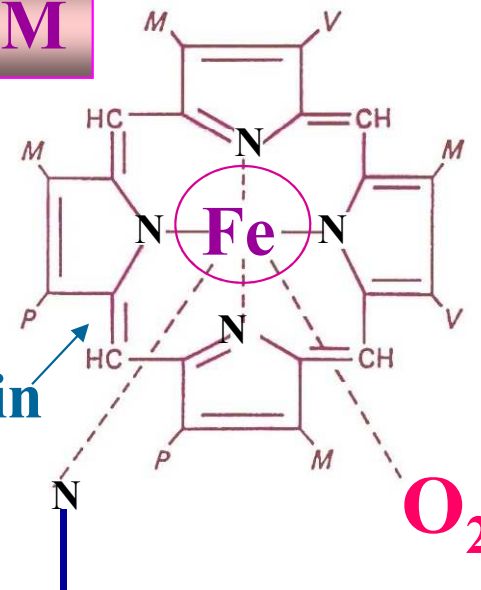
DEOXY

OXY

HAEM



porphyrin



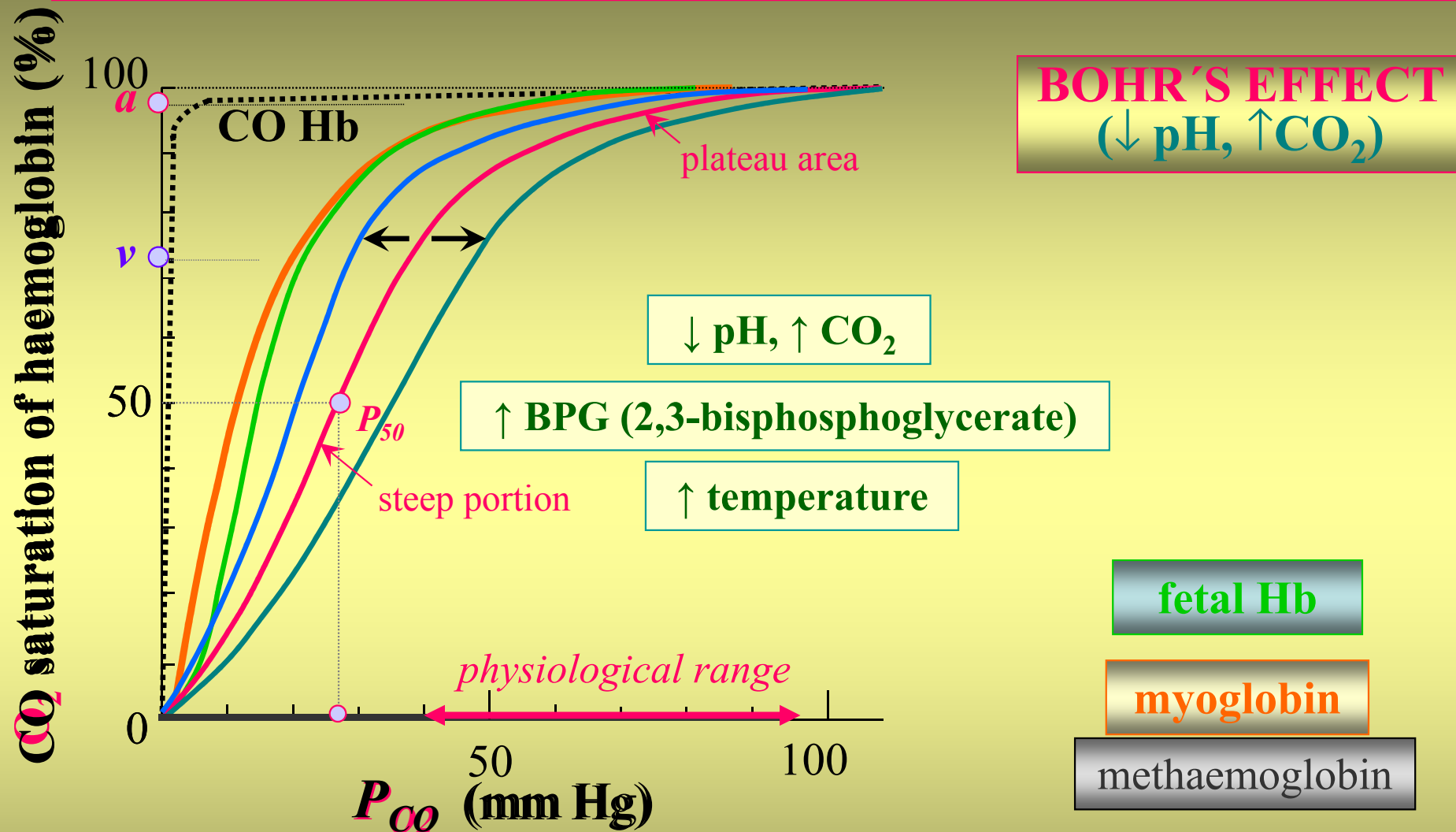
polypeptide chain

polypeptide chain

fetal Hb

Fe^{3+} (methaemoglobin)
oxidation

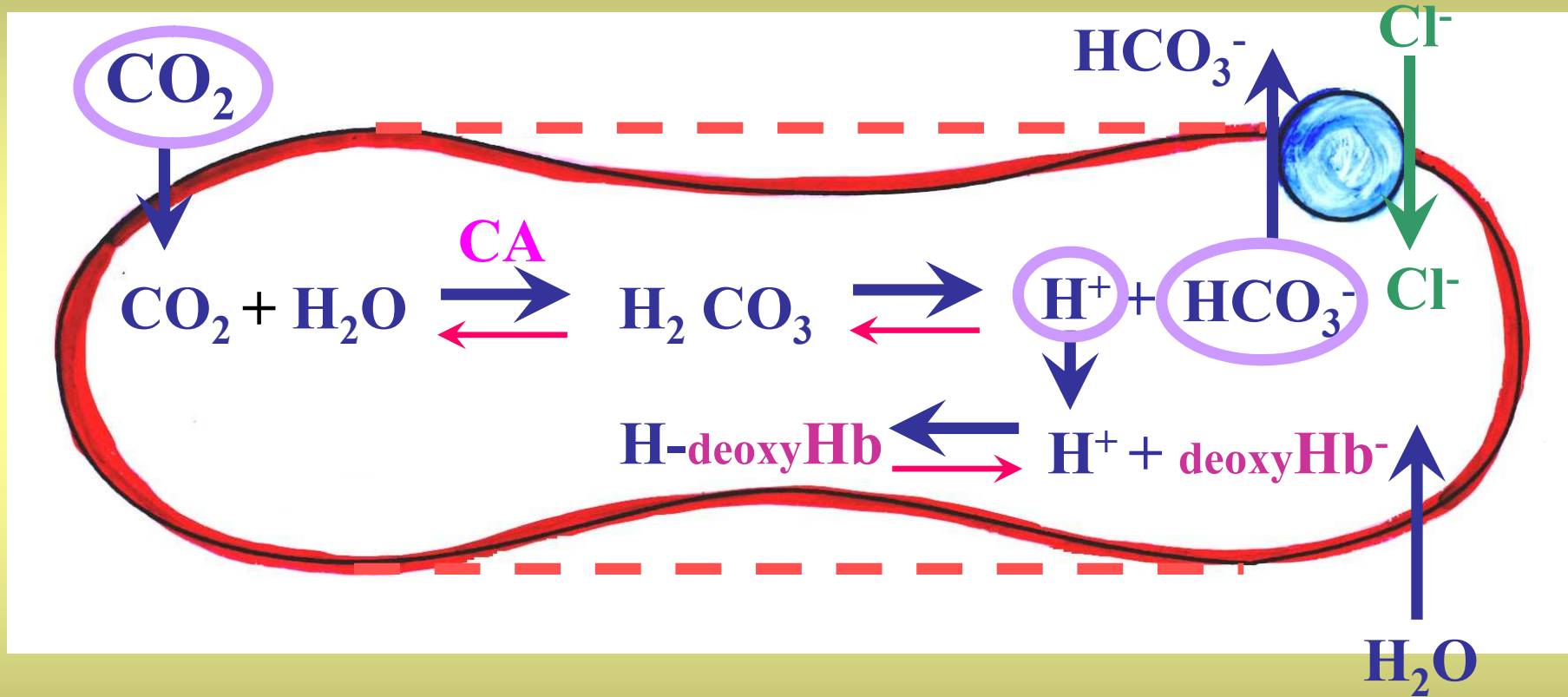
O_2 -HAEMOGLOBIN DISSOCIATION CURVE



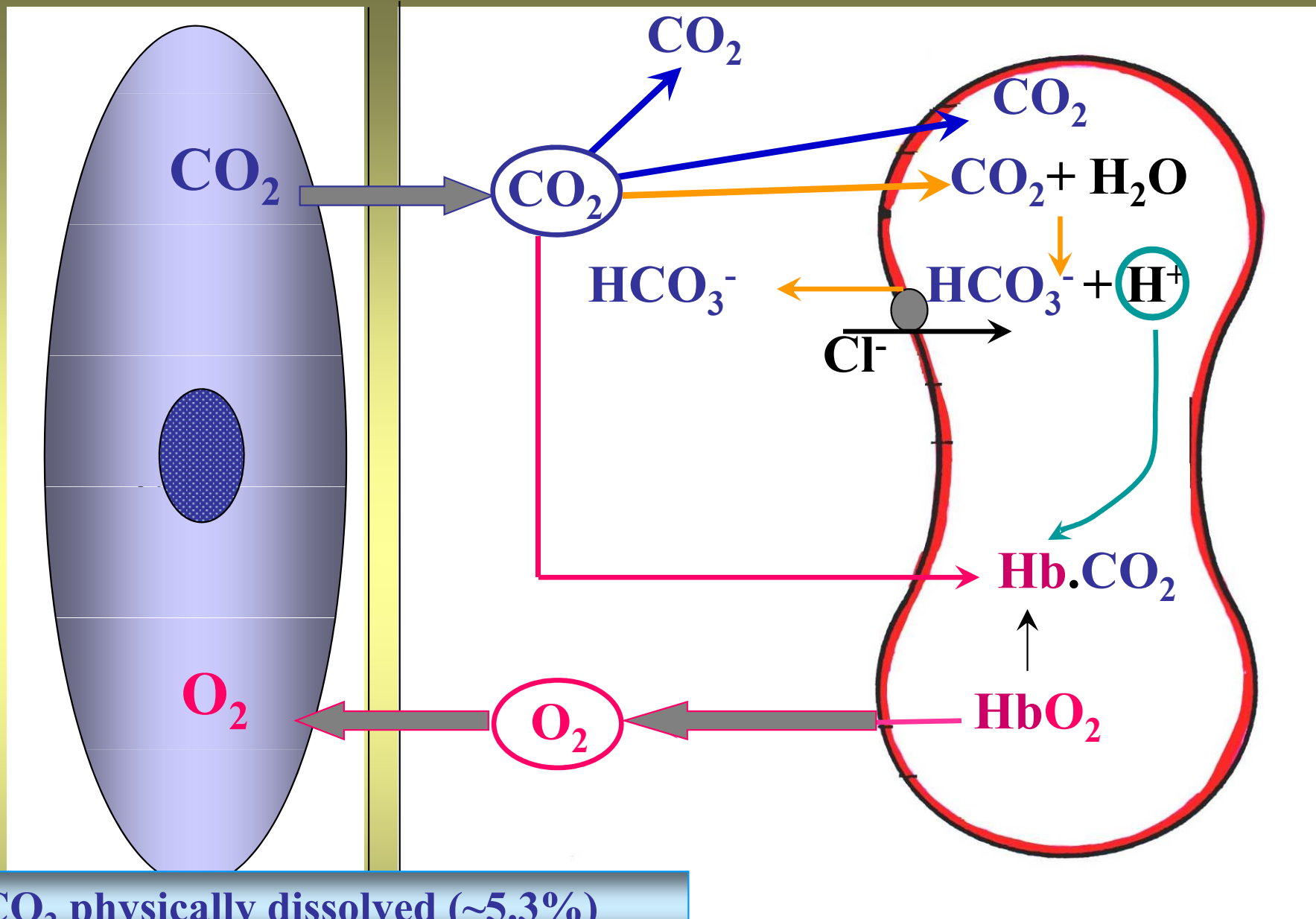
physically dissolved O_2 (1.4%)

TRANSPORT OF CO₂

HAMBURGER CHLORIDE SHIFT



CA – carbonic anhydrase



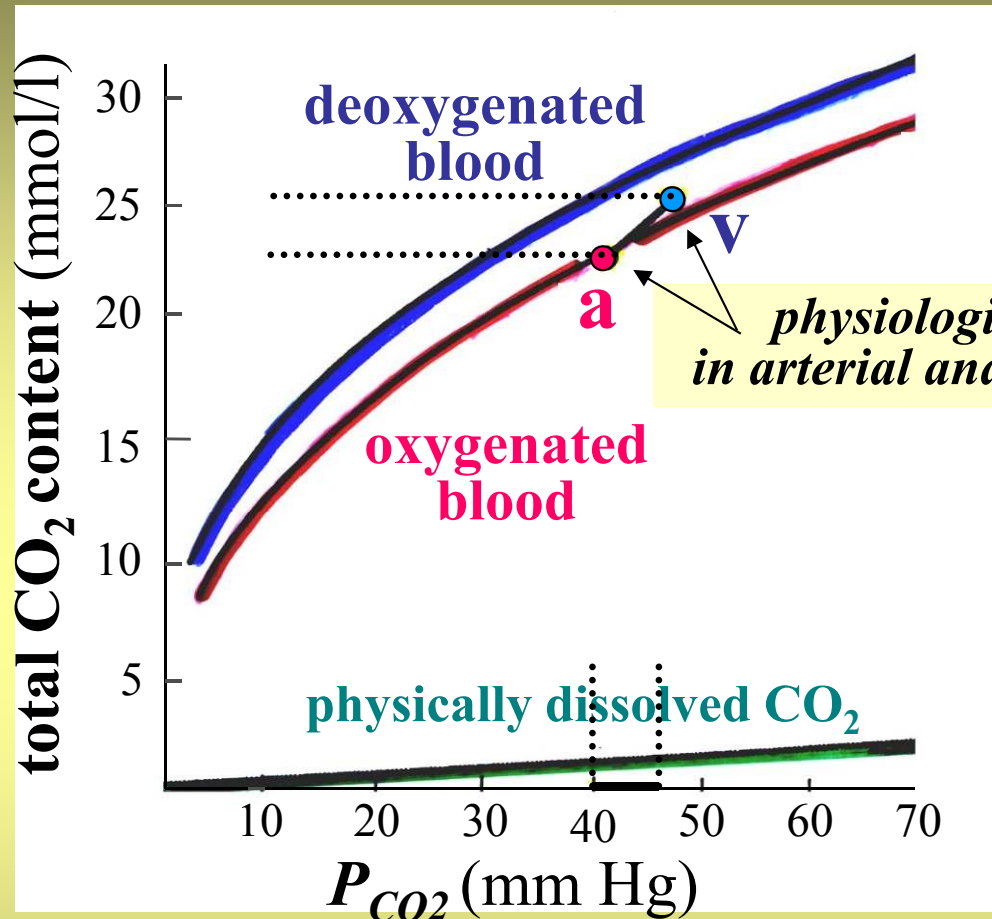
- CO₂ physically dissolved (~5.3%)

- CO₂ + Hb-NH₂ ⇌ Hb.NH-COO⁻ (carbamino-Hb) (~5.3 %)

- CO₂ + H₂O ⇌ HCO₃⁻ + H⁺ (~89%)

60% in plasma, 29% in red blood cell

CO₂ DISSOCIATION CURVE



HALDANE EFFECT

?

DEOXY-Hb

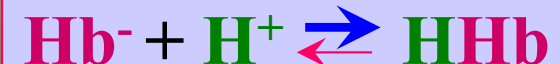


→ deoxygenated blood in peripheral tissues

← oxygenated blood in the lungs

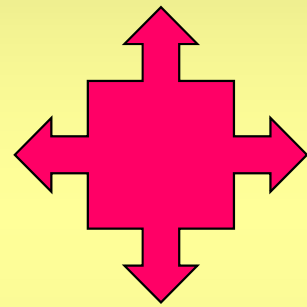


↑
↓



TISSUES: DEOXY-Hb binds H⁺ more readily (weaker acid) ⇒ ↑ amount of chemically bound CO₂

LUNGS: H⁺ is released from OXY-Hb ⇒ ↓ amount of chemically bound CO₂



END

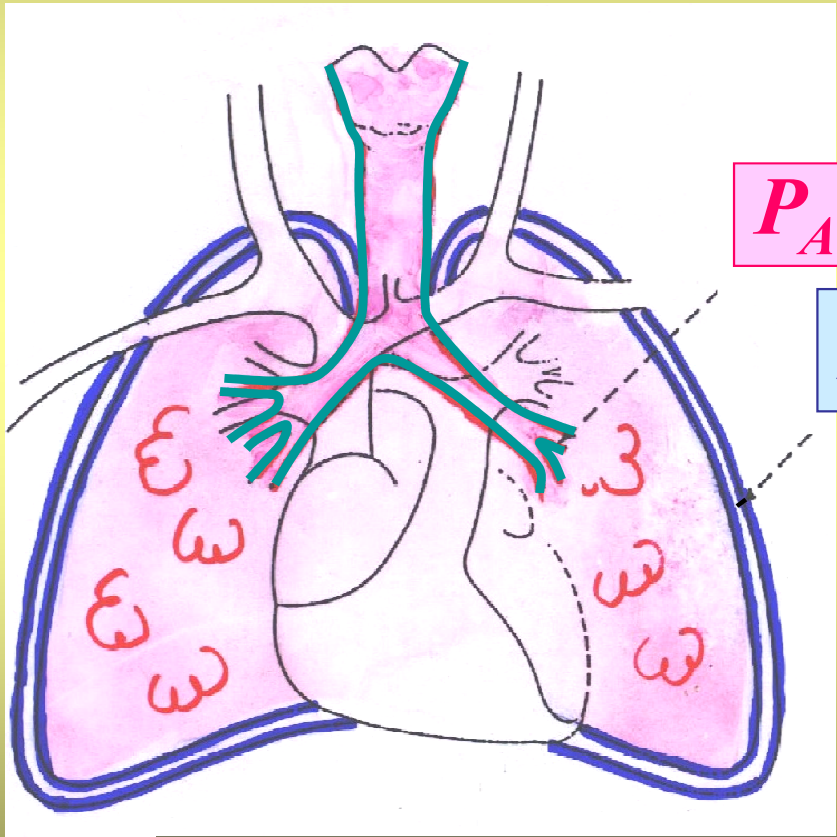
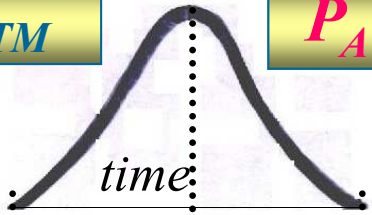
TIME COURSE OF PRESSURES AT QUIET RESPIRATION

$$P \cdot V = \text{const}$$

$$P = \frac{\text{const}}{V}$$

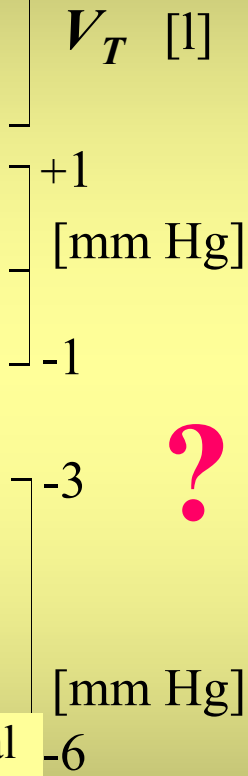
INSPIRATION EXPIRATION

$P_A < P_{ATM}$ $P_A > P_{ATM}$



P_A

P_{PL}

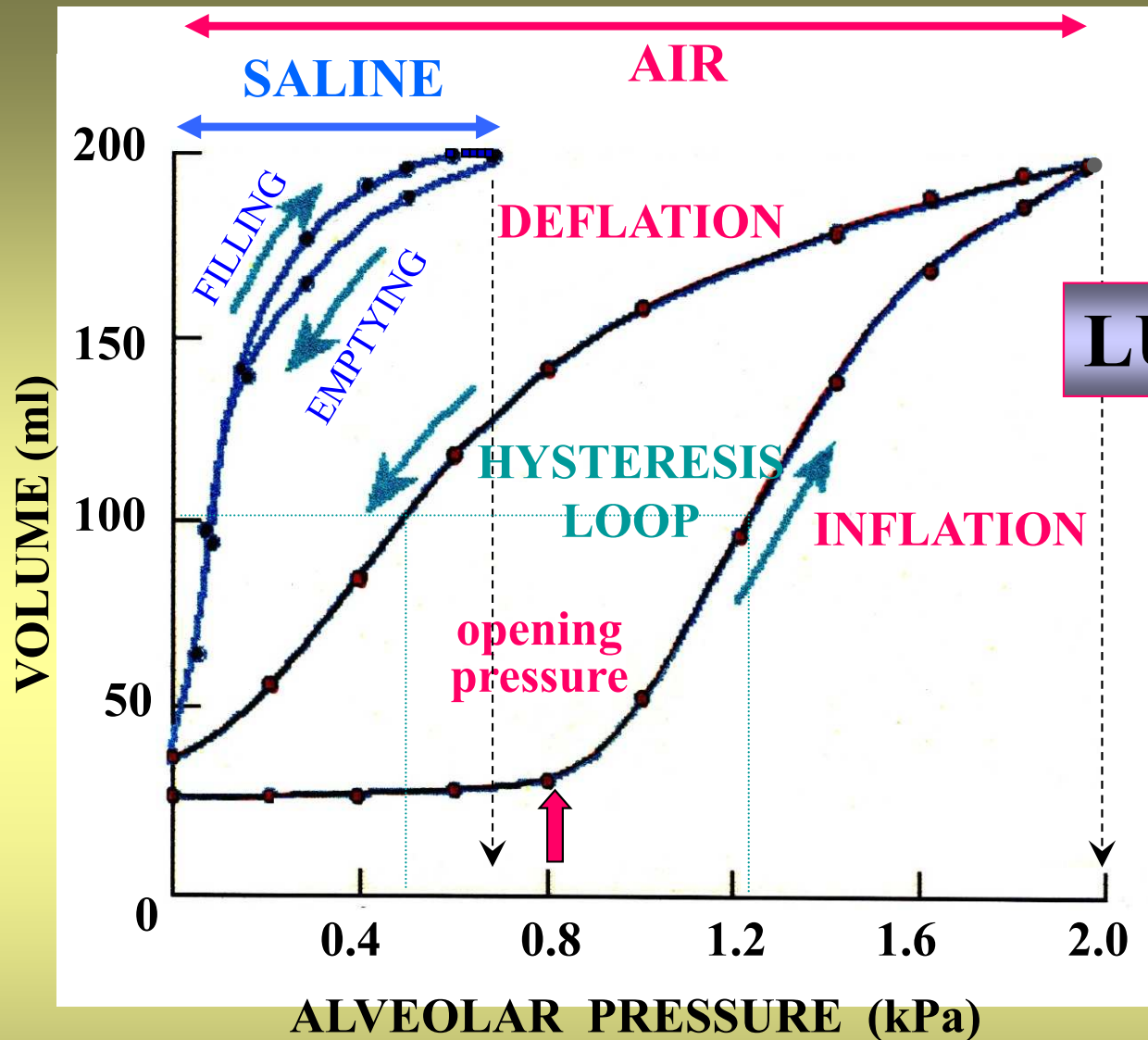


measured curve

theoretical curve

P_A ALVEOLAR (INTRAPULMONARY, LUNG)

P_{PL} INTRAPLEURAL (INTRATHORACIC)



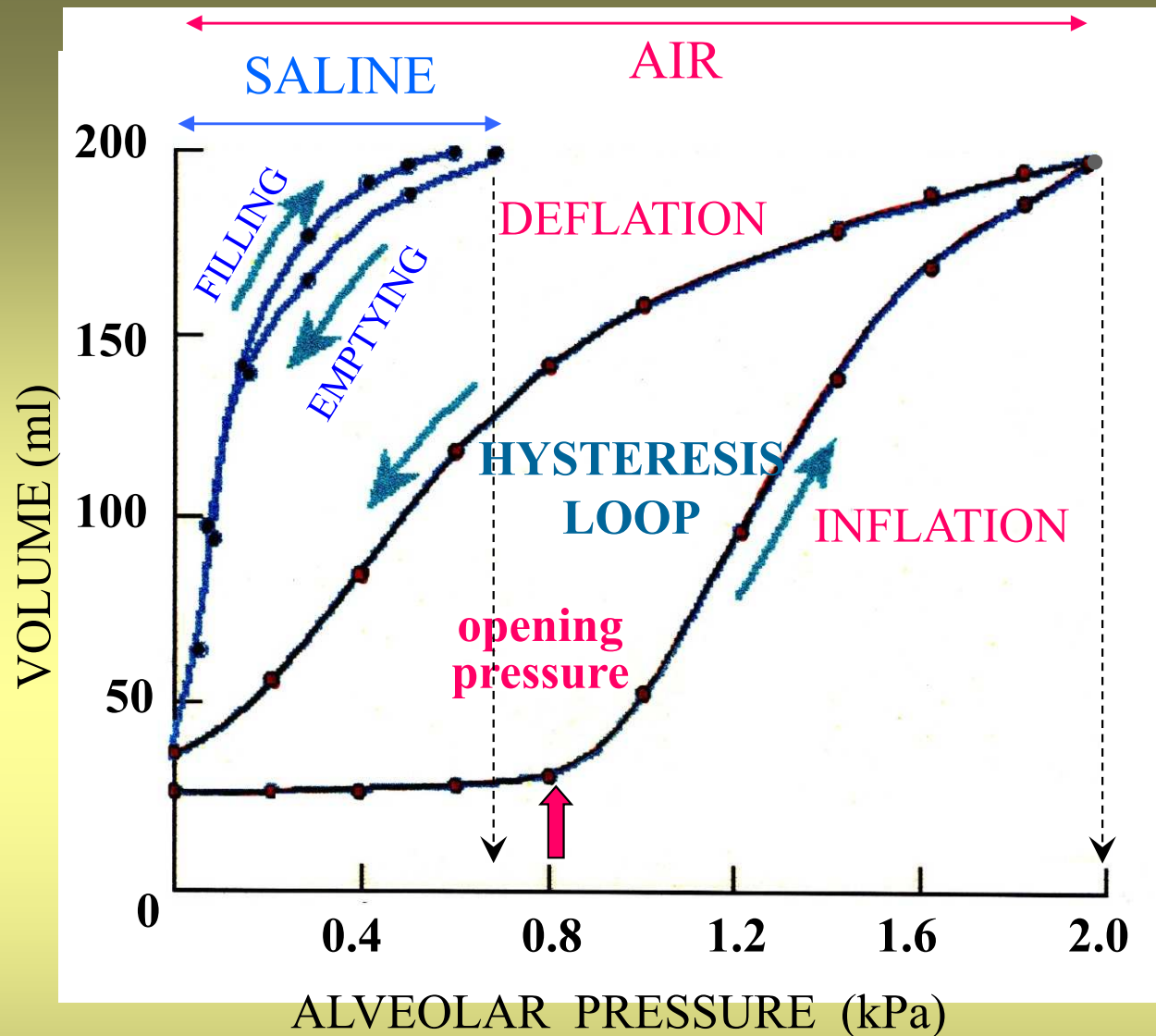
LUNGS ELASTICITY

1 kPa = 7.5 mm Hg

LUNGS ELASTICITY

INHERENT TISSUE ELASTICITY
(elastin and collagen fibres)

SURFACE TENSION FORCES
air-liquid interface in alveoli

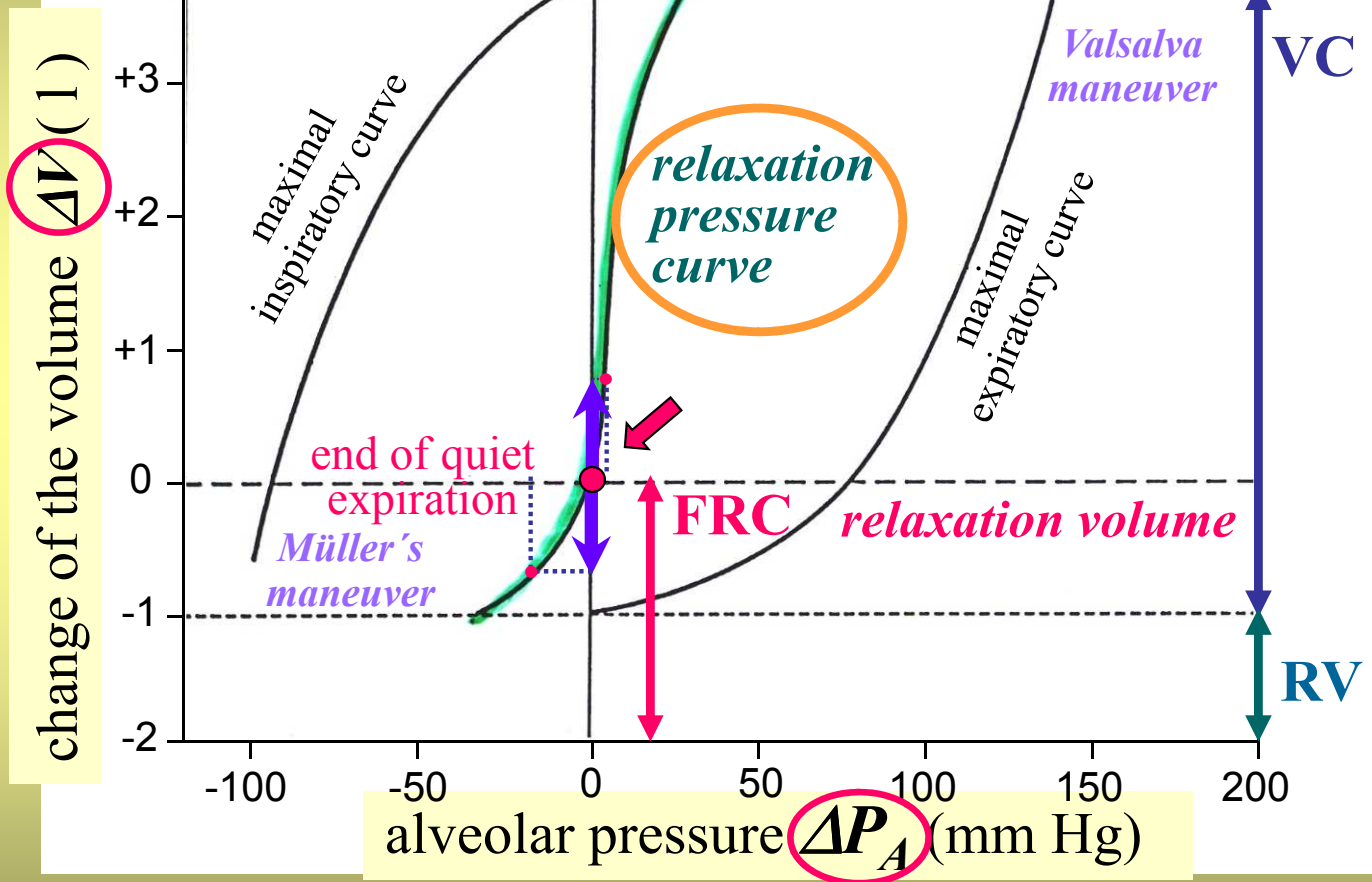


Factors involved in HYSTeresis LOOP

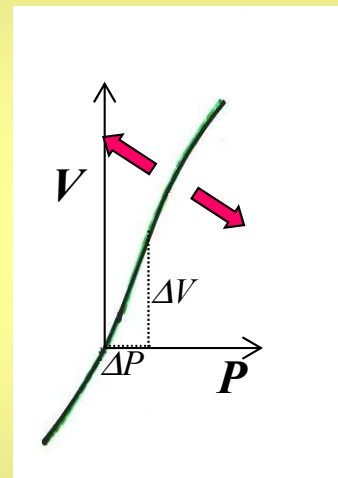
- **LAPLACE LAW** (responsible for high **opening pressure** of alveoli)
- **Dynamic changes in the DENSITY** of surfactant molecules during **INSPIRATION** and **EXPIRATION**

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%)