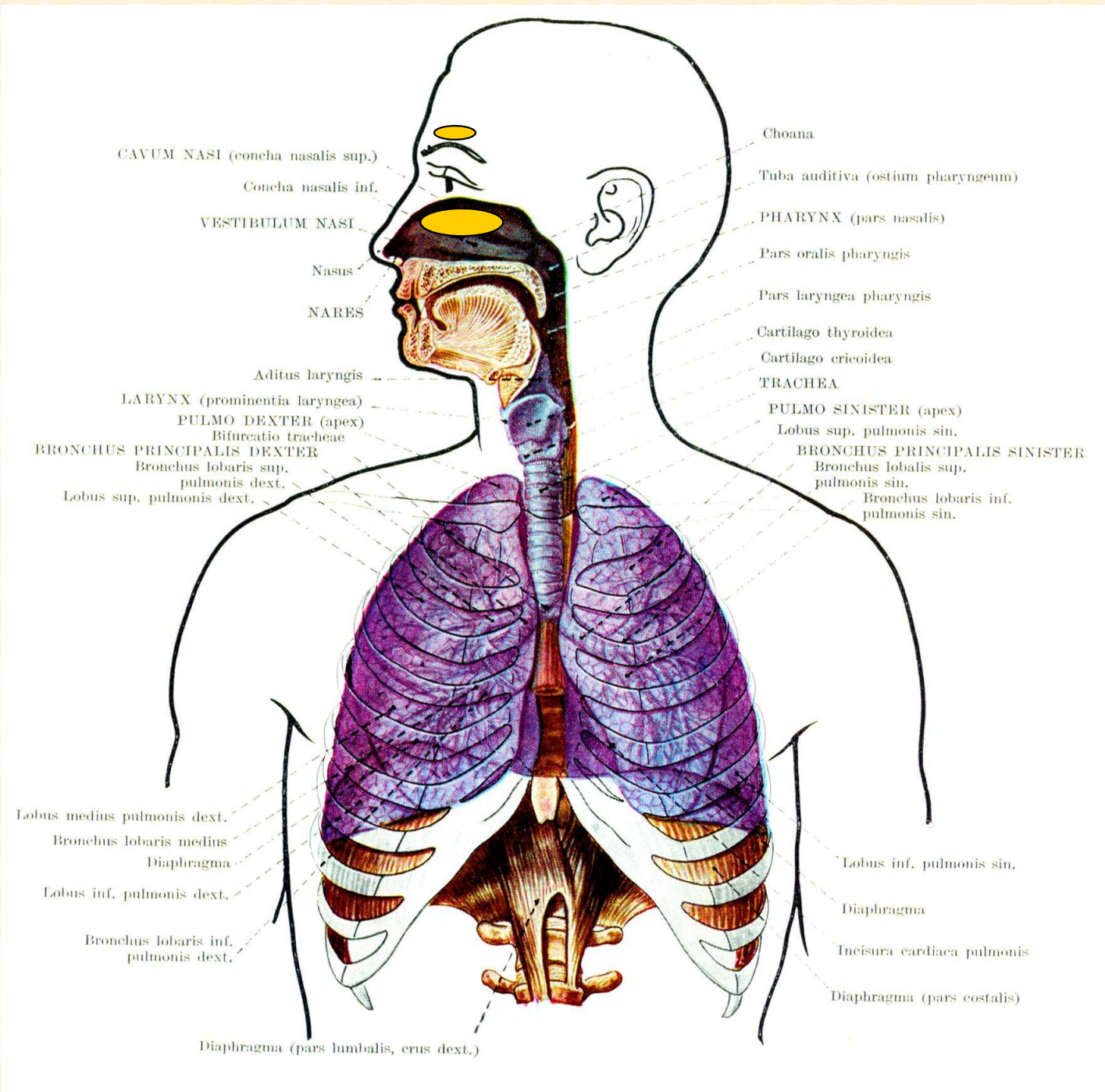
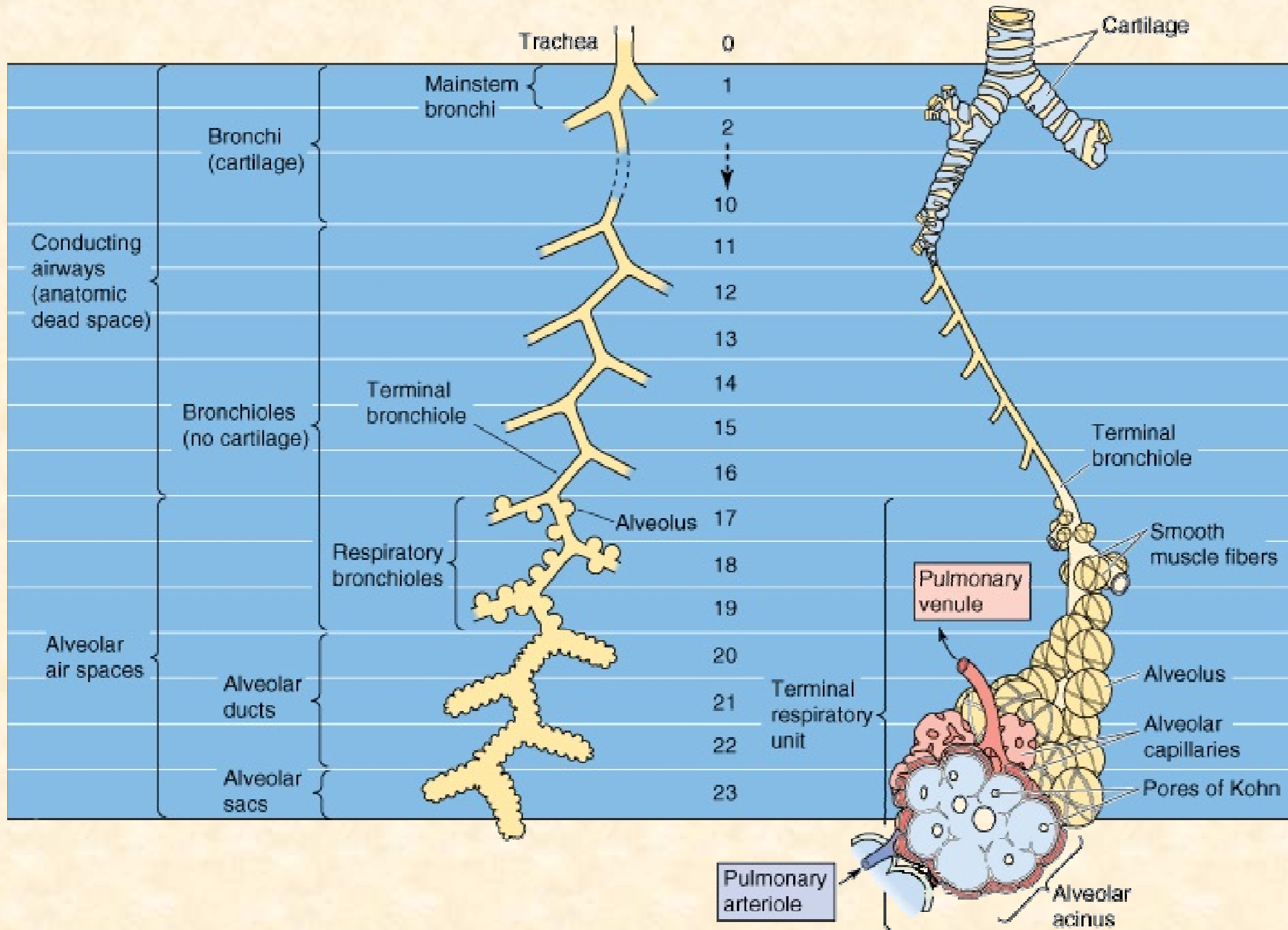
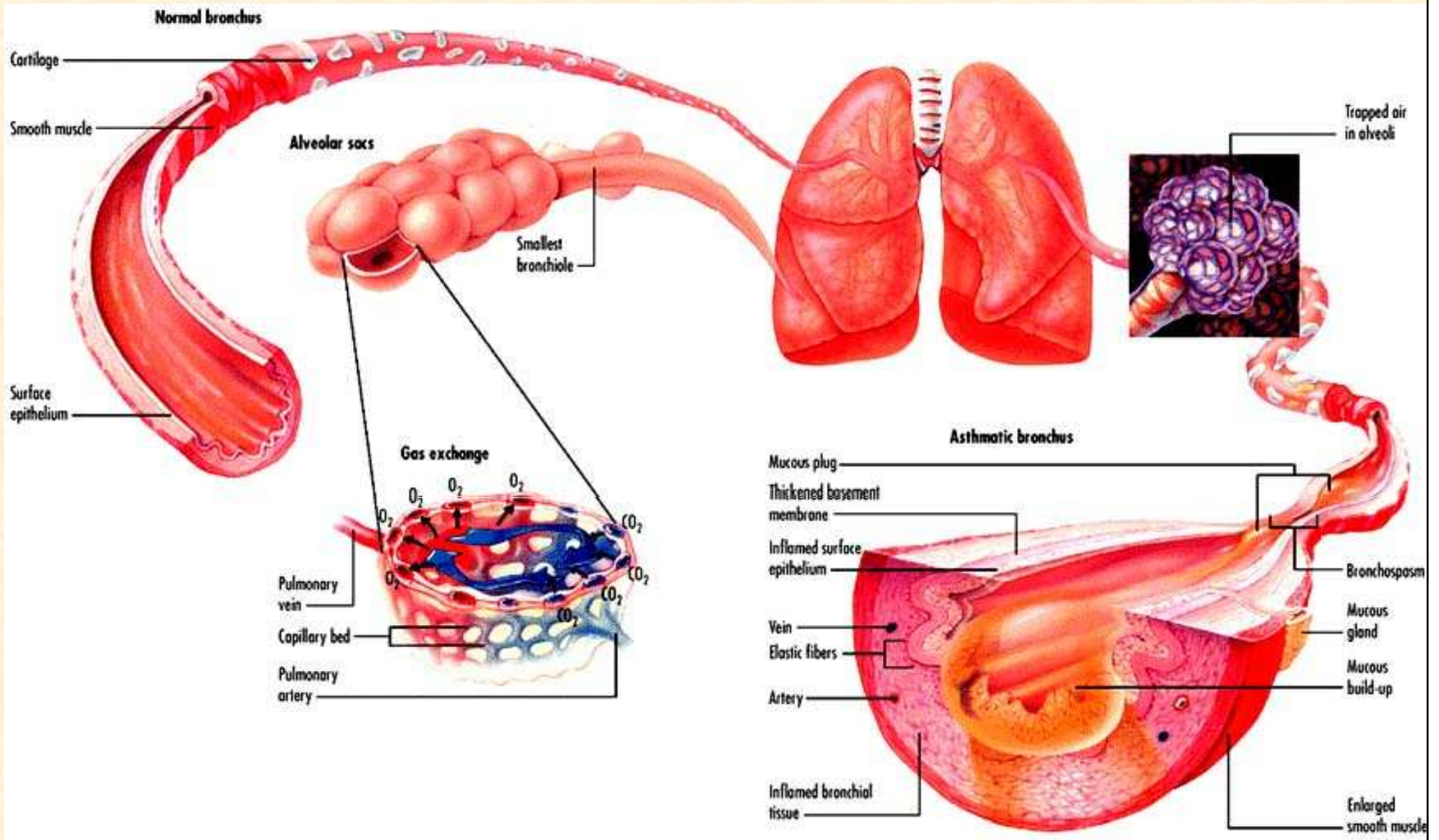


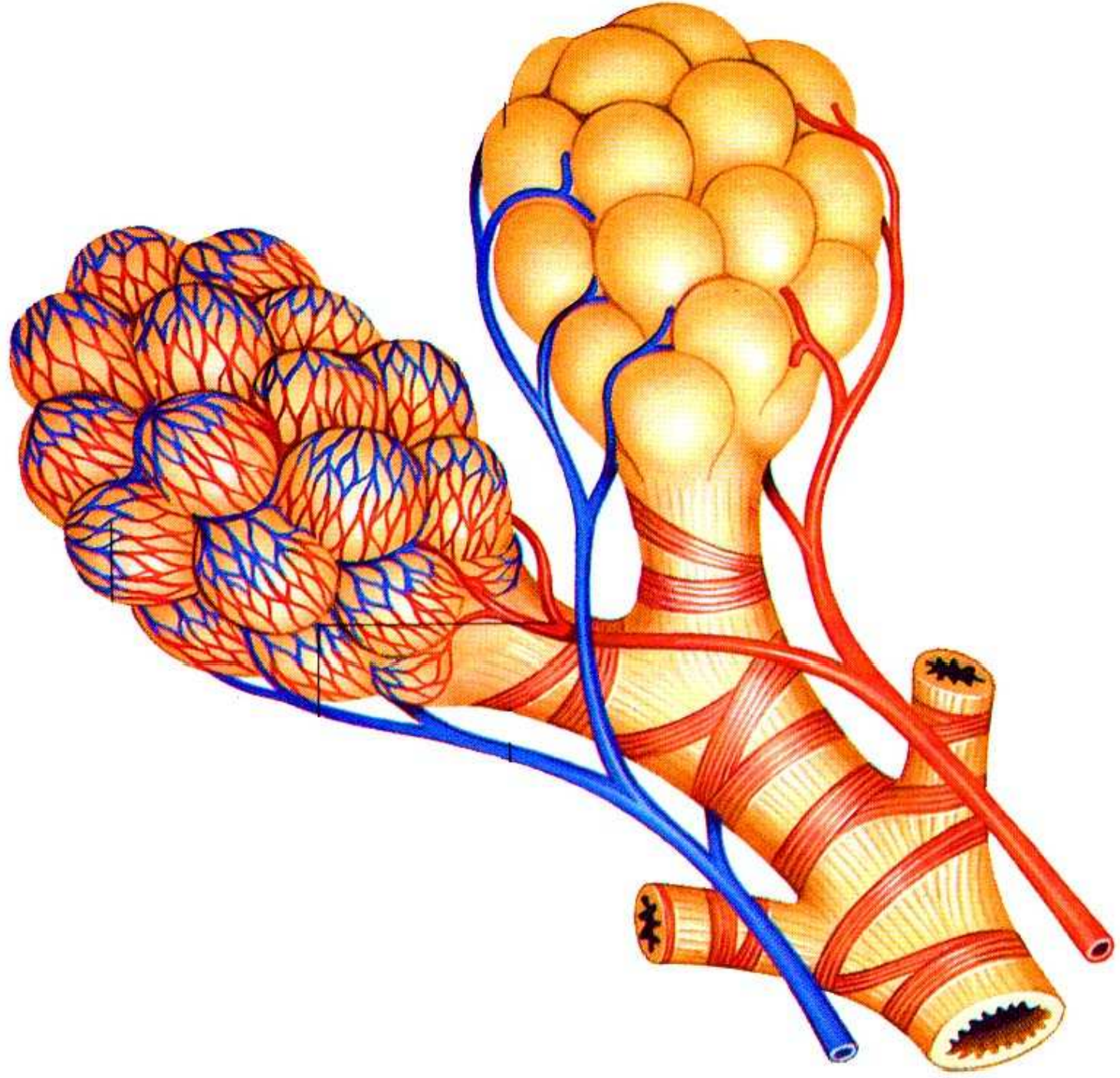
RESPIRATORY SYSTEM

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









STEPS IN THE DELIVERY OF O_2 TO THE CELLS

VENTILATION
OF THE LUNGS

DIFFUSION OF O_2 ACROSS
ALVEOLAR-CAPILLARY
MEMBRANE

DIFFUSION OF O_2
FROM CAPILLARY TO
THE CELLS

TRANSPORT
OF O_2 IN
THE BLOOD

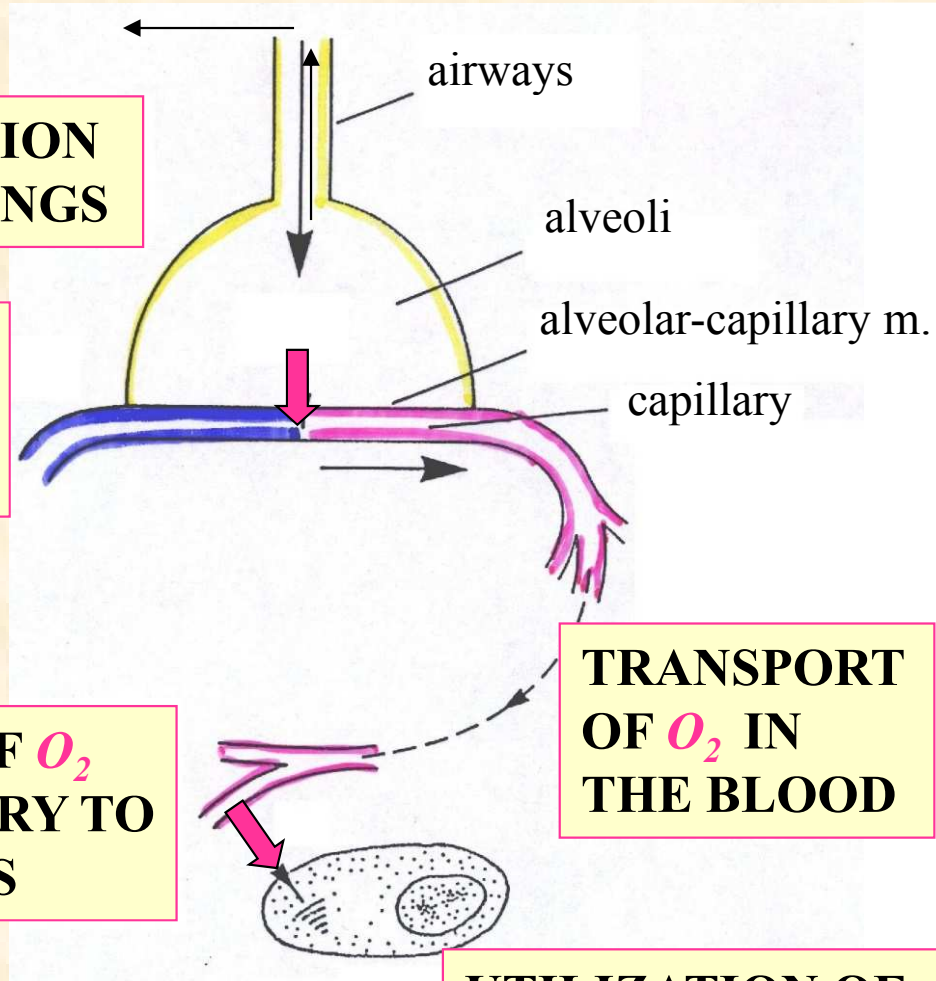
UTILIZATION OF O_2
BY MITOCHONDRIA

AT REST

O_2 UPTAKE ~300 ml / min

CO_2 OUTPUT ~250 ml / min

INTERNAL RESPIRATION



AIR PASSAGES

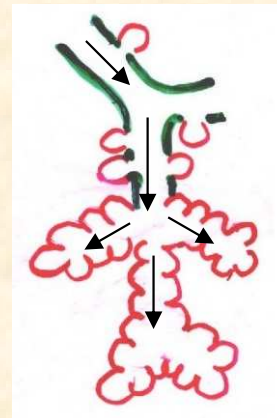
ANATOMICAL DEAD SPACE – **CONDUCTING ZONE**



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

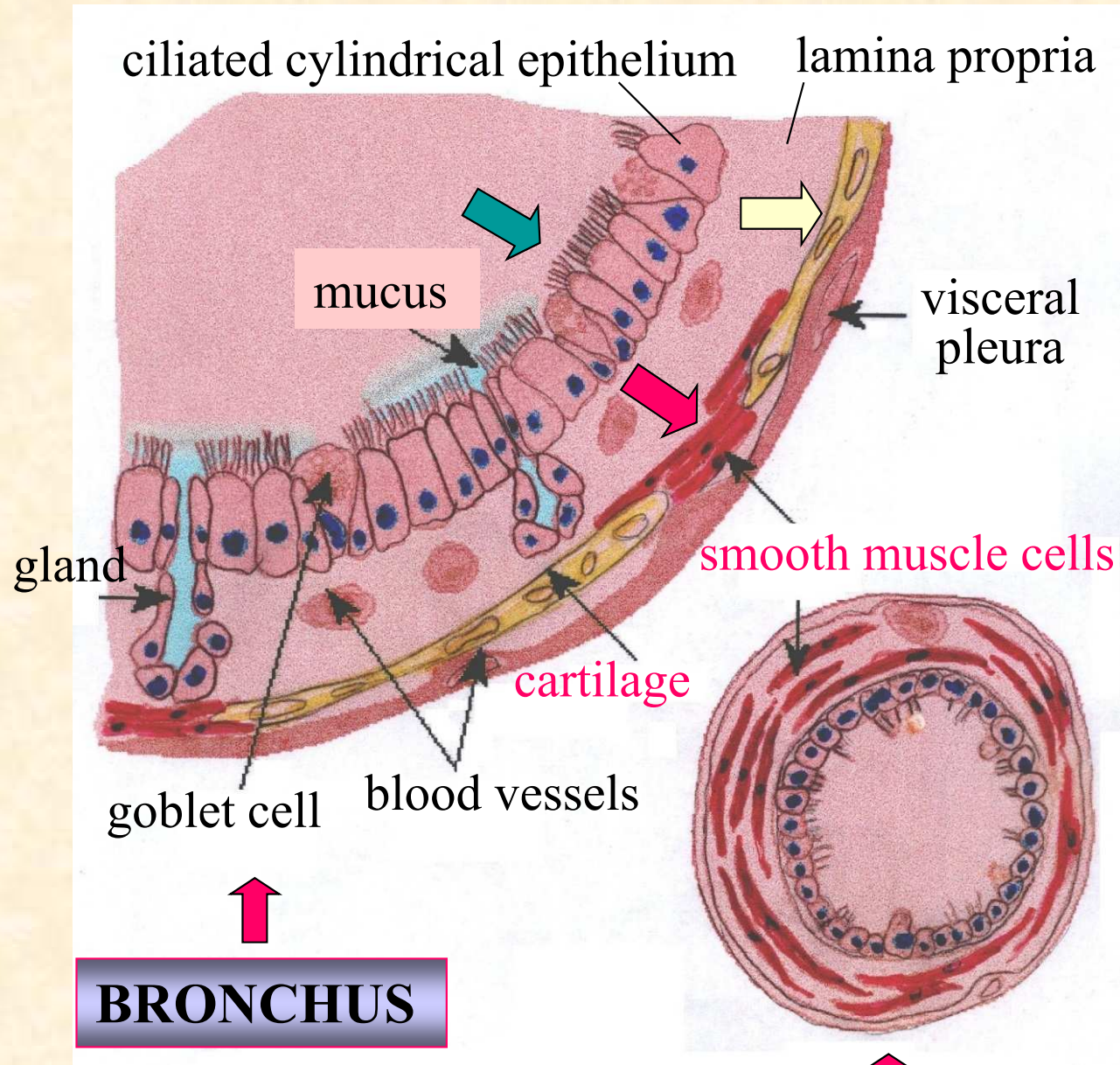
Other physiological functions:

- 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 $\sim 100 \text{ m}^2$



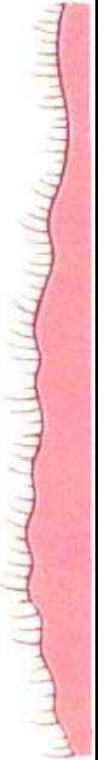
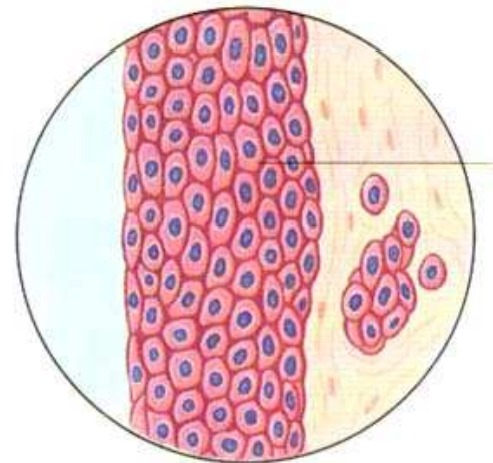
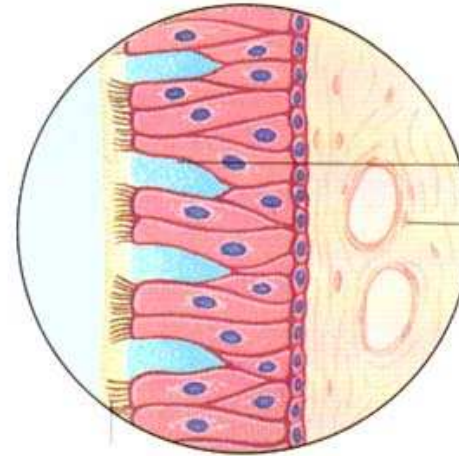
AUTONOMIC INNERVATION of smooth muscle cells

Stimulation via parasympathetic NS - n.vagus due to **Muscarinic** receptors: Acetylcholine activates bronchoconstriction

Stimulation via to sympathetic NS – due to catecholamins in circulation
 β_2 -adrenergic receptors:
 Noradrenaline activates bronchodilatation

TERMINAL BRONCHIOLE

$\varnothing < 1 \text{ mm}$



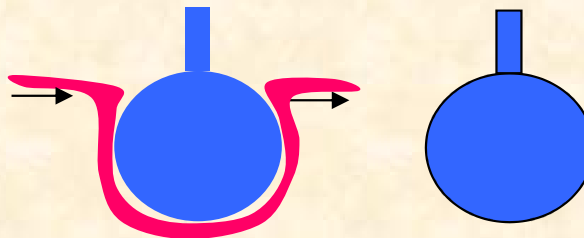
Cylindrical epithelium with cilia

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

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

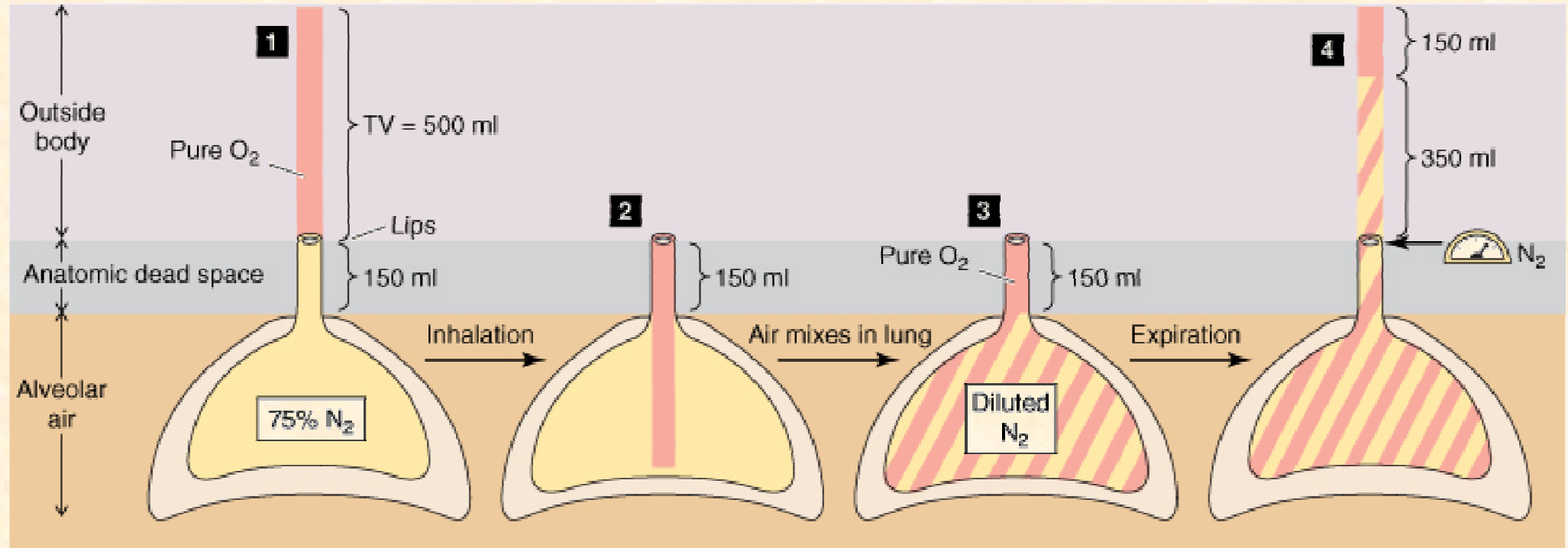
$$\dot{V}_D = V_D \times f$$

DEAD SPACE VENTILATION

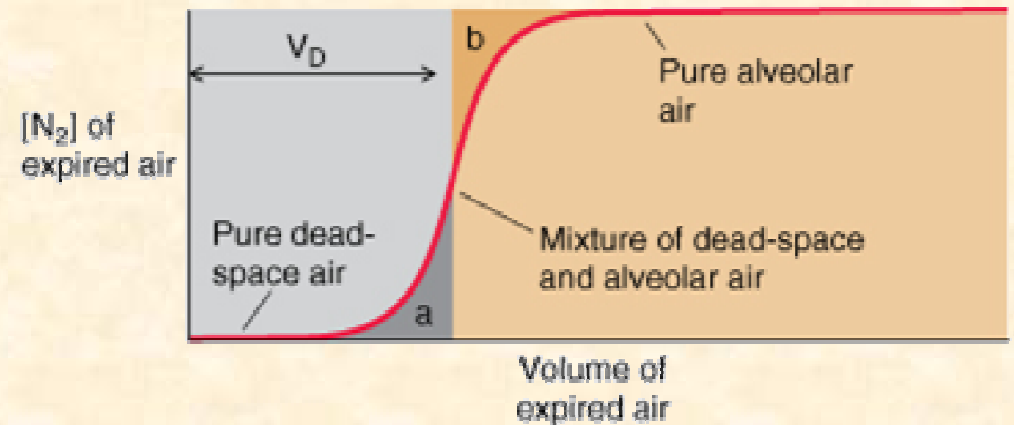
1.8 l/min

DEAD SPACE – nitrogen test (force inspiration of pure O₂, follow slowly expiration with monitoring of concentration of nitrogen)

A DILUTION OF INSPIRED 100% O₂

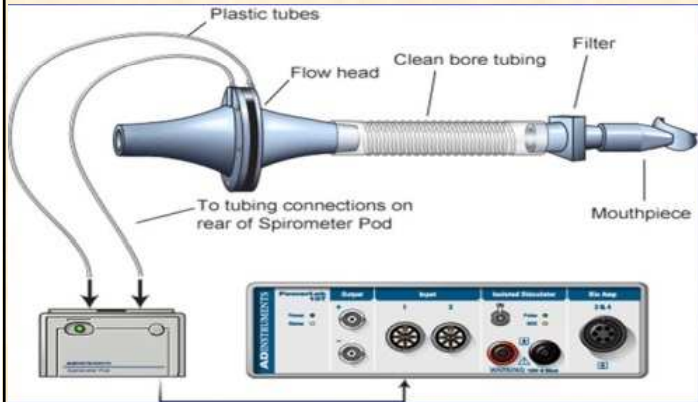


C MEASURED [N₂] PROFILE

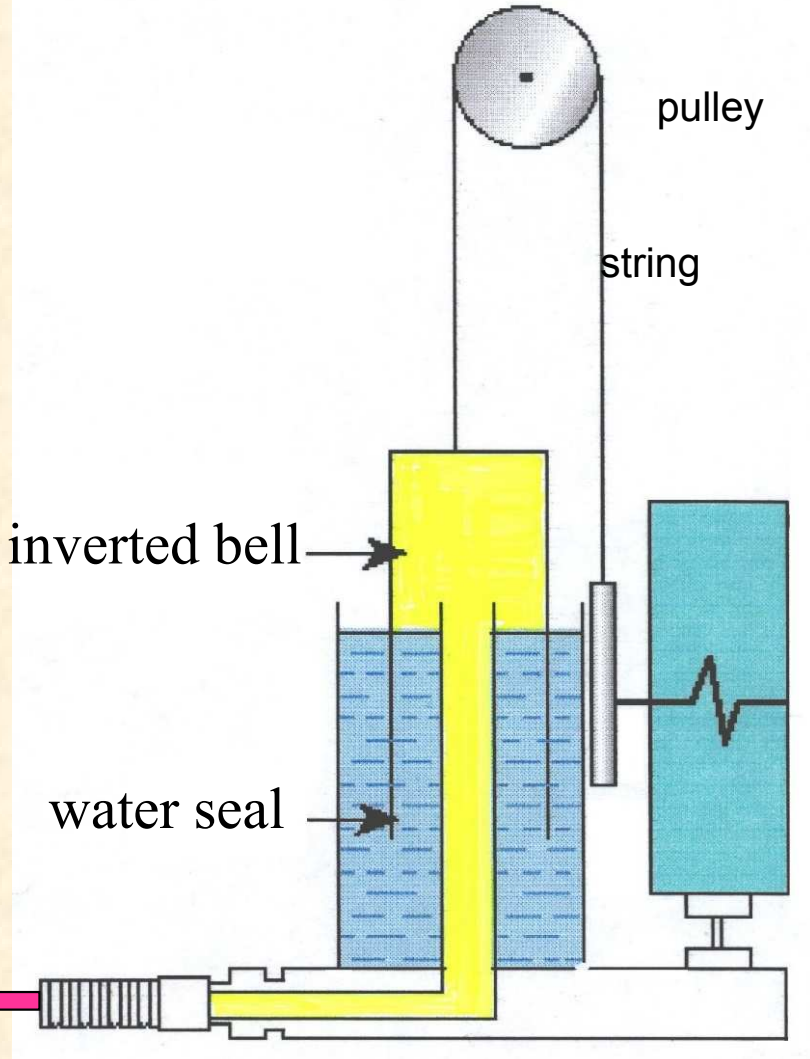


SPIROMETRY

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

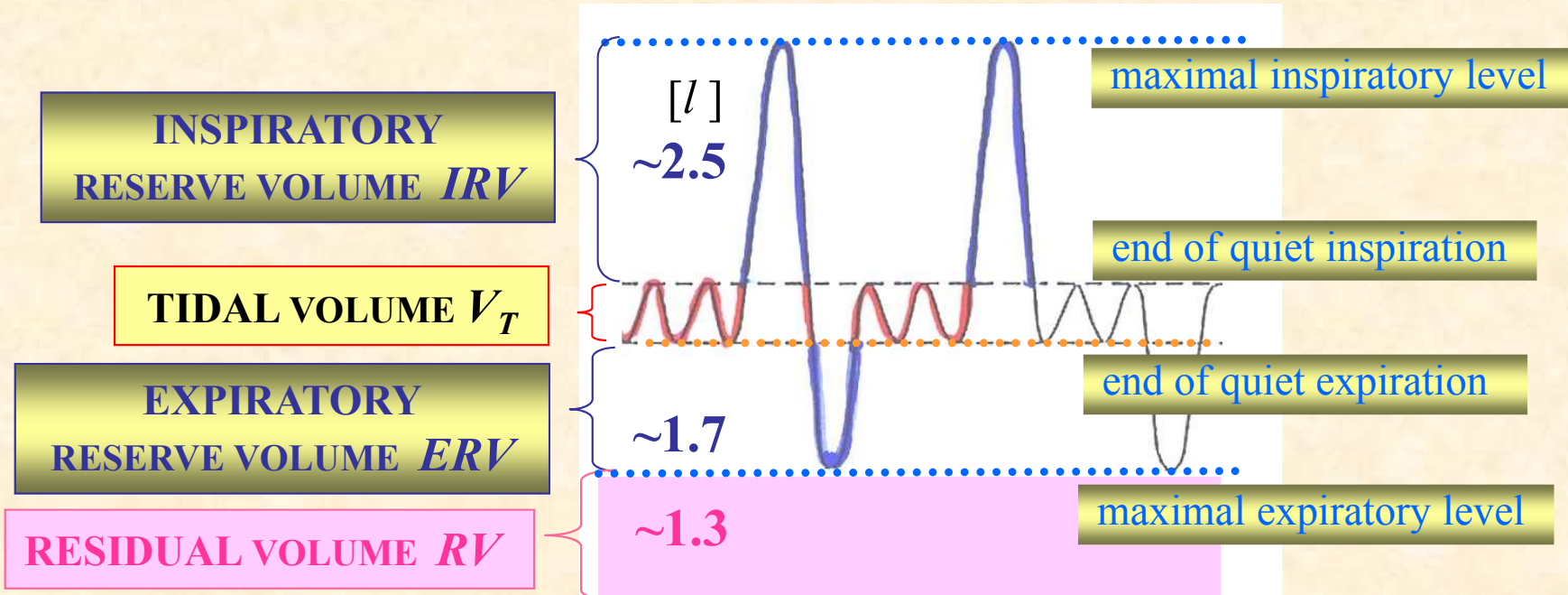


subject

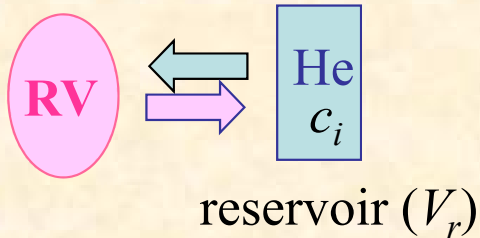


↑ inspiration
↓ expiration

LUNG VOLUMES



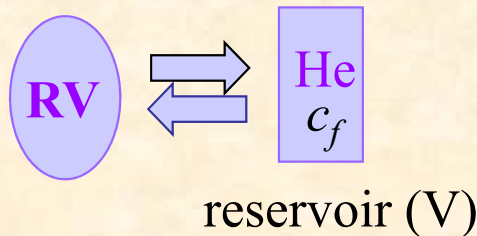
DILUTION METHOD He



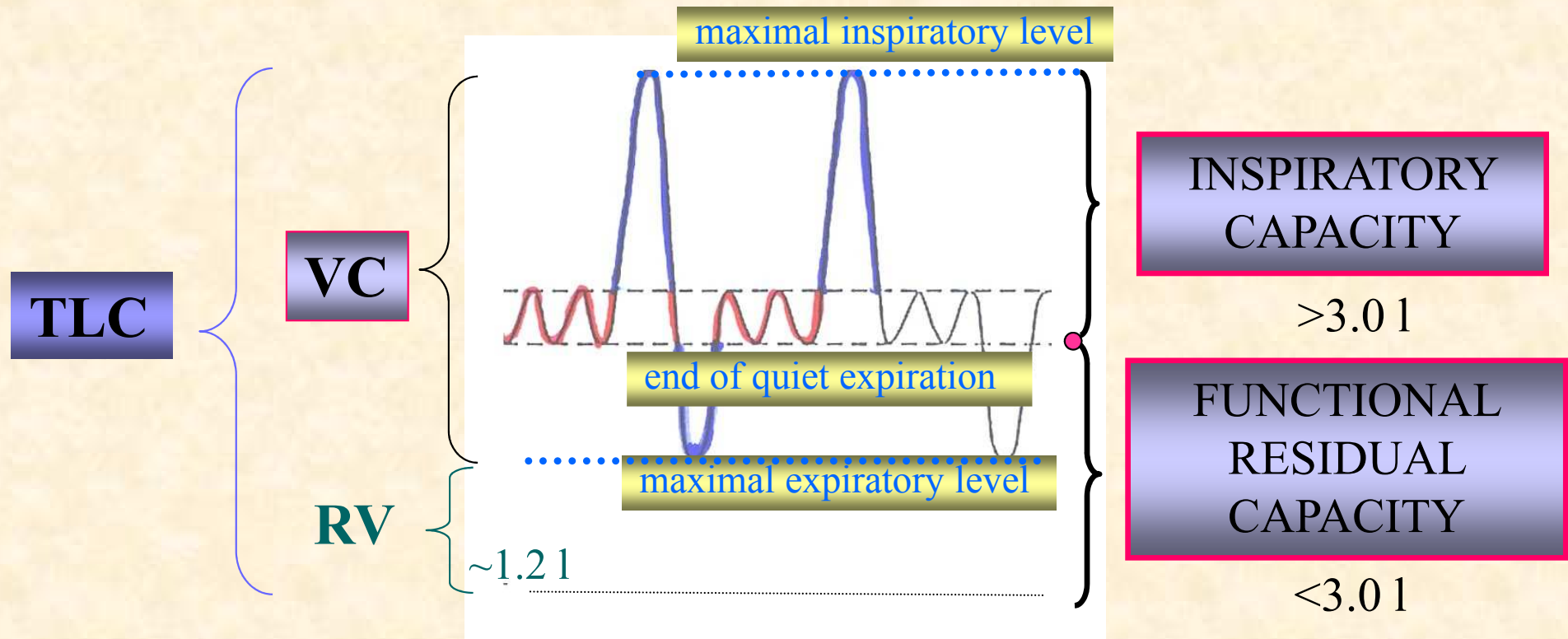
Principle of method: **1** Maximal expiration, **2** Repeated inspiration from and expiration into a reservoir (known volume V_r) with inert gas He (known concentration c_i)

\Rightarrow 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).



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



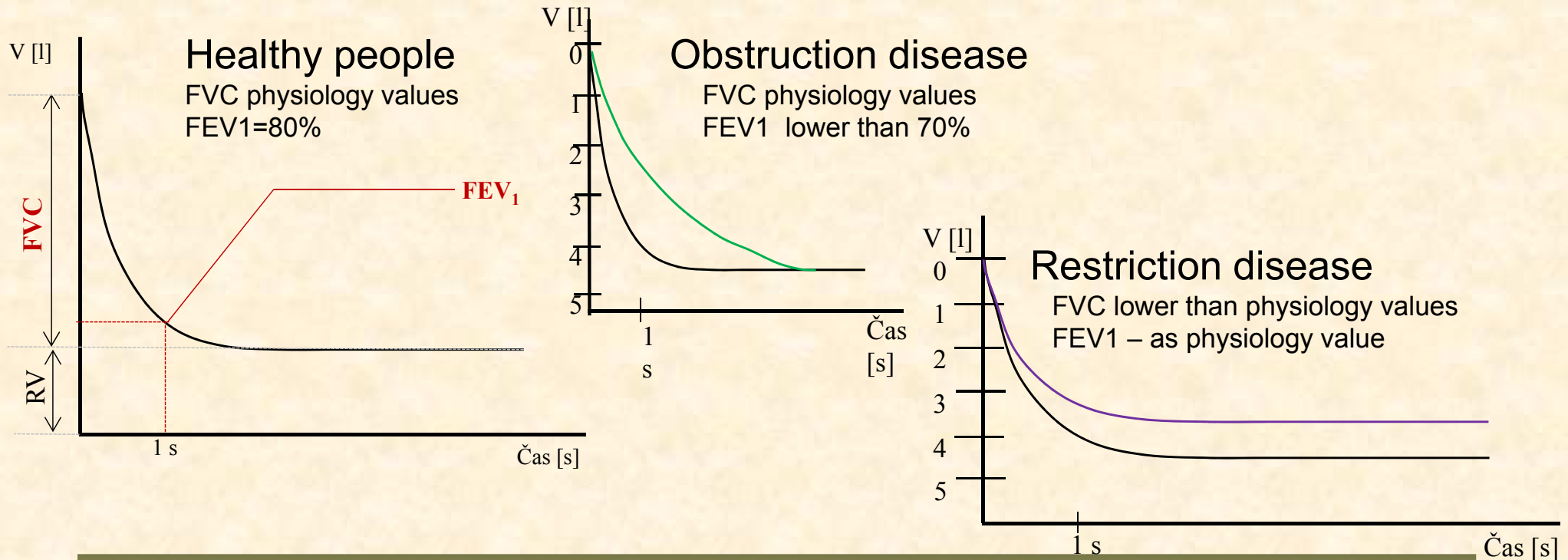
VC **VITAL CAPACITY** = $V_T + IRV + ERV$ ~ 4.7 l

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** ($0.5 \text{ l} \times 12 \text{ breathes/min} = 6 \text{ l/min}$)

- **MAXIMAL VOLUNTARY VENTILATION (MVV)** (125-170 l/min)

- **PEAK EXPIRATORY FLOW RATE ($PEFR$)** ($\sim 10 \text{ l/s}$)

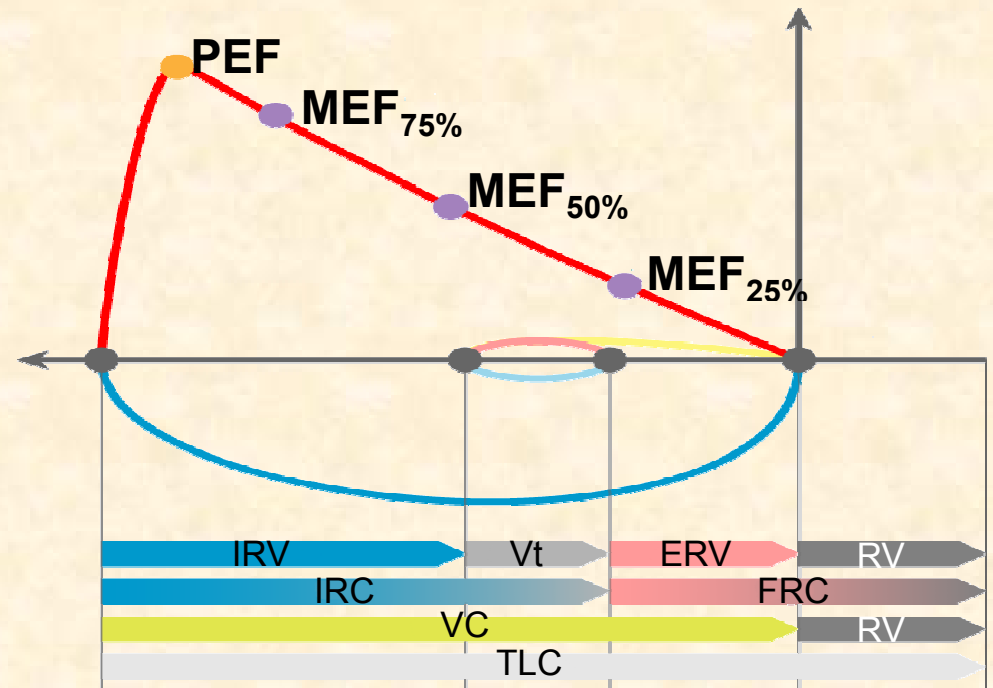
Flow – volume curve



Propeller spirometer



- **PEF** – peak expiratory flow
- **MEF** – maximální maximal expiratory flow on the differential levels of FVC - 75 %, 50 % a 25 % FVC



PNEUMOGRAPHY

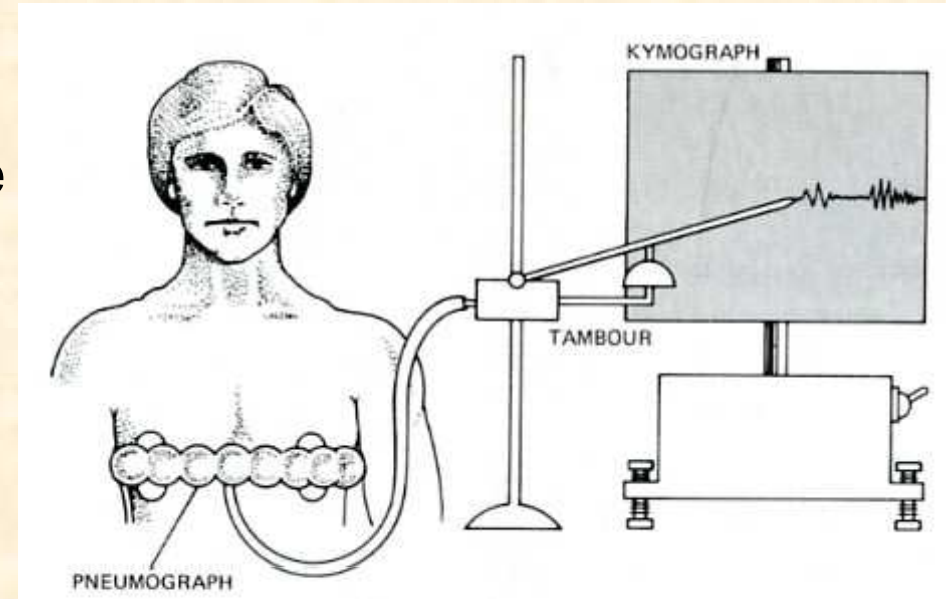
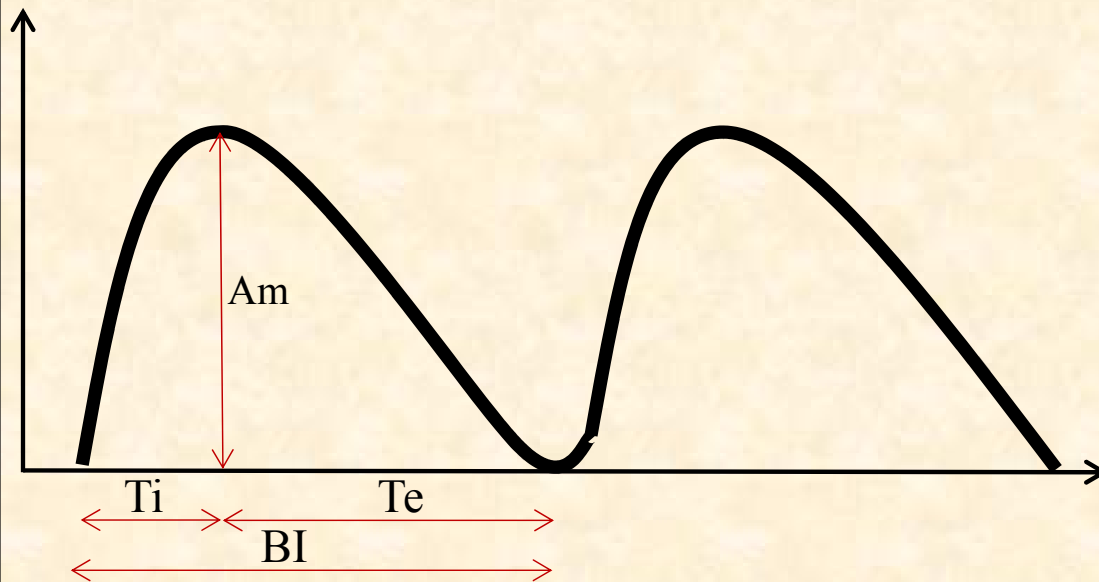
Principle

Pneumography – measurement of respiratory movements (via chest or abdomen)

- respiratory belt (piezoelectrical principle – is the ability of crystal to generate of electrical voltage during its deformation)

Record:

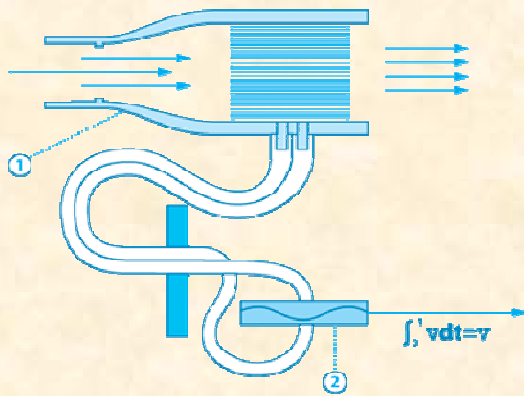
- Resting breathing
- Breathing after mild or intensive exercise
- Evaluation of record – T_i , T_e , BI a A_m



PNEUMOTACHOGRAPHY

Principle

Pneumotachograph - the device consists of tubes of the same diameter arranged in parallel. One of the tubes has branches with tubes near both its ends (oral and external). These are connected to a pressure sensor that allows you to measure the differences in air pressure at the beginning and end of the pneumotachograph in proportion to the speed of the inhaled or exhaled air.

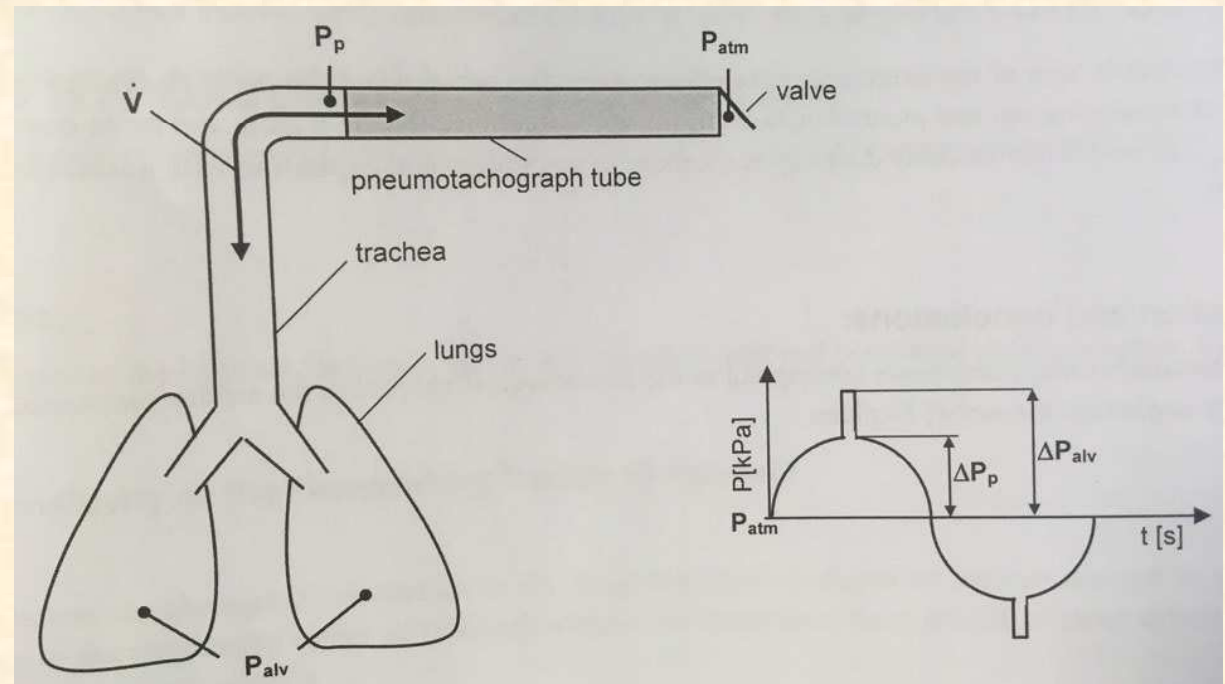


$$\Delta P_p = P_p - P_{atm}$$

$$\Delta P_{alv} = P_{alv} - P_{atm}$$

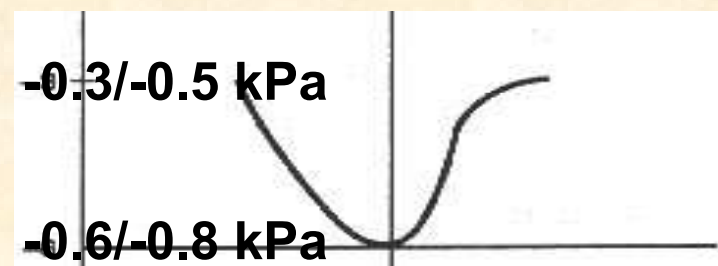
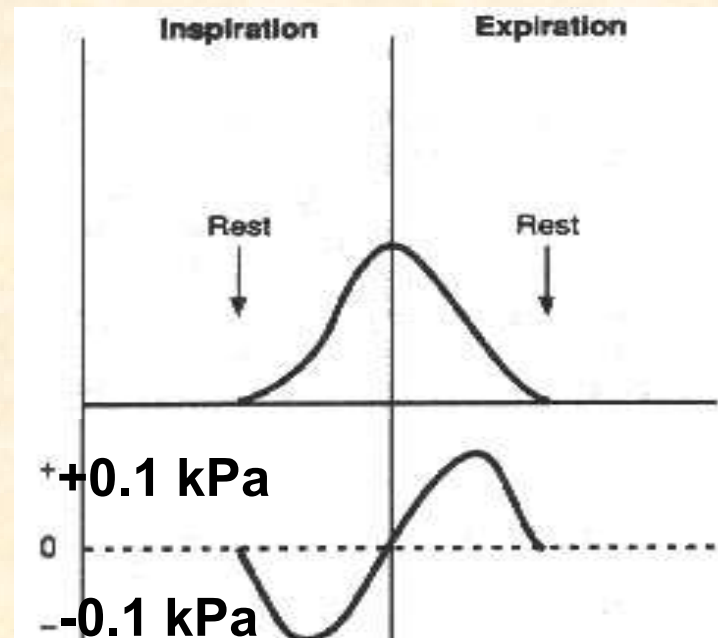
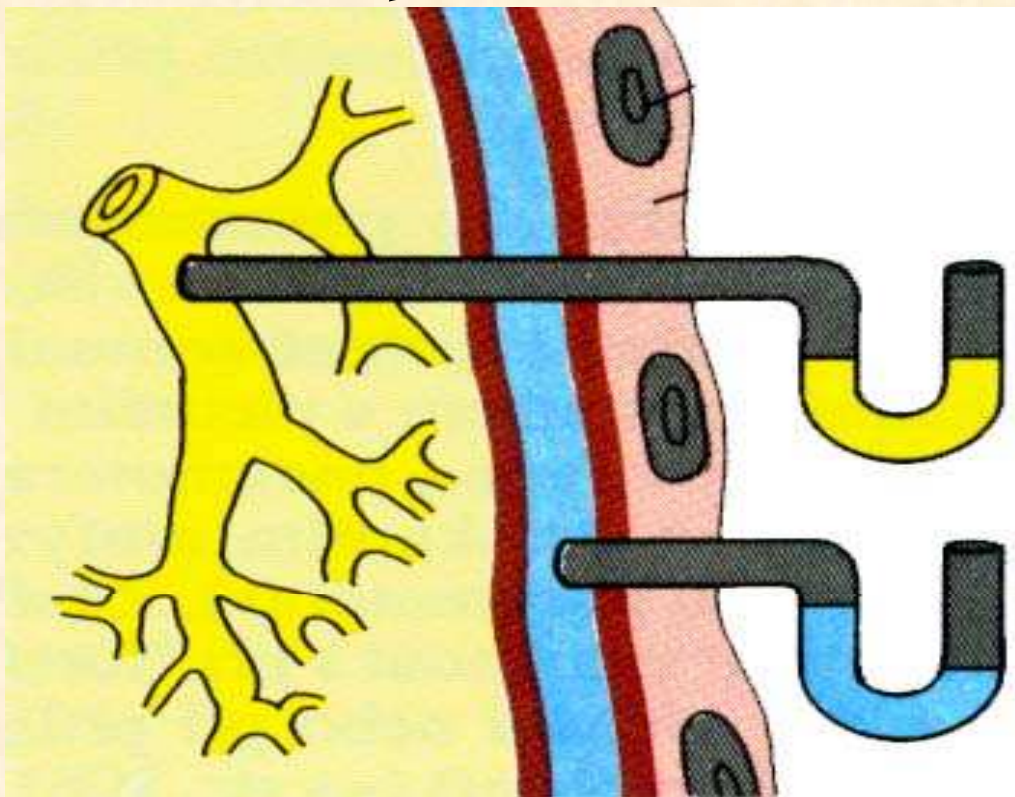
$$\frac{P_p - P_{atm}}{R_p} = \dot{V} = \frac{P_{alv} - P_p}{R_d}$$

$$R_d = R_p \cdot \left(\frac{\Delta P_{alv}}{\Delta P_p} - 1 \right)$$



- **Mechanics of breathing**

PLEURA
pulmonalis parietalis



FORCES PARTICIPATING IN RESPIRATION

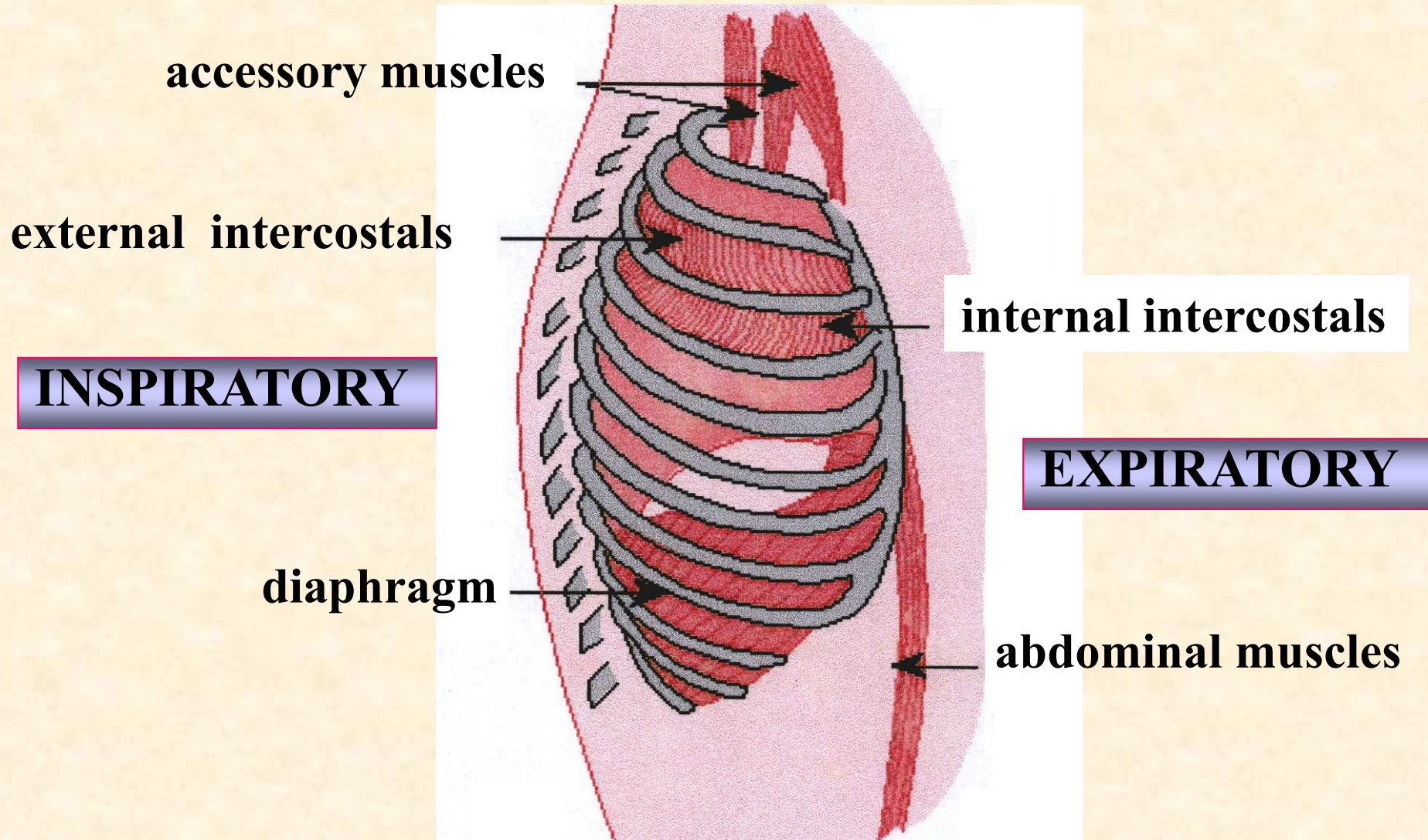
- **ACTIVE FORCES** performed by respiratory muscles
- **PASSIVE FORCES** represented by:
 - lungs elasticity
 - chest elasticity

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

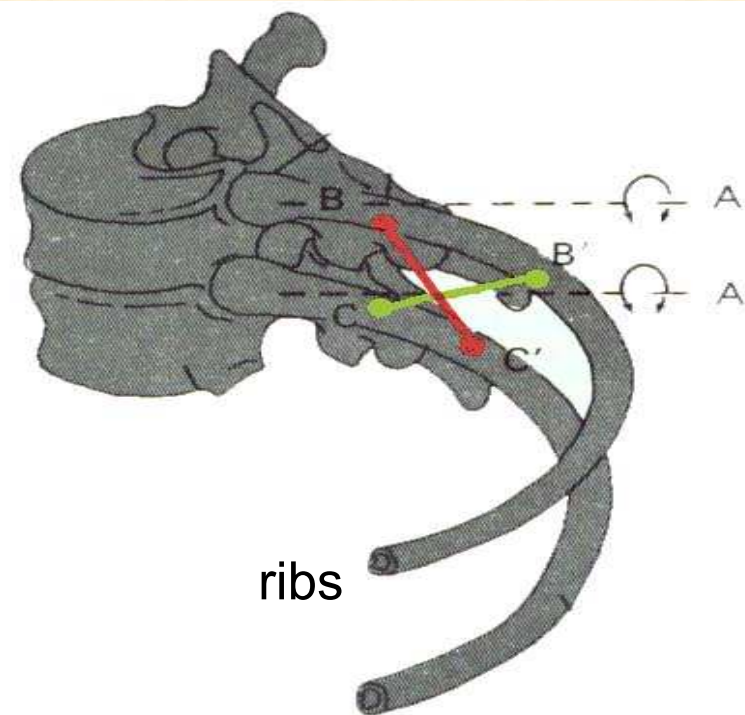
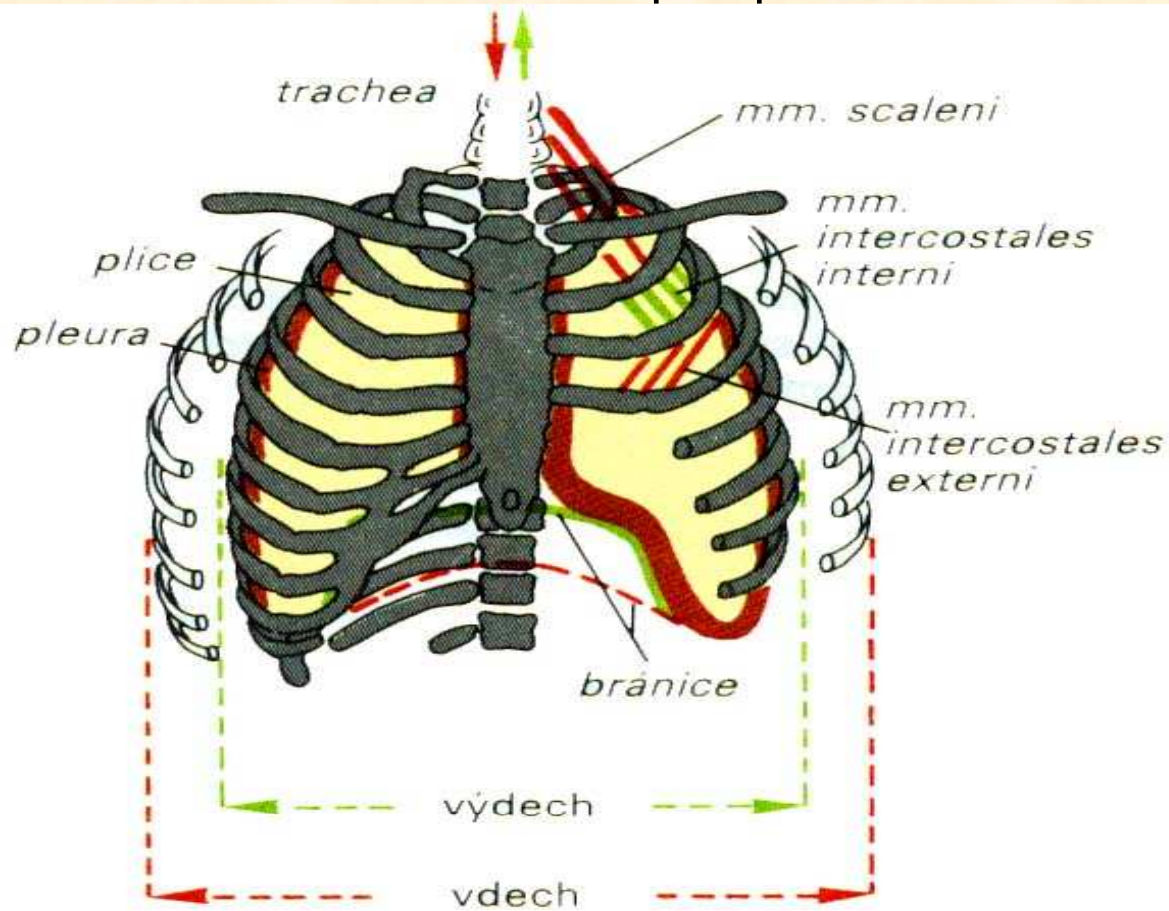
- *accessory inspiratory muscles* (mm. scalene)

EXPIRATORY muscles

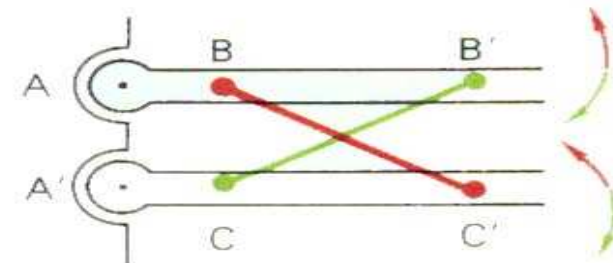
Only at FORCED breathing

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

Bucket-handle and water-pump handle effects



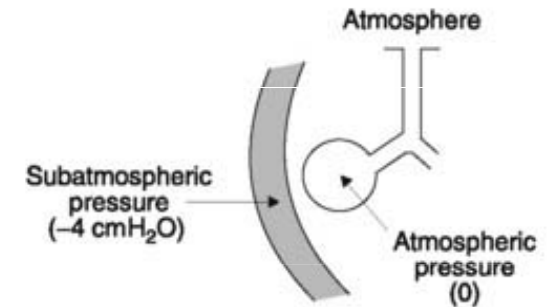
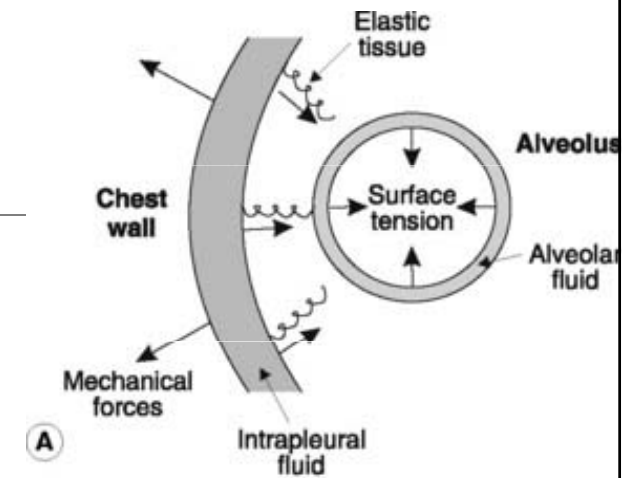
páka $A - B < A' - C'$ → zvedání žeber



páka $A - B' > A' - C$ → klesání žeber

Forces acting on the lung

1. elasticity of lung (elastic recoil) (collapsing force)
2. Lung surface tension (collapsing force)
3. Chest wall recoil (opening force)
4. Intrapleural pressure-IPP (opening force)



Distending pressure
= Alveolar pressure - Intrapleural pressure

(B) End of expiration = 0 - (-4) = +4 cmH₂O

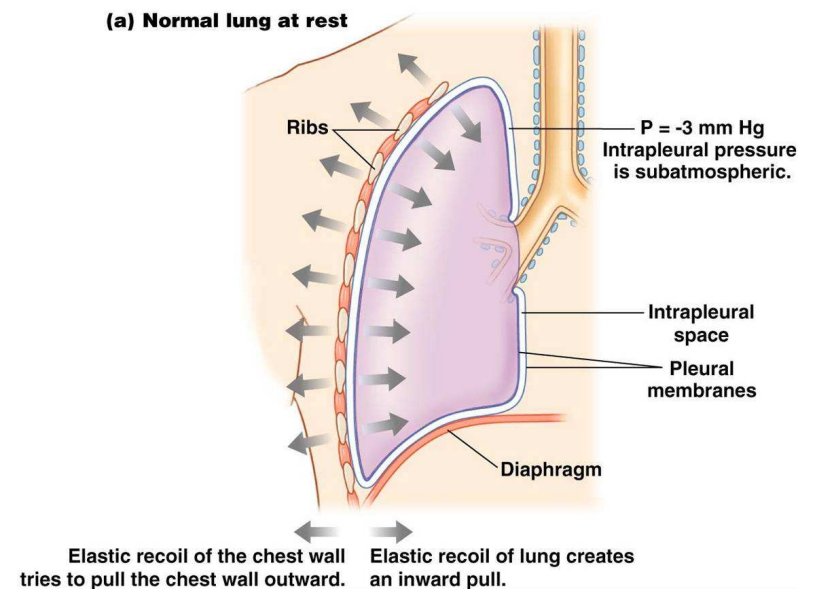
Lung recoil and chest wall recoil

Lung Recoil

- Represents the inward force created by the elastic recoil properties of alveoli.
- As the lung expands, recoil increases; as the lung gets smaller, recoil decreases.
- Recoil, as a force, always acts to collapse the lung.

Chest Wall Recoil

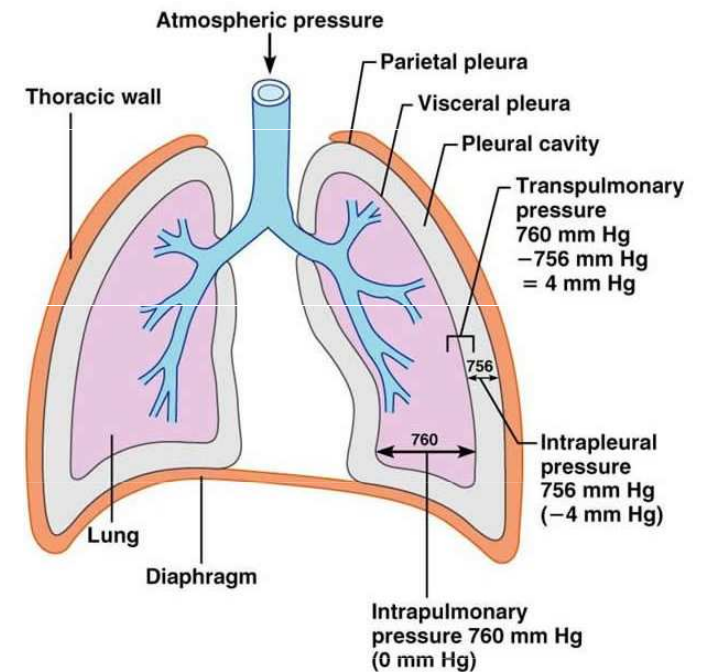
- Outward force of the chest wall
- FRC represents the point where this outward recoil of the chest wall is counterbalanced by the inward recoil of the lung.



Intrapleural pressure

Intrapleural Pressure (IPP)

- Represents the pressure inside the thin film of fluid between the visceral pleura, which is attached to the lung, and the parietal pleura, which is attached to the chest wall.
- The outward recoil of the chest and inward recoil of the lung create a negative (subatmospheric) IPP.
- IPP is the outside pressure for all structures inside the chest wall.



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

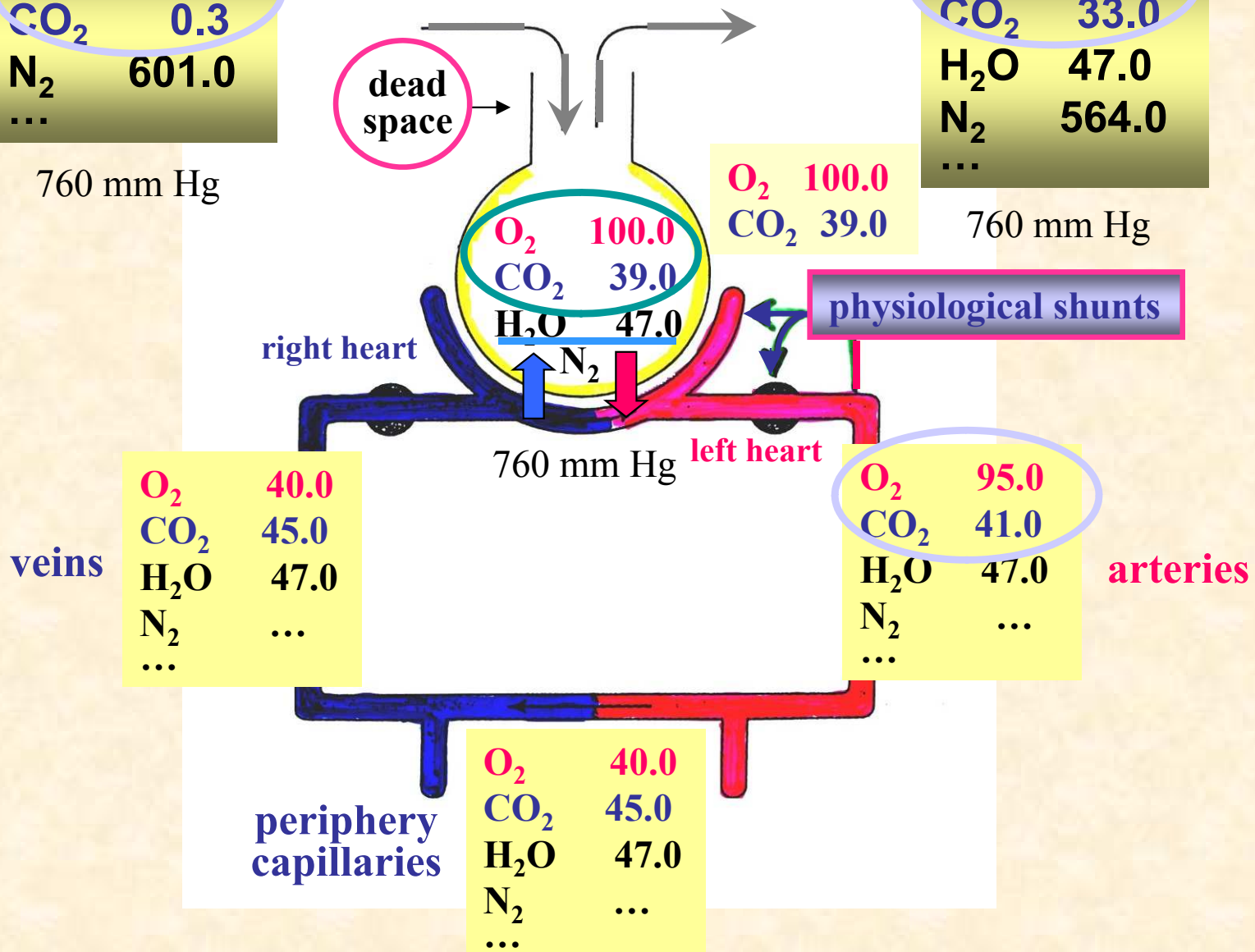
O ₂	158.8
CO ₂	0.3
N ₂	601.0
...	

760 mm Hg

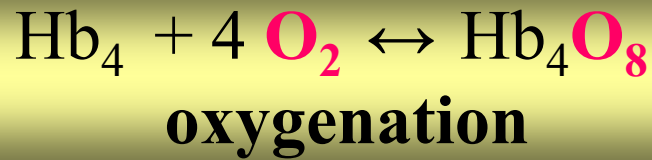
EXPIRED AIR

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

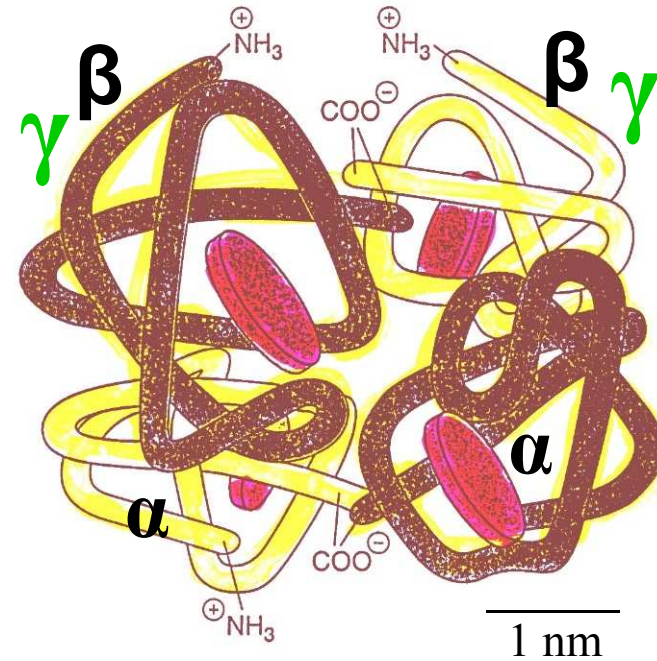
760 mm Hg



HAEMOGLOBIN



tetramer

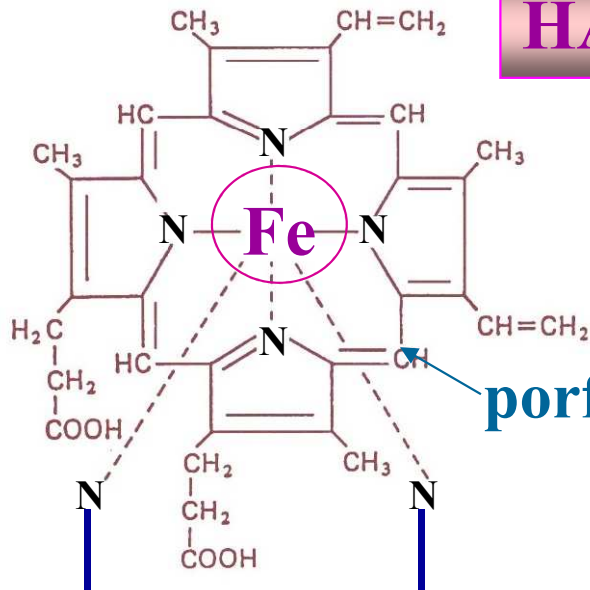


Fe^{2+}

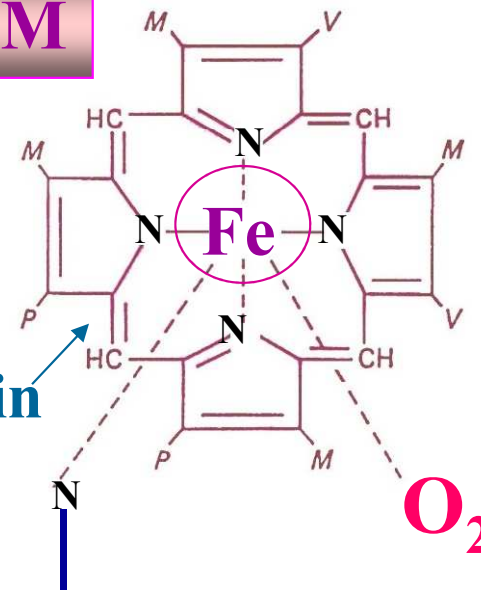
DEOXY

OXY

HAEM



porphyrin



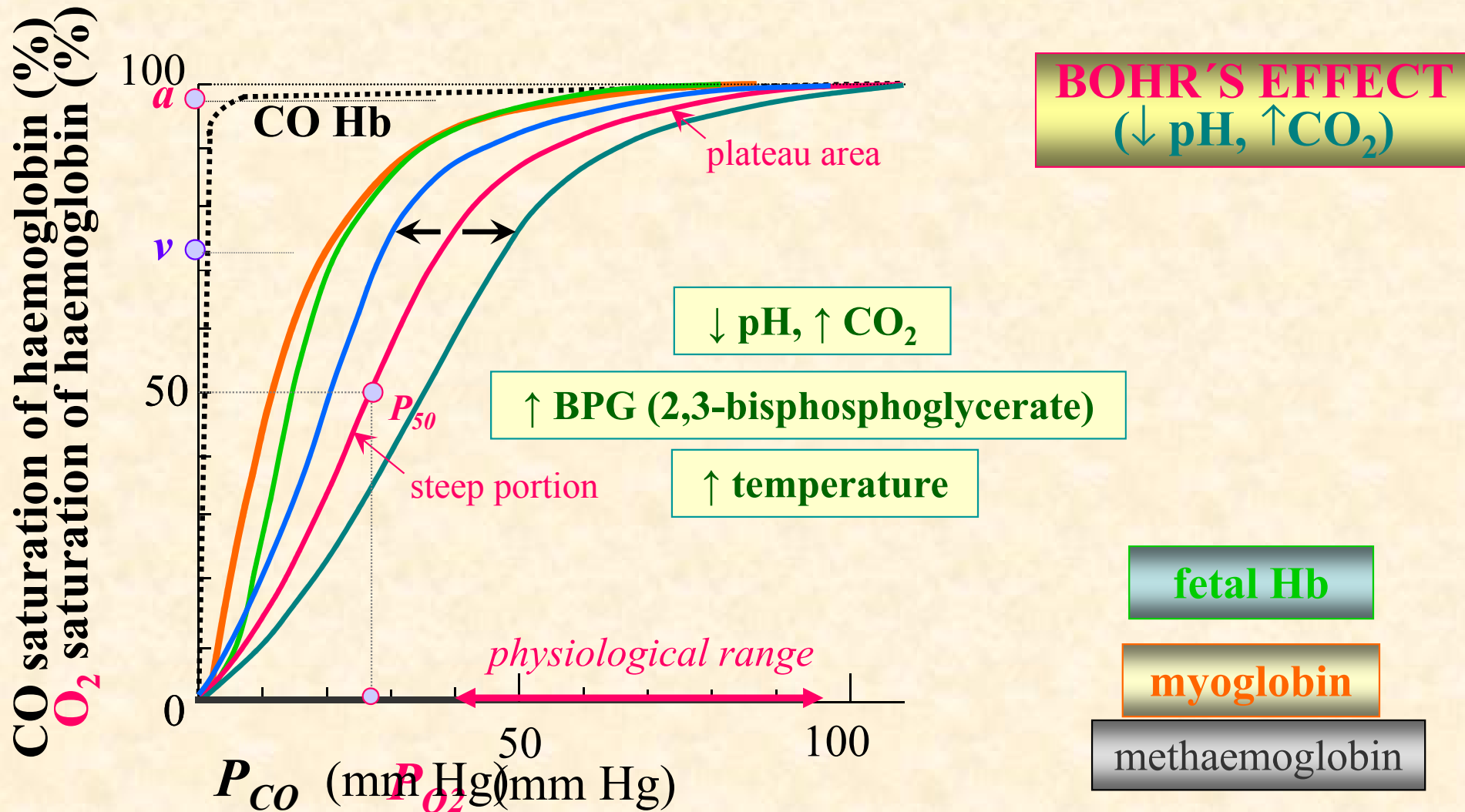
fetal Hb

Fe^{3+} (methaemoglobin)
oxidation

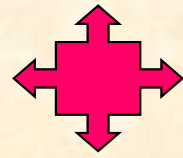
polypeptide chain

polypeptide chain

O_2 -HAEMOGLOBIN DISSOCIATION CURVE

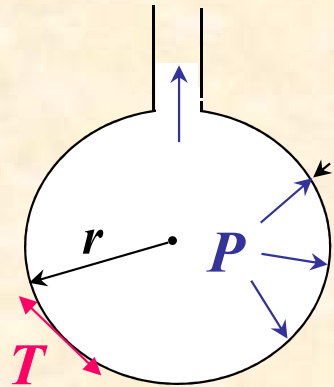


physically dissolved O_2 (1.4%)



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

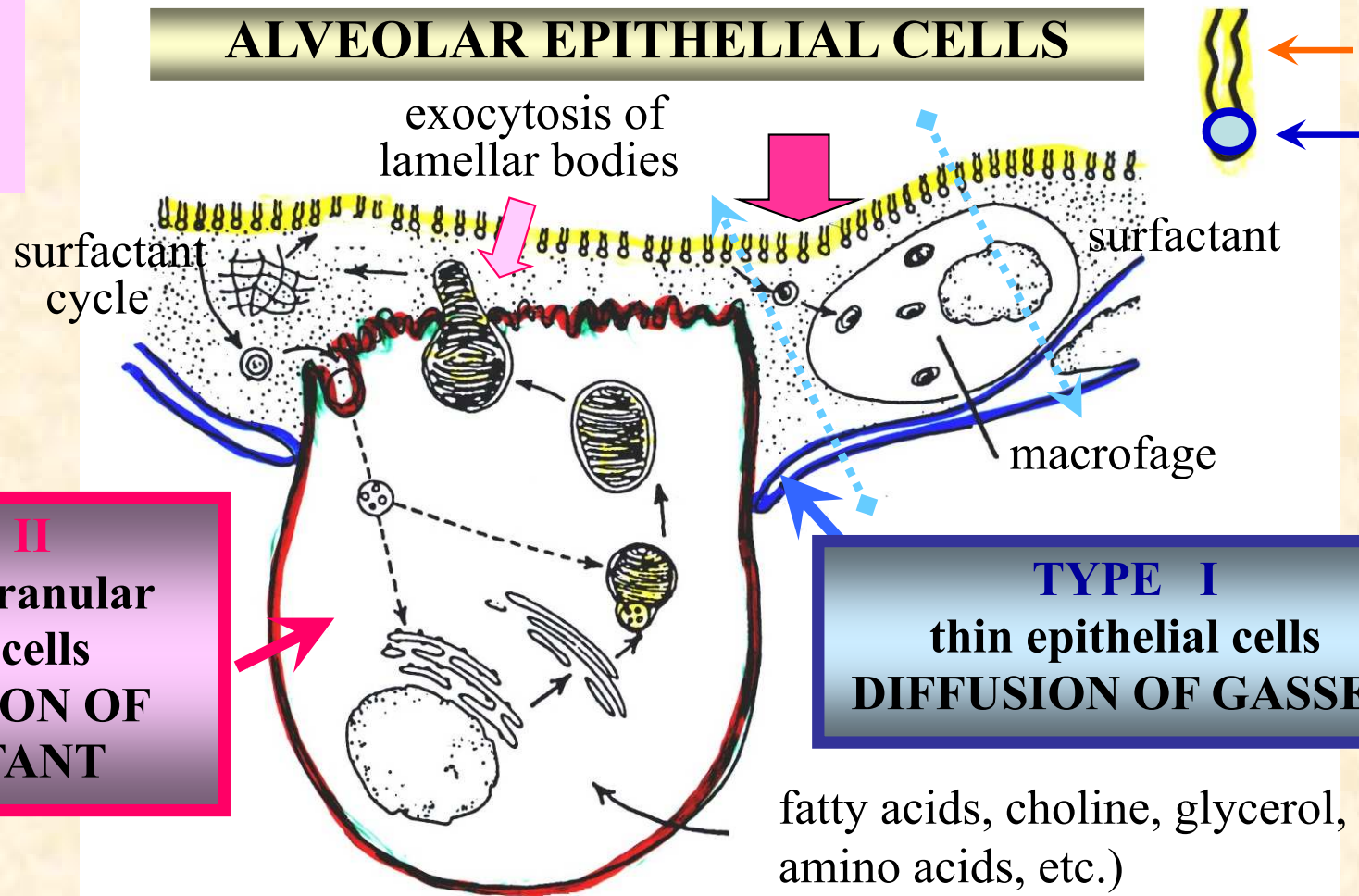
SURFACE TENSION LOWERING AGENT

EFFECT MAINLY IN THE EXPIRED POSITION

PHOSPHOLIPID

dipalmitoyl
fosfatidyl cholin

ALVEOLAR EPITHELIAL CELLS



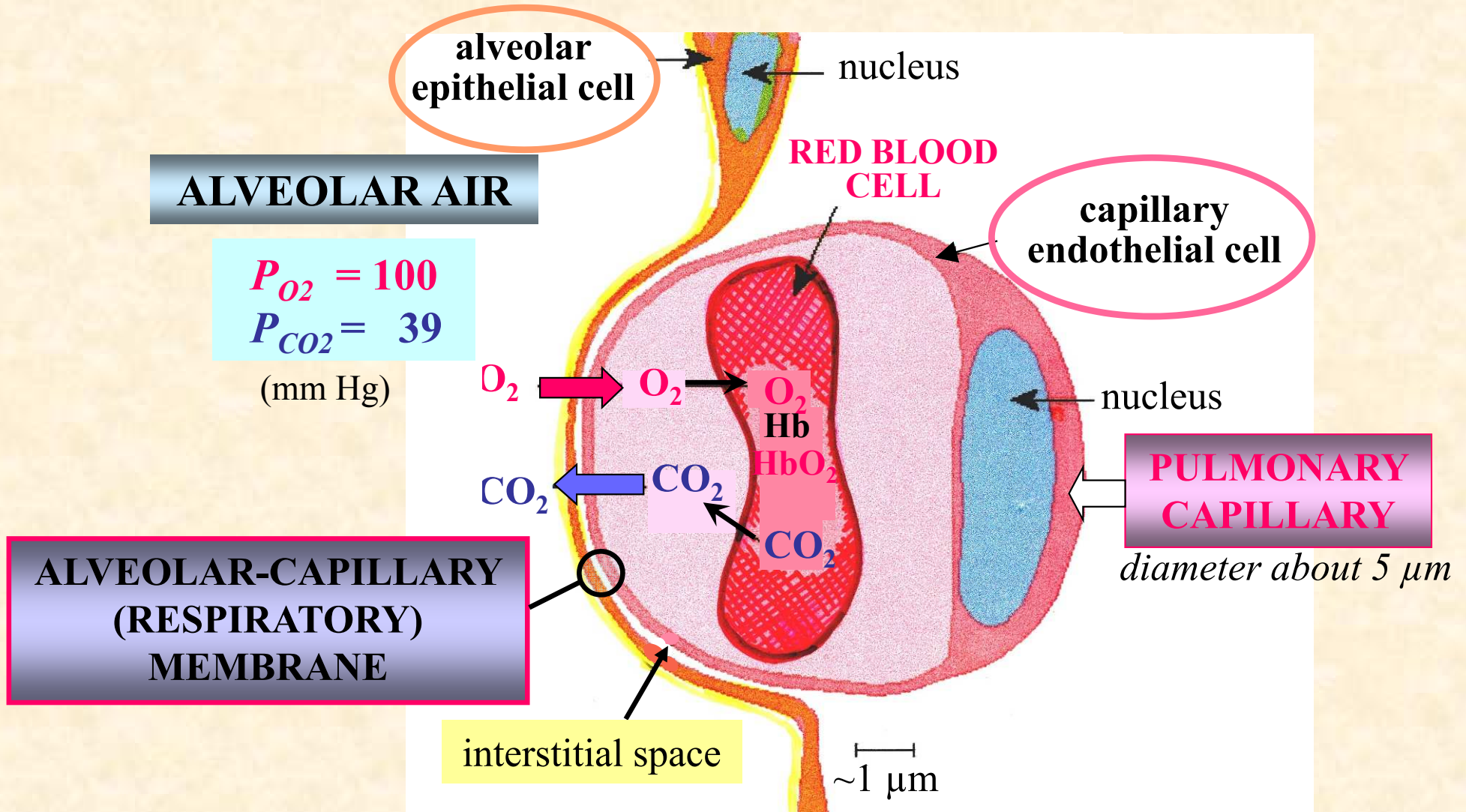
TYPE II
specialized granular
epithelial cells
**PRODUCTION OF
SURFACTANT**

TYPE I
thin epithelial cells
DIFFUSION OF GASSES



ALVEOLAR-CAPILLARY (RESPIRATORY) MEMBRANE

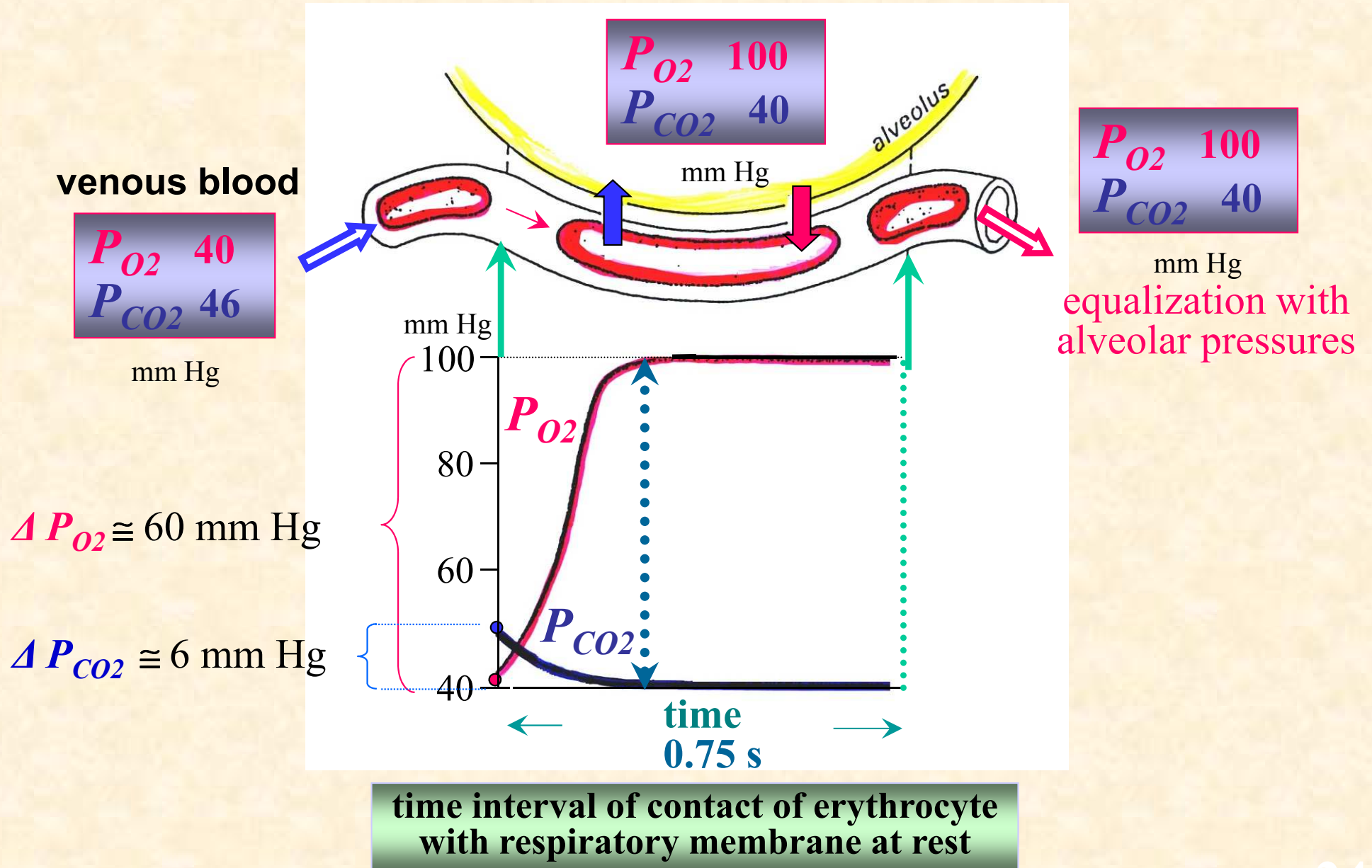
DIFFUSION OF GASES



0.75 s

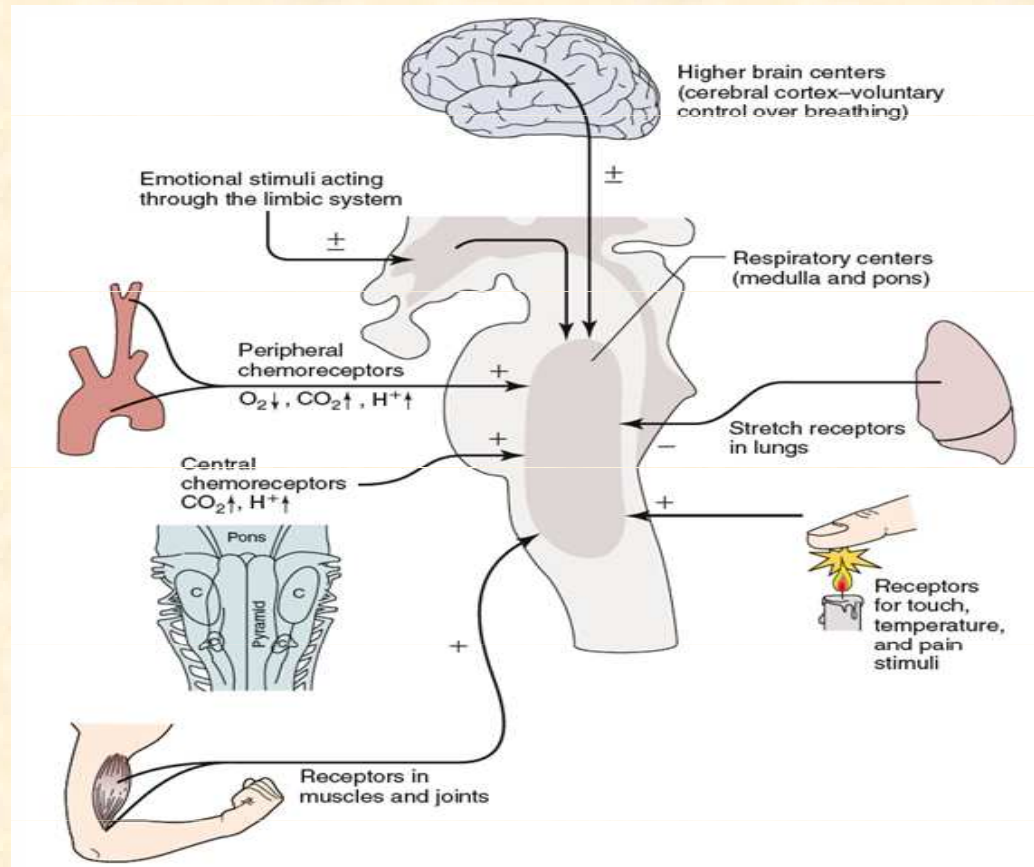
time interval of erythrocyte contact with respiratory membrane at rest

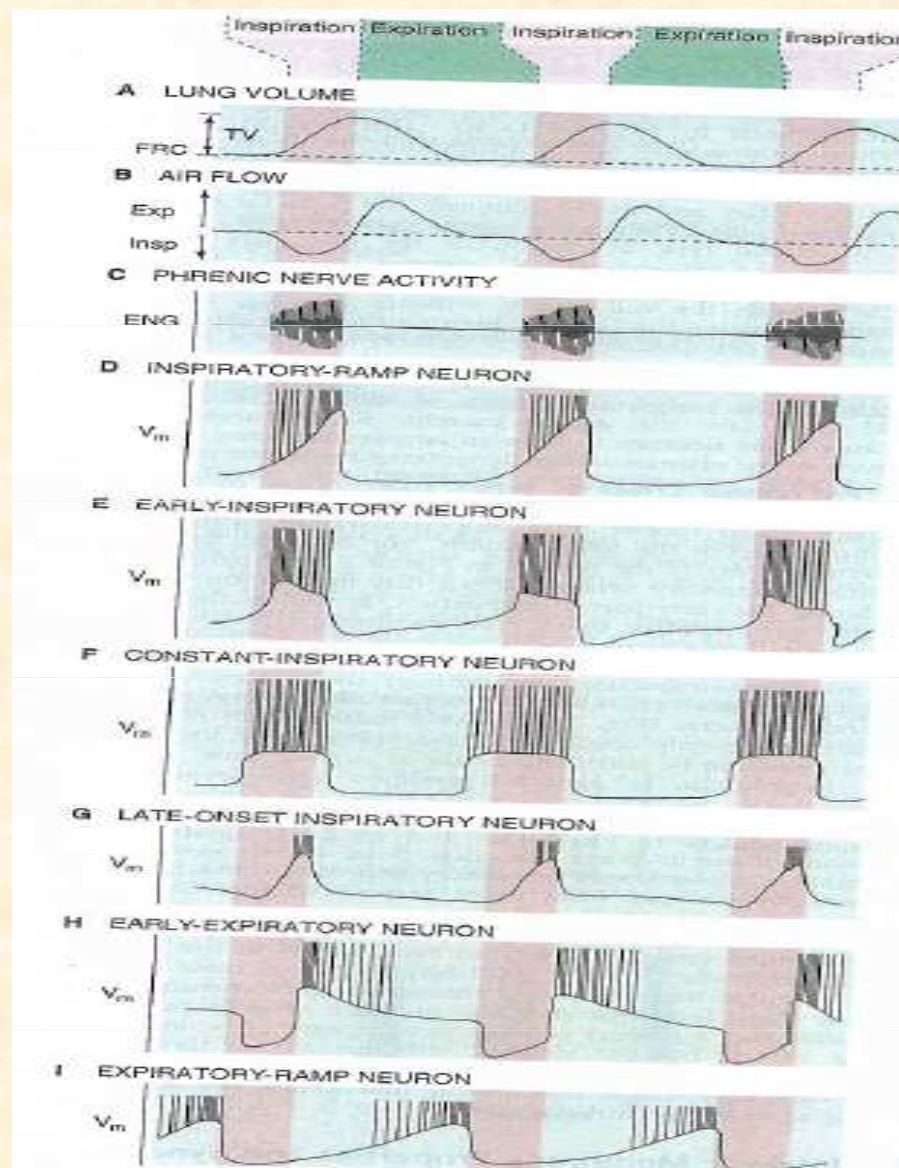
TIME COURSE OF CAPILLARY P_{O_2} AND P_{CO_2} DURING GRADUAL EQUILIBRATION WITH ALVEOLAR AIR





Control of ventilation





- **Breathing is an automatic process that takes place unconsciously. Automaticity of breathing comes from regular (rhythmic) activity of groups of neurons anatomically localized in the medulla and its vicinity.**

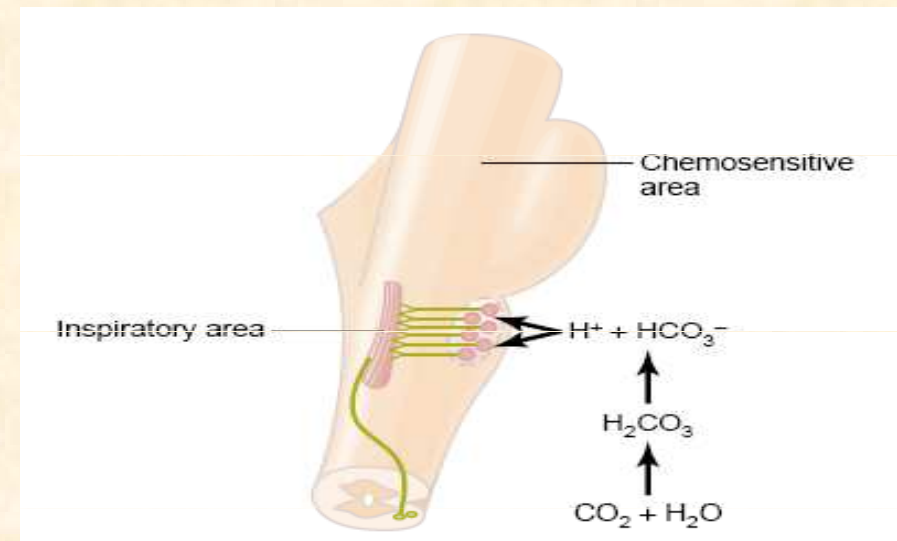
- They can be divided into three **main groups**:
 - *dorsal respiratory group* – placed bilaterally on the dorsal side of the medulla oblongata, only inspiratory neurons, sending axons to motoneurons of inspiratory muscles (diaphragm, external intercostal muscles; their activation=inspiration, their relaxation=expiration; participates on inspiration at rest and forced inspiration
 - *ventral respiratory group* - located on the ventrolateral part of the medulla oblongata, the upper part: neurons whose axons of motor neurons activate the main and auxiliary inspiratory muscles; the lower part: expiratory neurons which innervate expiratory muscles (internal intercostal muscles). Neurons in this group operate only during forced inspiration and forced expiration.
 - *Pontine respiratory group* - *pneumotaxic center* - dorsally placed on top of the pont, contributes to the frequency and depth of breathing; affects the activity of respiratory neurons in the medulla oblongata.

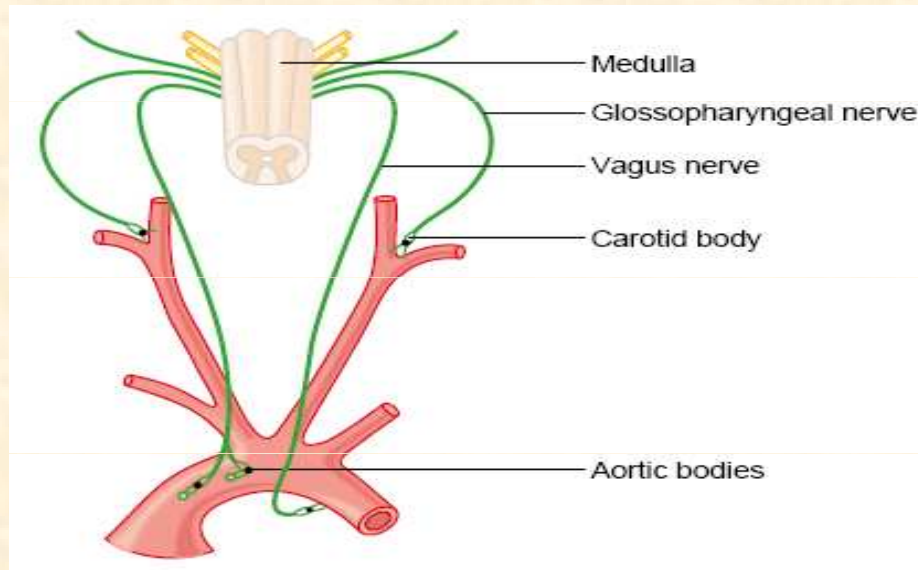
Chemical factors affecting the respiratory center:

Central chemoreceptors

- on the front side of the medulla
- sensitive only to increase of arterial $p\text{CO}_2$ (by increasing H^+)

- Notice:
- central chemoreceptor are stimulated by other types of acidosis (lactate acidosis, ketoacidosis)



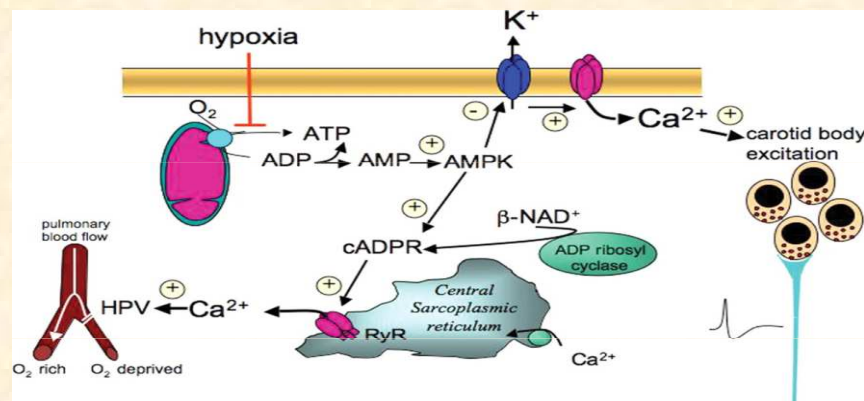


Peripheral chemoreceptors

– located in the aortic and carotid bodies

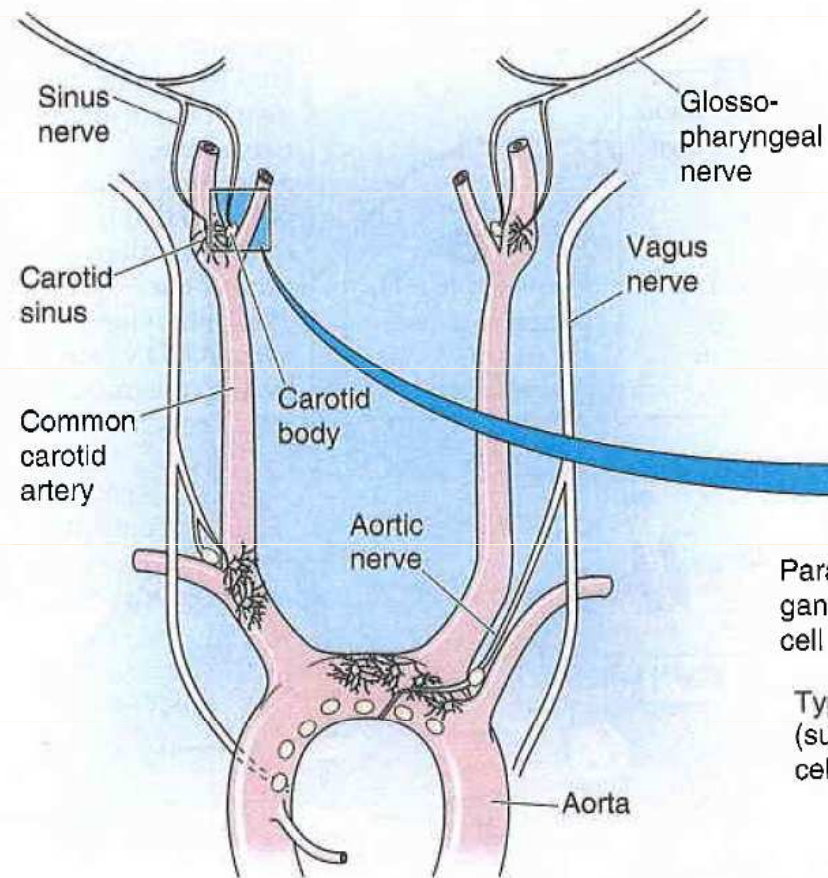
-primarily sensitive to decrease in arterial pO_2 , particularly to decrease of O_2 under 10-13 kPa in the arterial blood.

They convey their sensory information to the medulla via the vagus nerve and glossopharyngeal nerve.

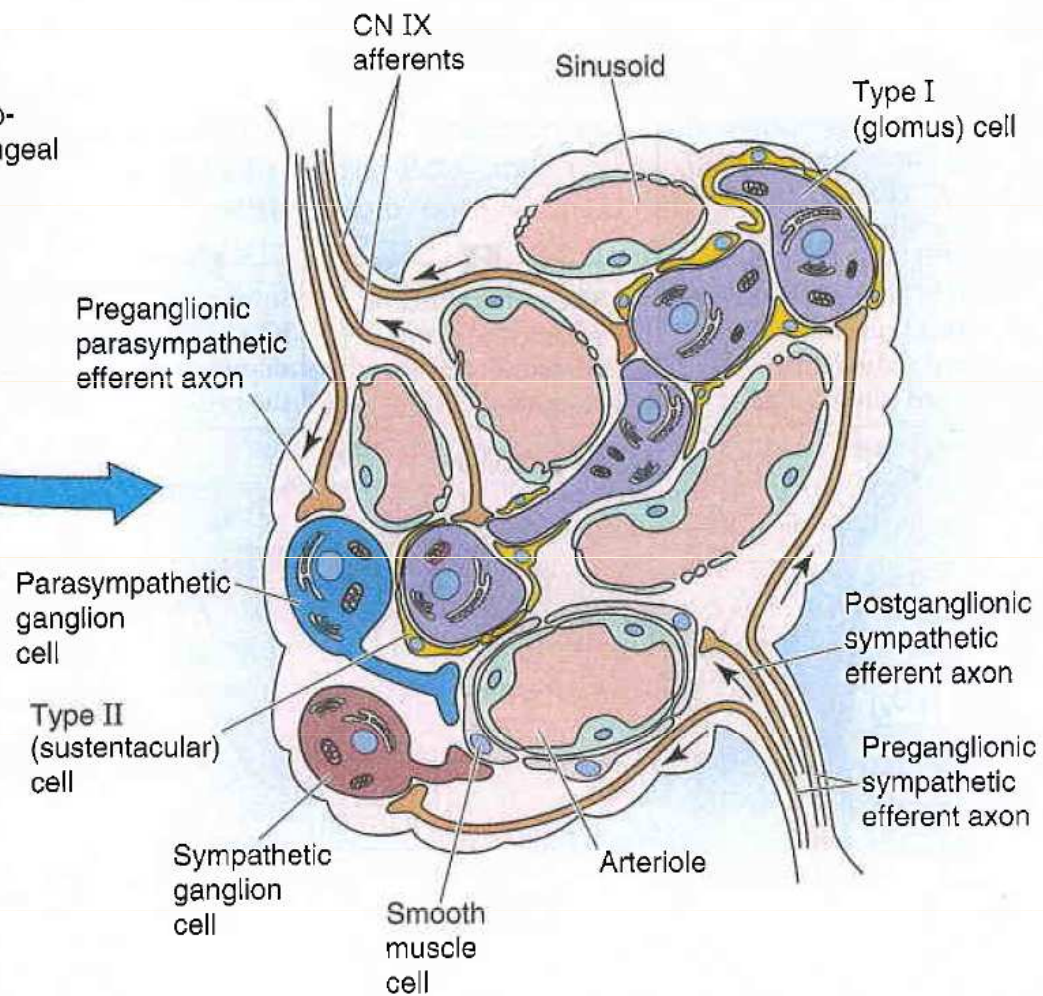


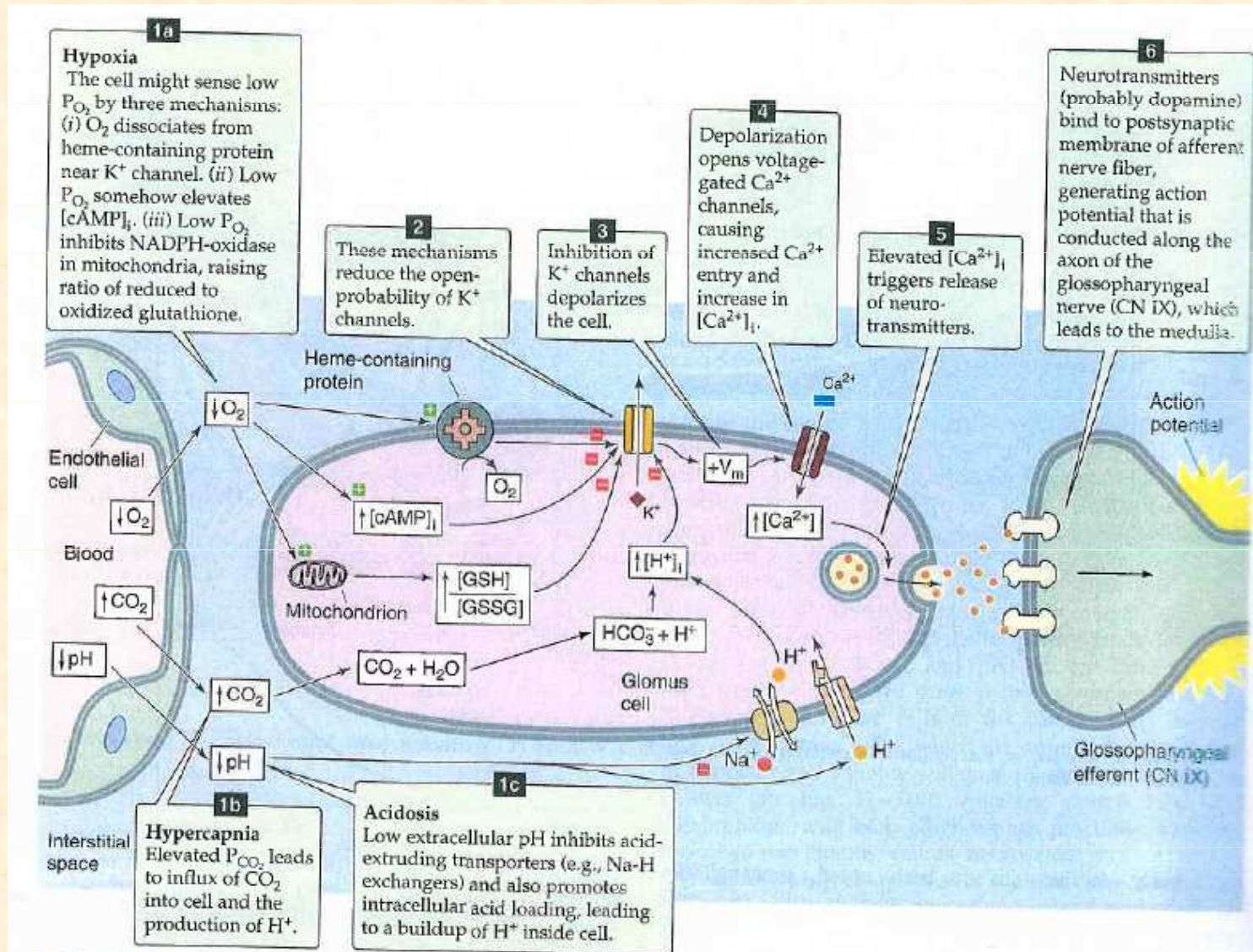
Mechanism of action: Decreased ATP production in mitochondria leads to depolarization of receptors membrane and to excitation of chemoreceptor

A LOCATION OF CAROTID AND AORTIC BODIES



B MICROSCOPIC ANATOMY OF CAROTID BODY





Modulation of respiratory output

Major parameters for feedback control – classical gases: pO_2 , pCO_2 , pH

In addition to these, the respiratory system receives input from two other major sources:

1. **variety of stretch and chemical/irritant receptors** that monitor the size of airways and the presence of noxious agents/receptors in respiratory system
2. **Higher CNS centers** that modulate respiratory activity for the sake of nonrespiratory activities

Irritants receptors on mucosa of respiratory system – rapidly adapting

Stimulus: agents - chemical substances (histamine, serotonin, prostaglandins, ammonia, cigarette smoke).

Response: increase mucus secretion, constriction of larynx and bronchus

C-fibre receptors (juxtacapillary=J receptors) – free nerve ending of n.vagus (unmyelinated axon) in interstitium of bronchus and alveolus;

Stimulus: Mechanical irritants (pulmonary hypertension, pulmonary oedema)+chemical

Response: hypopnoea, rapid shallow breathing, bronchoconstriction, cough

Stretch receptors slowly adapting (mechanoreceptors in tracheobronchial tree that detect the changes in lung volume by sensing the stretch receptors of the airway wall), inform to brain about the lung volume to optimize respiratory; its irritants triggered decrease activity of respiratory centre – **Hering-Breuer's reflexes**. (protecting the lungs from overinflation/deflation)

Baroreceptors – suppresses activity of respiratory centre

Irritants of **proprioceptors of muscles, tendons** during active and passive movements of limbs

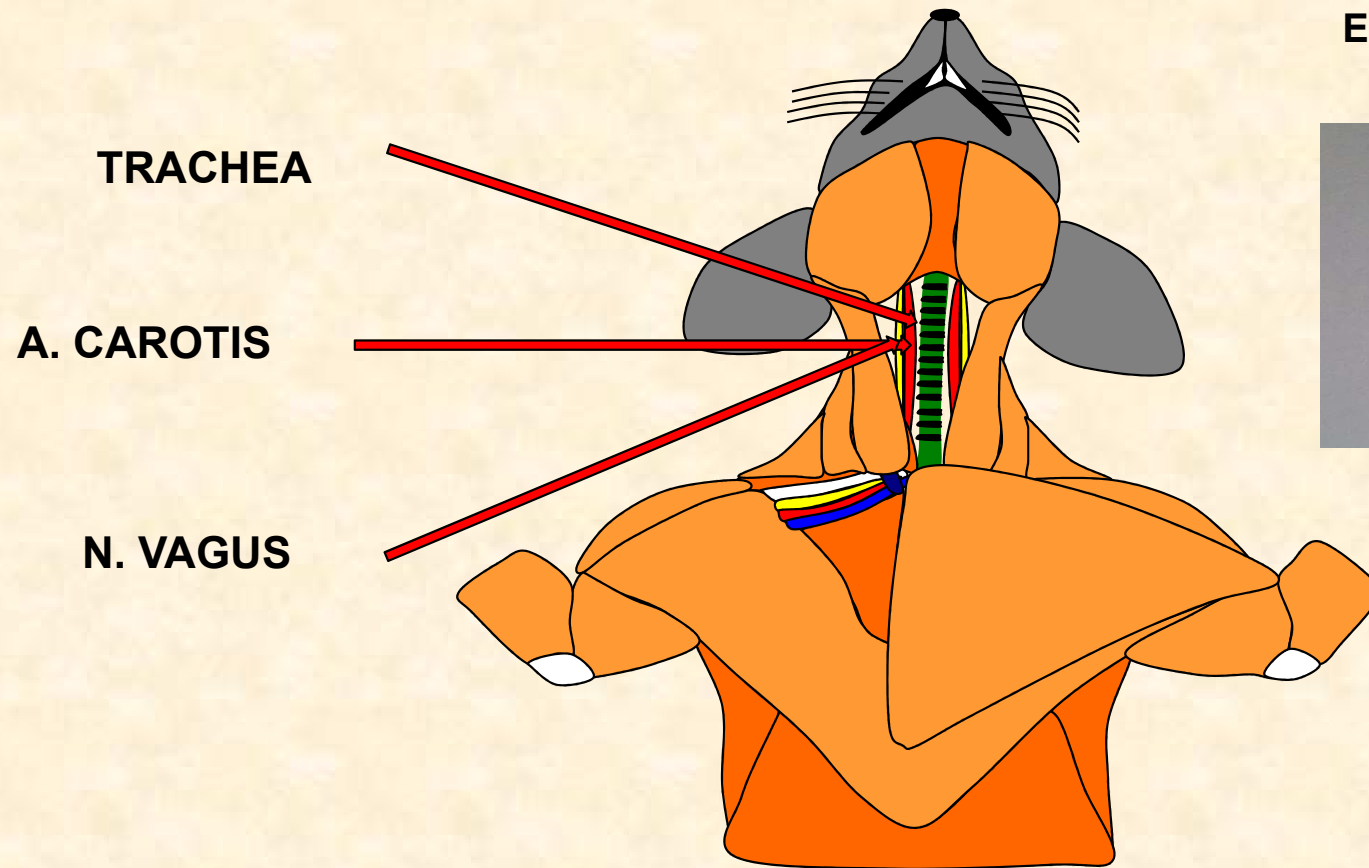
Influenced activity of respiratory neurons (increase minute ventilation during work load)

Limbic system, hypothalamus – strong pain, emotion

Tractus corticospinalis =cortex – activated RC during work load

temperature

- Hering – Breuer 's reflex in animal experimentH

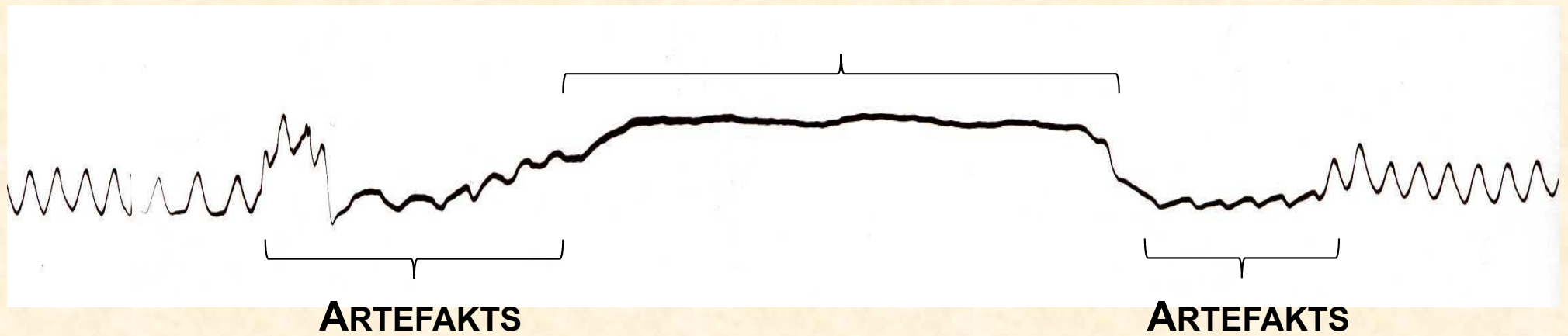


ENDOTRACHEAL CANNULA

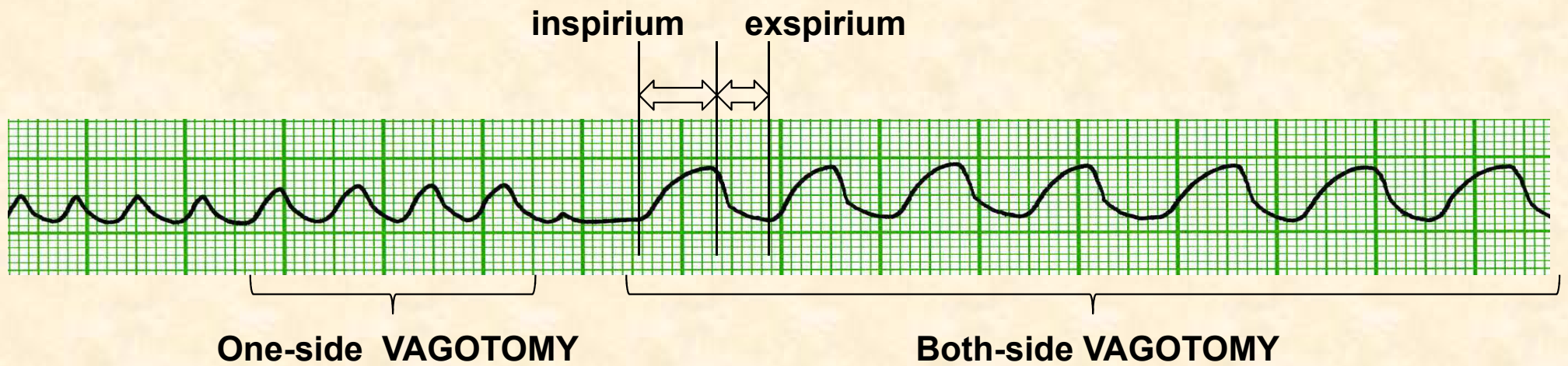


HERING-BREUER REFLEX

REFLEX STOP BREATHING



Changes of breathing after VAGOTOMY



Hypoxia, hypoxemia

- **Hypoxia** is a general name for a lack of oxygen in the body or individual tissues.
- Hypoxemia is lack of oxygen in arterial blood.
- Complete lack of oxygen is known as anoxia.

The most common types of hypoxia:

1. Hypoxic - physiological: stay at higher altitudes, pathological: hypoventilation during lung or neuromuscular diseases
2. Transport (anemic) - reduced transport capacity of blood for oxygen (anemia, blood loss, CO poisoning)
3. Ischemic (stagnation) - restricted blood flow to tissue (heart failure, shock states, obstruction of an artery)
4. Histotoxic - cells are unable to utilize oxygen (cyanide poisoning - damage to the respiratory chain)

Hypercapnia

- Hypercapnia - increase of concentration of carbon dioxide in the blood or in tissues that is caused by retention of CO₂ in the body
- possible causes: total alveolar hypoventilation (decreased respiration or extension of dead space)
- mild hypercapnia (5 -7 kPa) causes stimulation of the respiratory center (therapeutic use: pneumoxid = mixture of oxygen + 2-5% CO₂)
- hypercapnia around 10 kPa - CO₂ narcosis - respiratory depression (preceded by headache, confusion, disorientation, a feeling of breathlessness)
- hypercapnia over 12 kPa - significant respiratory depression - coma and death.

THANK YOU FOR YOUR
ATTENTION