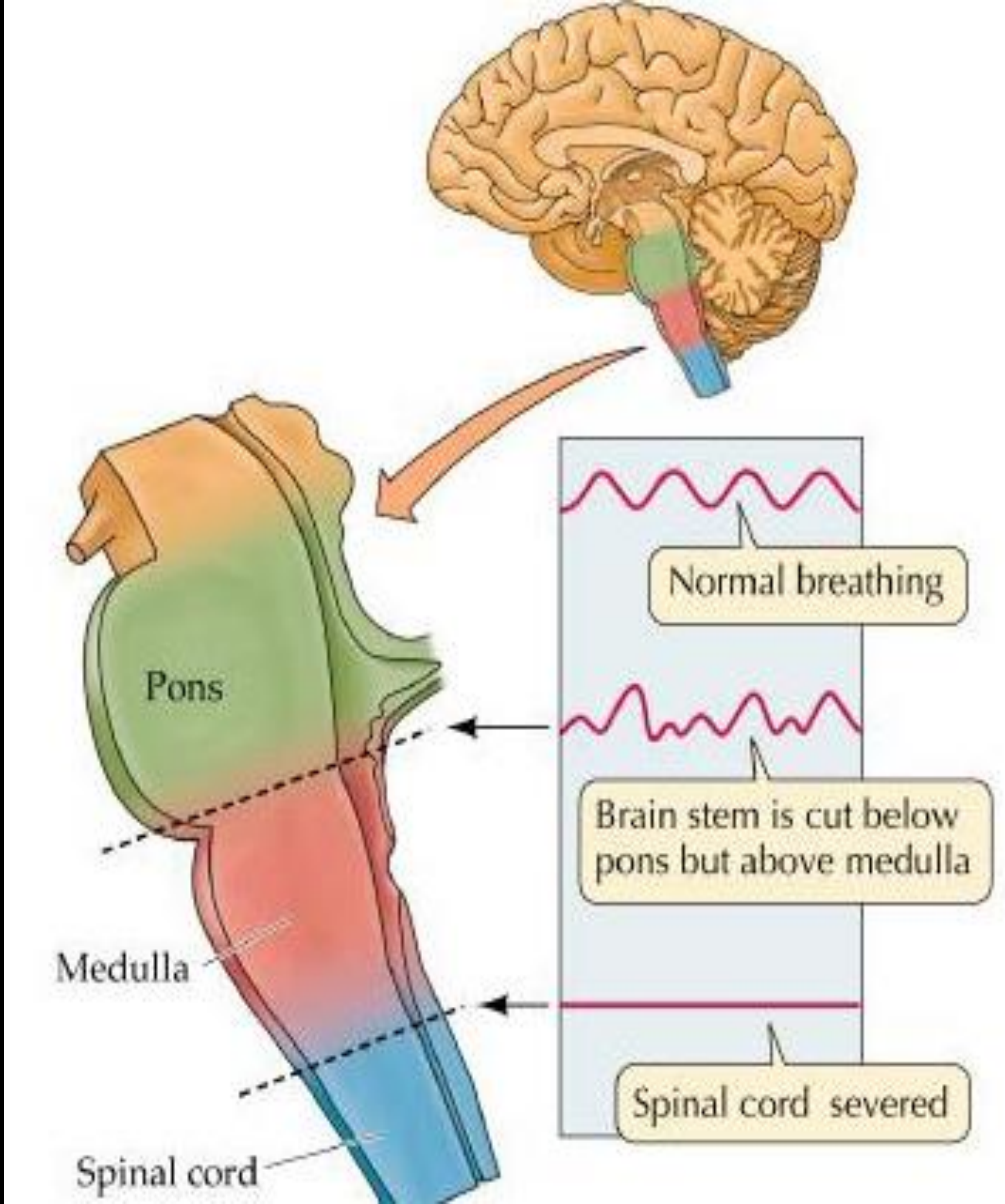
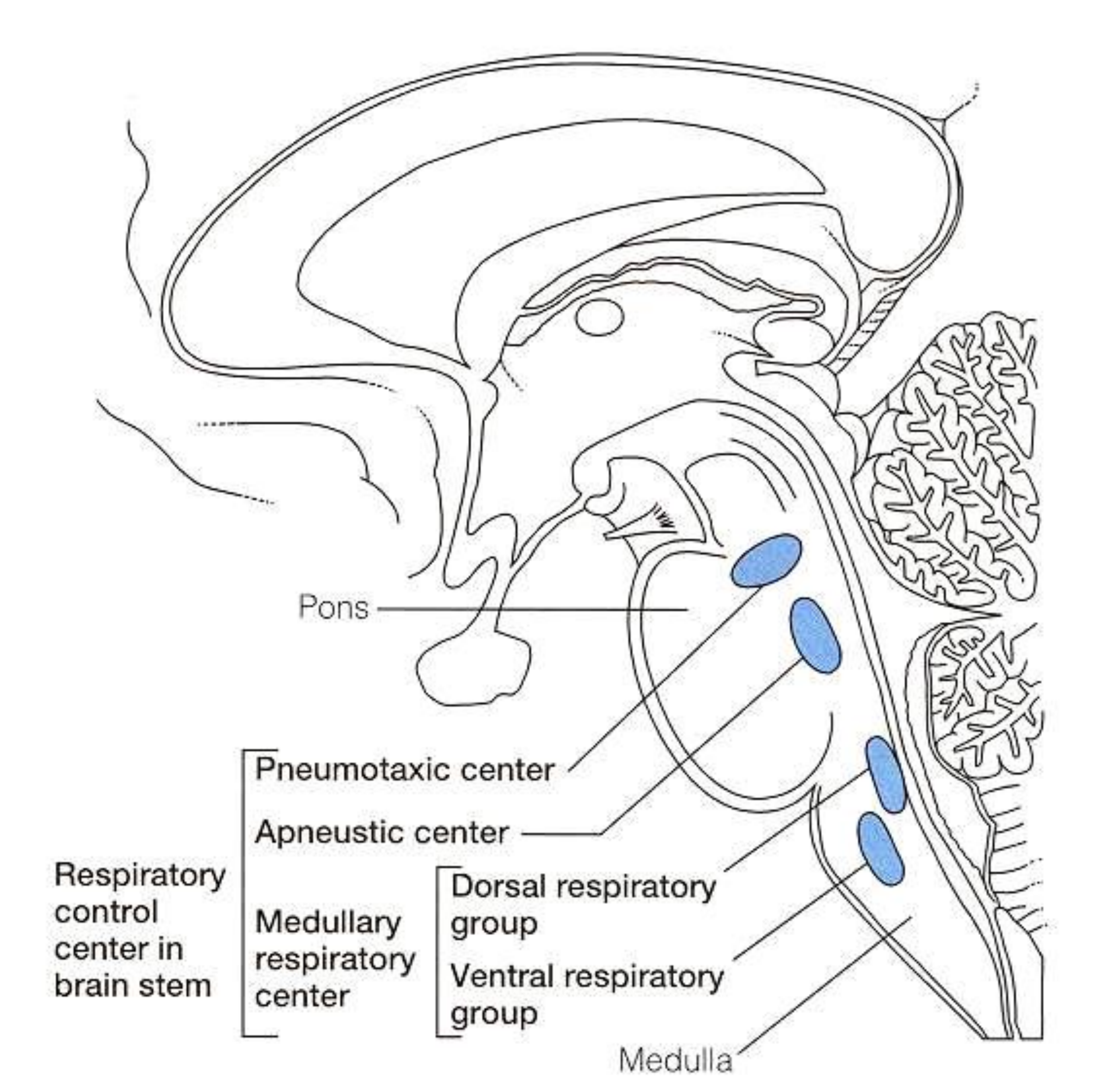
Control of Respiration


Normal breathing
Pons
Brain stem is cut below pons but above medulla
Medulla
Spinal cord severed
Spinal cord

Respiratory Centers



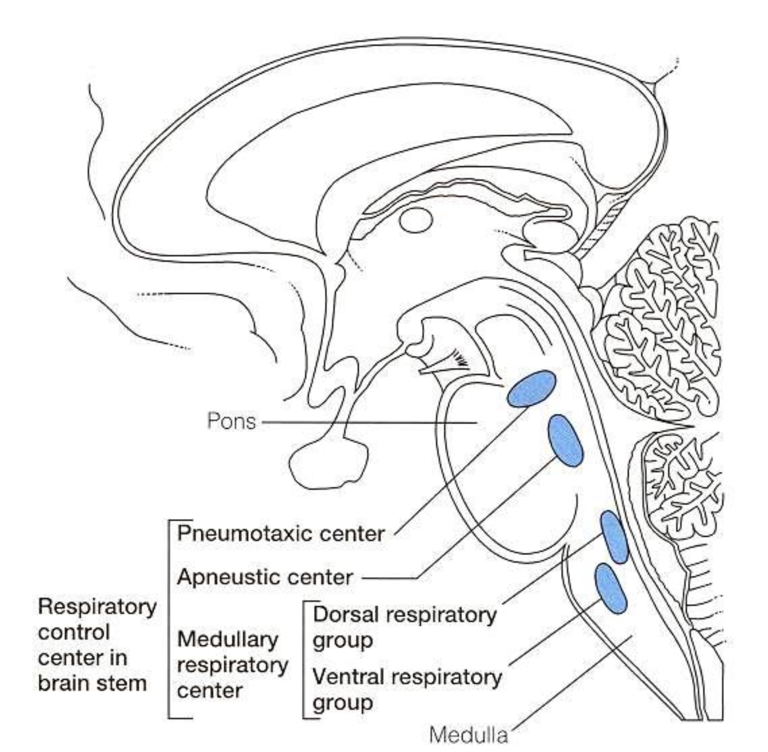
Two respiratory nuclei in medulla oblongata

Inspiratory center (dorsal respiratory group, DRG)

- more frequently they fire, more deeply you inhale
- longer duration they fire, breath is prolonged, slow rate

Expiratory center (ventral respiratory group, VRG)

- involved in *forced* expiration



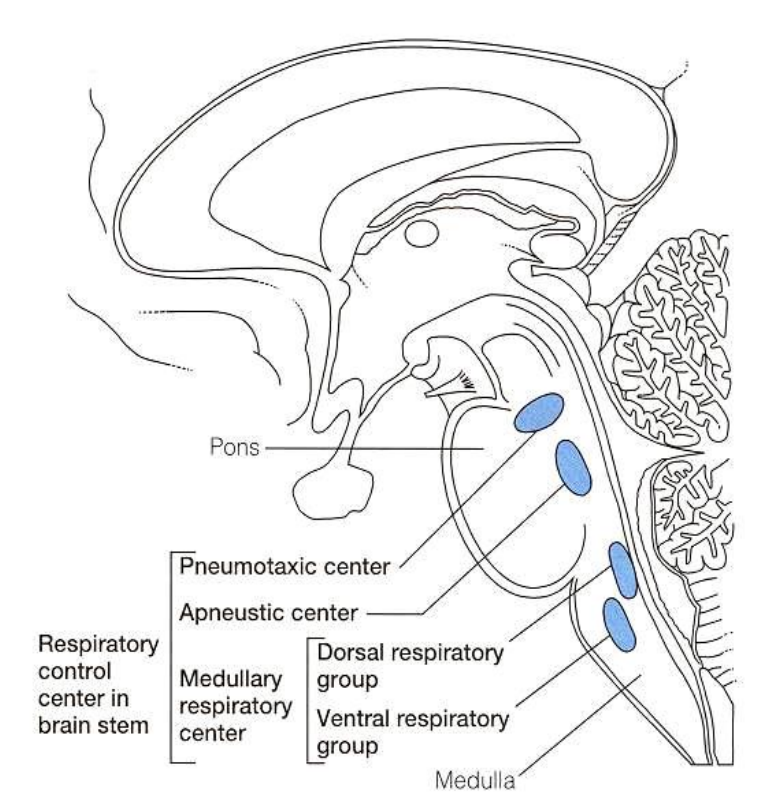
Respiratory Centers in Pons

Pneumotaxic center (upper pons)

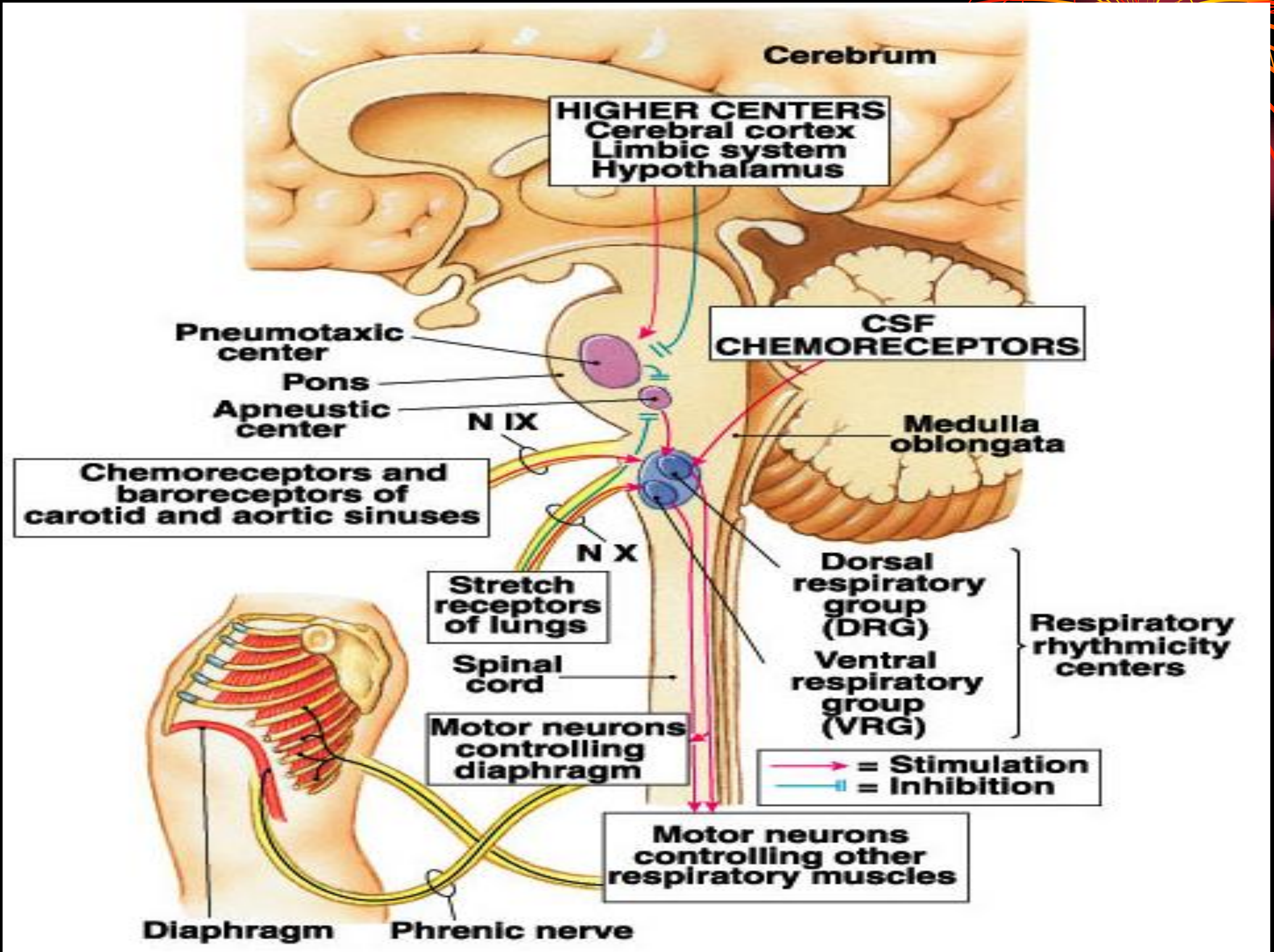
- Sends continual inhibitory impulses to inspiratory center of the medulla oblongata,
- As impulse frequency rises, breathe faster and shallower

Apneustic center (lower pons)

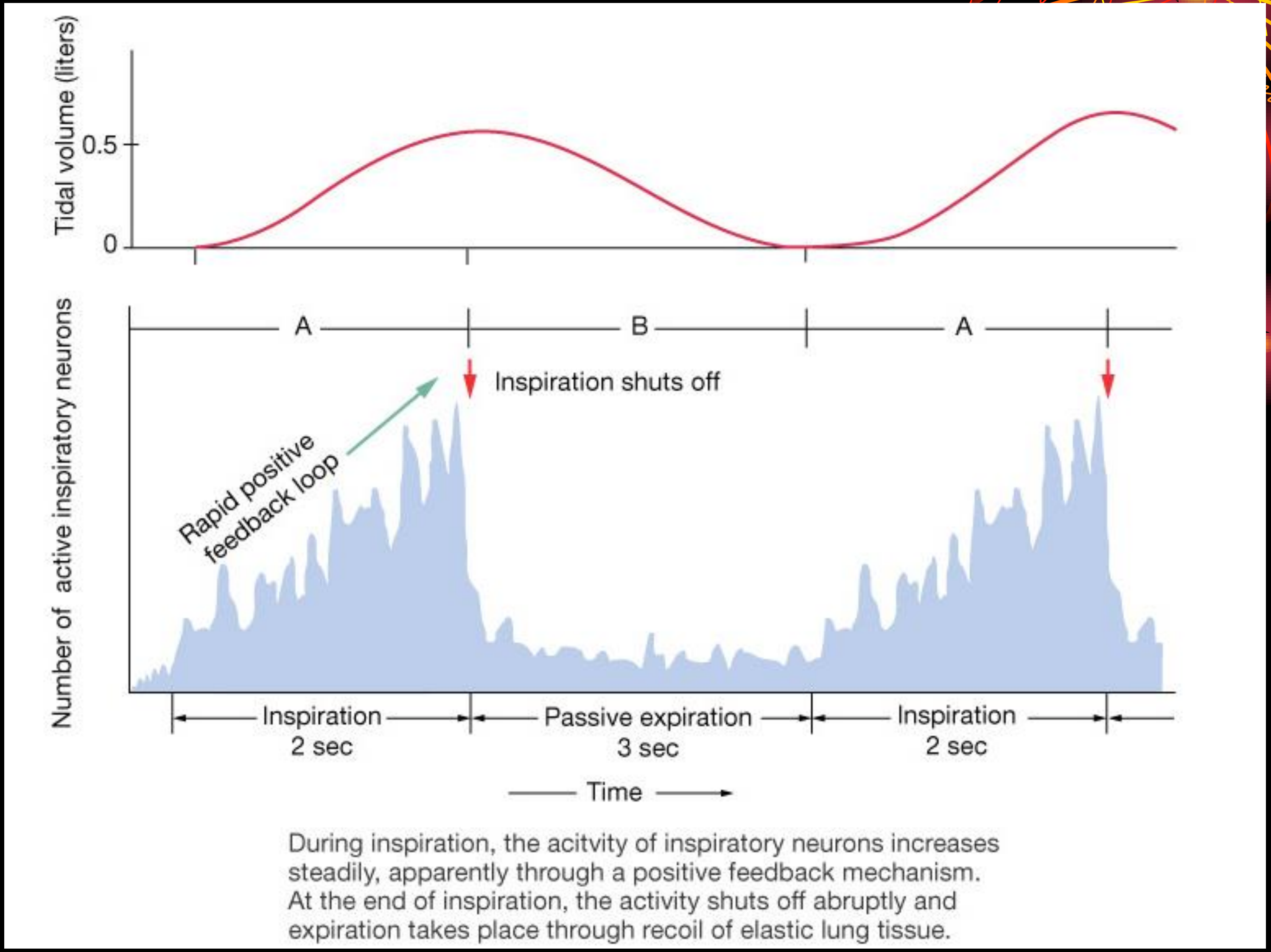
- Stimulation causes apneusis
- Integrates inspiratory cutoff information



Respiratory Structures in Brainstem



Regulation of Ventilation

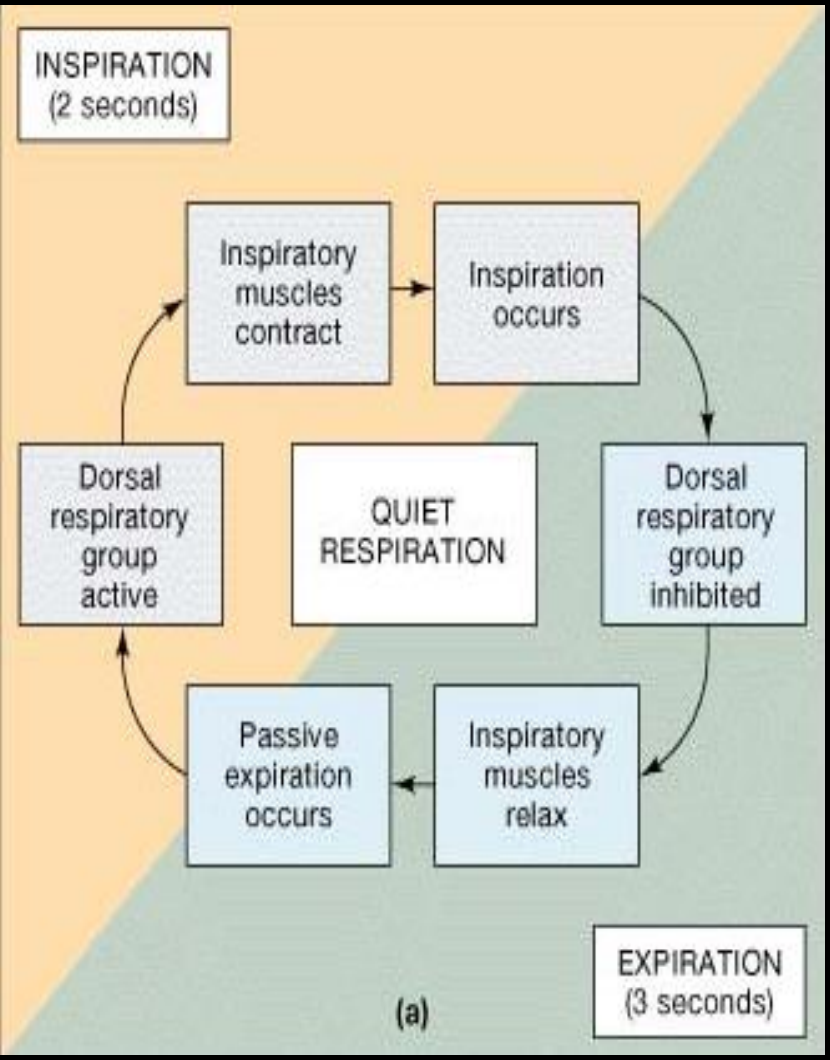
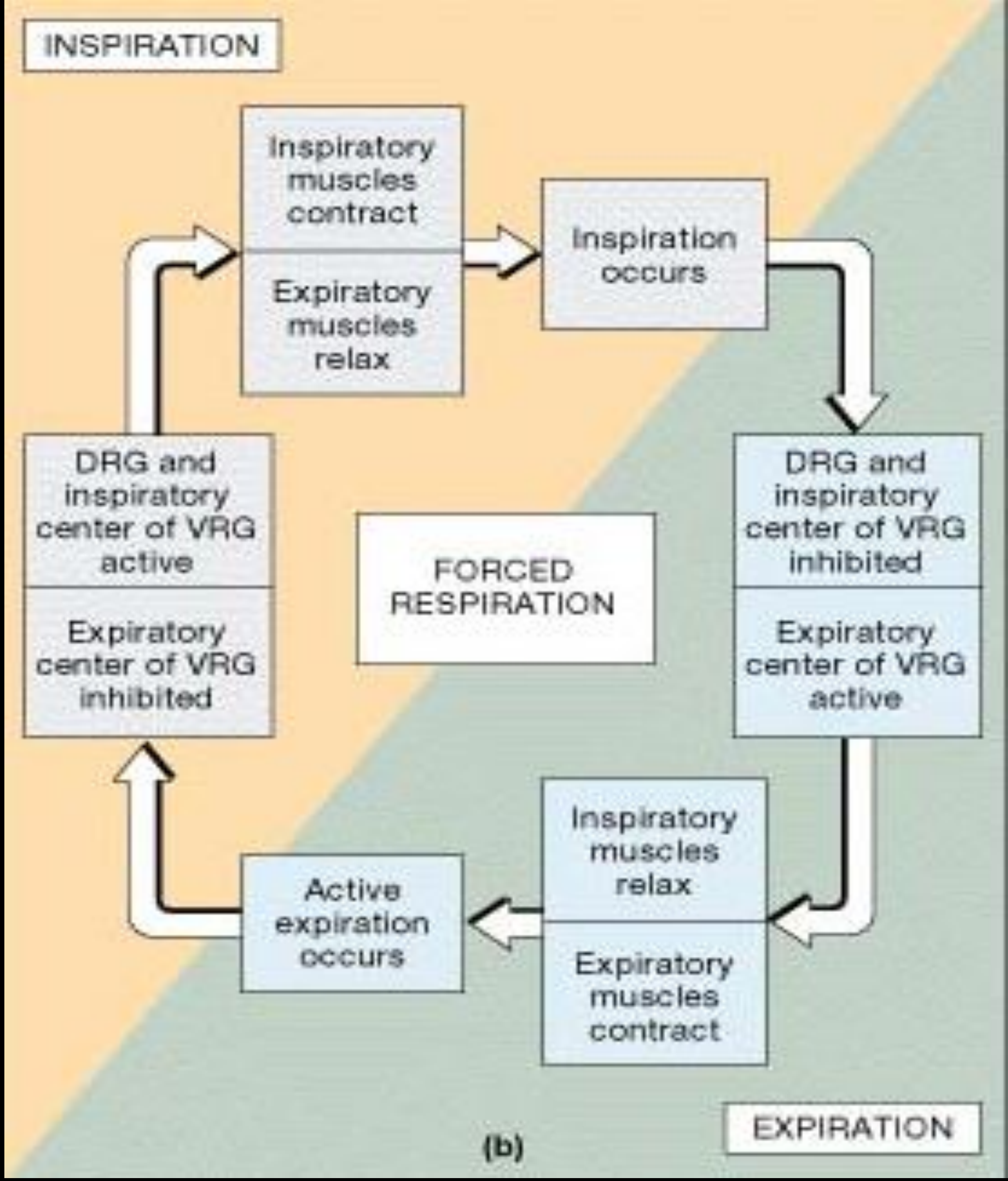


Rhythmic breathing

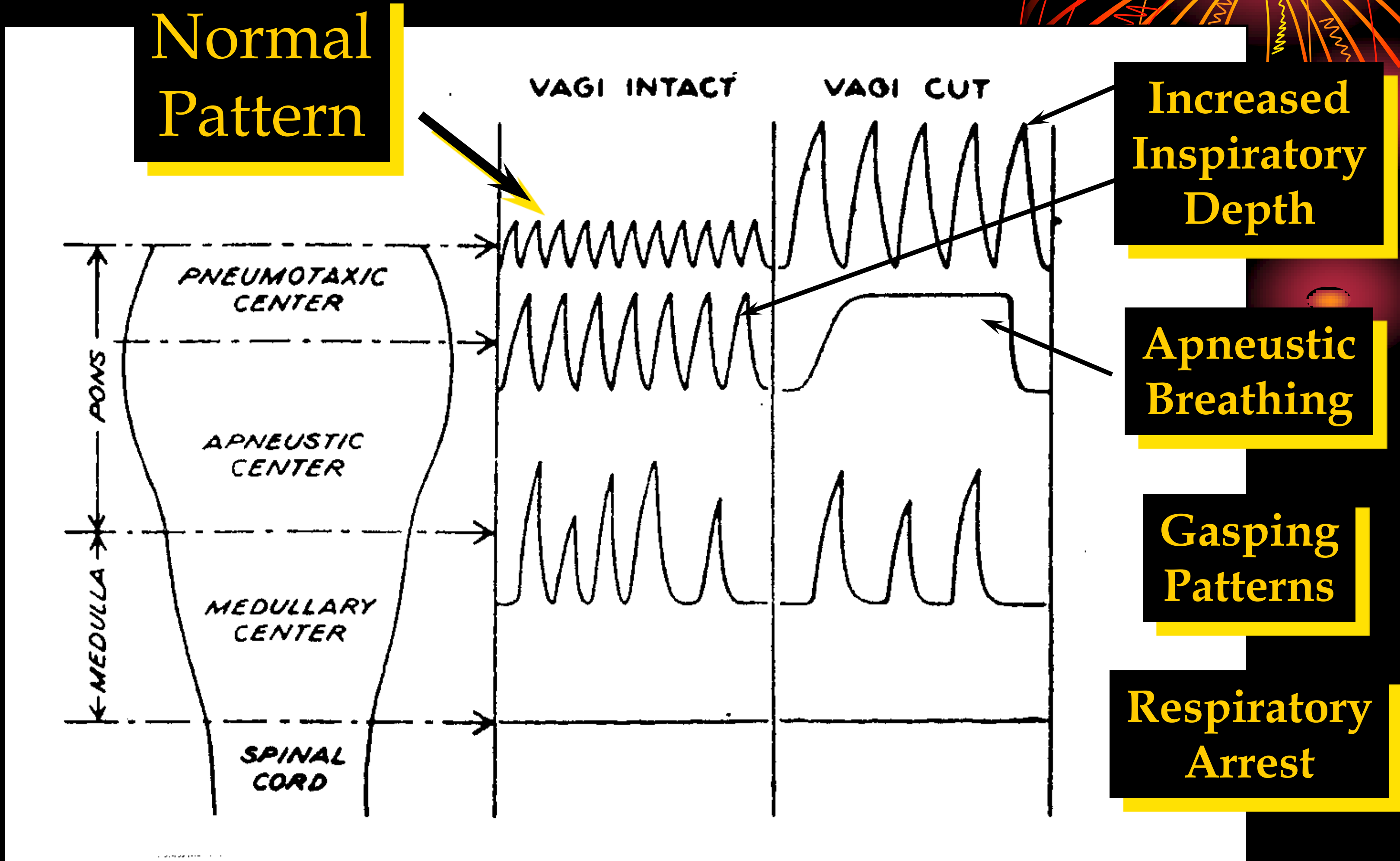
2. Rhythmic Ventilation (Inspiratory Off Switch)

- **Starting inspiration**
  - Medullary respiratory center neurons are continuously active (spontaneous)
  - Center receives stimulation from receptors and brain concerned with voluntary respiratory movements and emotion
  - Combined input from all sources causes action potentials to stimulate respiratory muscles

- **Increasing inspiration**
  - More and more neurons are activated
- **Stopping inspiration**
  - Neurons receive input from pontine group and stretch receptors in lungs.
  - Inhibitory neurons activated and relaxation of respiratory muscles results in expiration.
  - Inspiratory off switch.


INSPIRATION (2 seconds)
Inspiratory muscles contract
Inspiration occurs
Dorsal respiratory group inhibited
Inspiratory muscles relax
Passive expiration occurs
Dorsal respiratory group active
QUIET RESPIRATION
EXPIRATION (3 seconds)
(a)

INSPIRATION
Inspiratory muscles contract
Expiratory muscles relax
Inspiration occurs
DRG and inspiratory center of VRG inhibited
Expiratory center of VRG active
Inspiratory muscles relax
Expiratory muscles contract
Active expiration occurs
DRG and inspiratory center of VRG active
Expiratory center of VRG inhibited
FORCED RESPIRATION
EXPIRATION
(b)

Brainstem Transection



Brainstem Respiratory Centers

- Dorsal Respiratory Group—Quiet inspiration
- Ventral Respiratory Group—Forceful inspiration and active expiration
- Pneumotaxic Center—Influences inspiration to shut off
- Apneustic Center—Prolongs inspiration

Factors controlling ventilation

A. Sensory Input

(1) Lung via the vagus nerve:

stretch receptors (smooth muscle)

Volume

irritant receptors (airway)

Cough and Sneeze reflex

J receptors (“juxtacapillary receptors”)

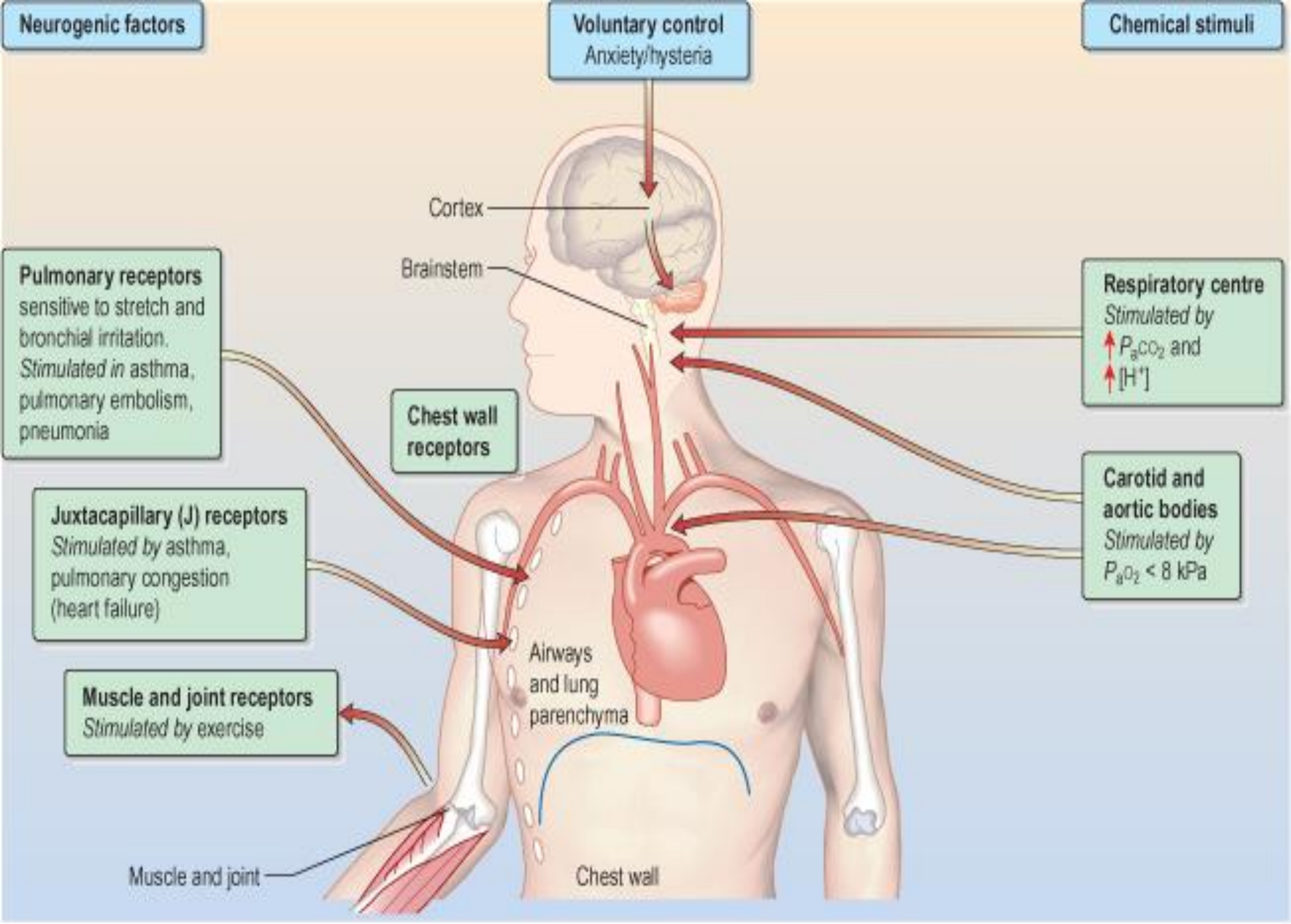
Emboli

(2) Muscles—muscle spindles

B. Chemoreceptors

C. Other sensations (pain, emotions)- limbic system and hypothalamus

D. Voluntary control of breathing-Cerebral cortex



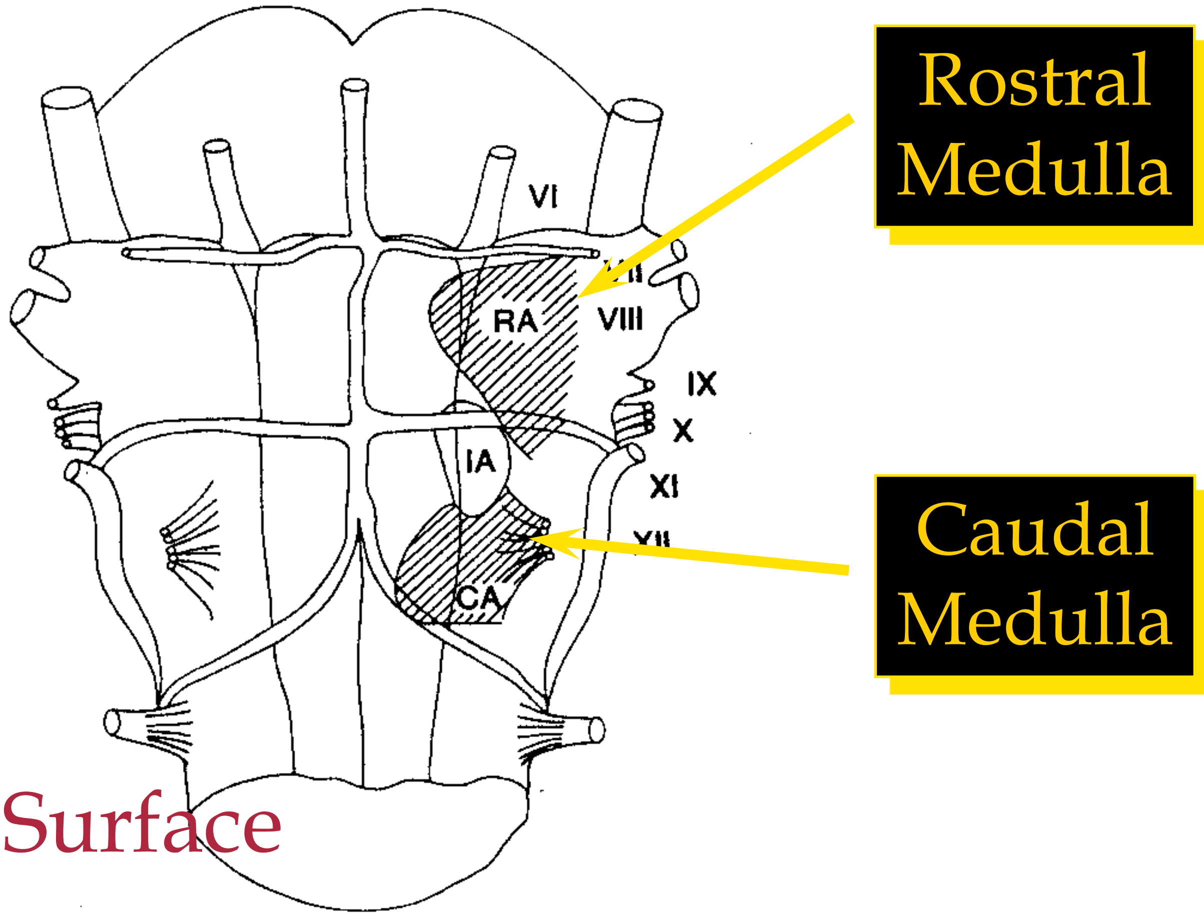
Neurogenic factors
Voluntary control
Anxiety/hysteria
Chemical stimuli
Cortex
Brainstem
Pulmonary receptors sensitive to stretch and bronchial irritation. Stimulated in asthma, pulmonary embolism, pneumonia
Respiratory centre Stimulated by ↑P_aCO_2 and ↑[H⁺]
Chest wall receptors
Carotid and aortic bodies Stimulated by P_aO_2 < 8 kPa
Juxtacapillary (J) receptors Stimulated by asthma, pulmonary congestion (heart failure)
Airways and lung parenchyma
Muscle and joint receptors Stimulated by exercise
Muscle and joint
Chest wall

Chemoreceptors

Two Sets of Chemoreceptors Exist

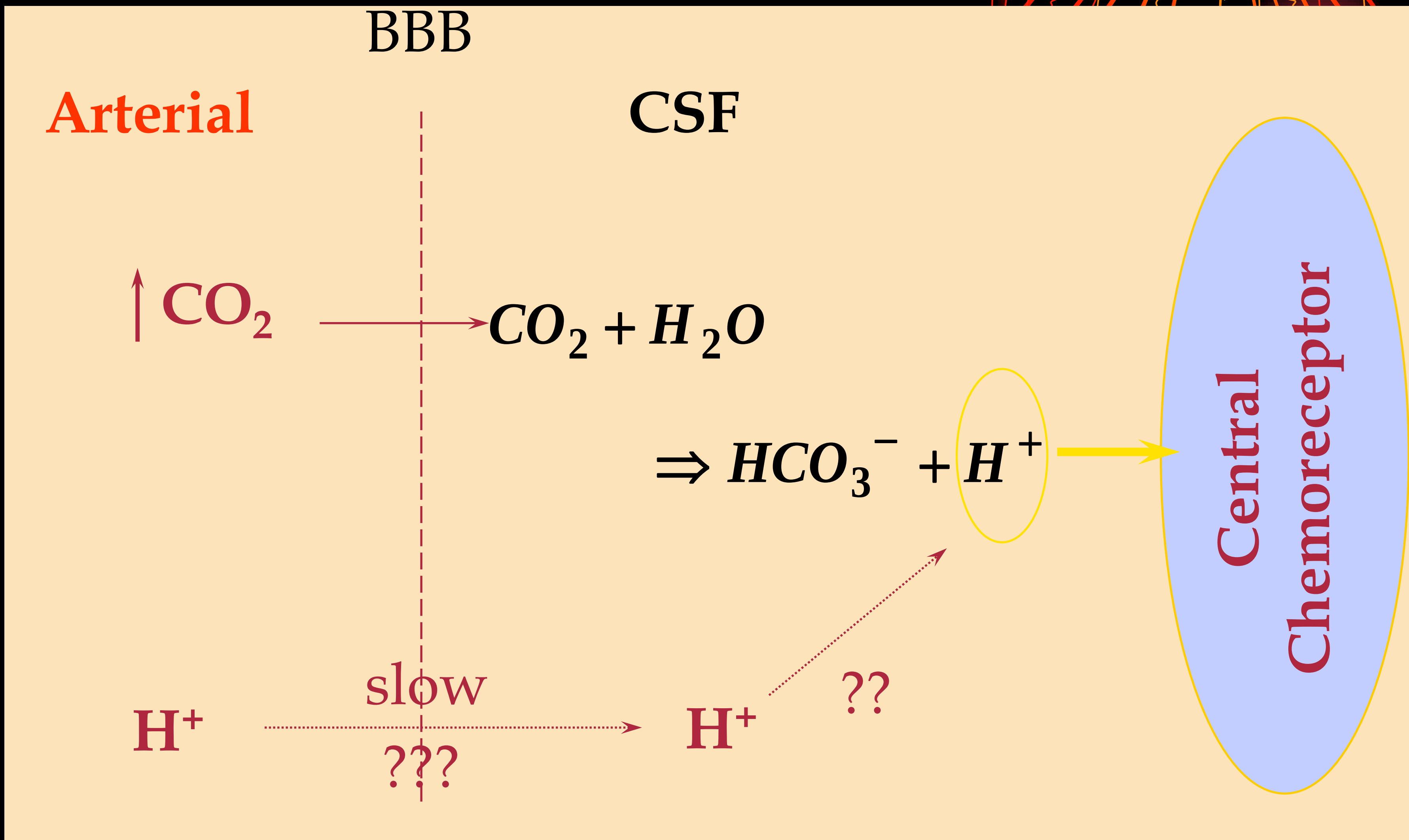
- Central Chemoreceptors
  - Responsive to increased arterial PCO_2
  - Act by way of CSF $[H^+]\uparrow$.
- Peripheral Chemoreceptors
  - Responsive to decreased arterial PO_2
  - Responsive to increased arterial PCO_2
  - Responsive to increased H^+ ion concentration.

Central Chemoreceptor Location

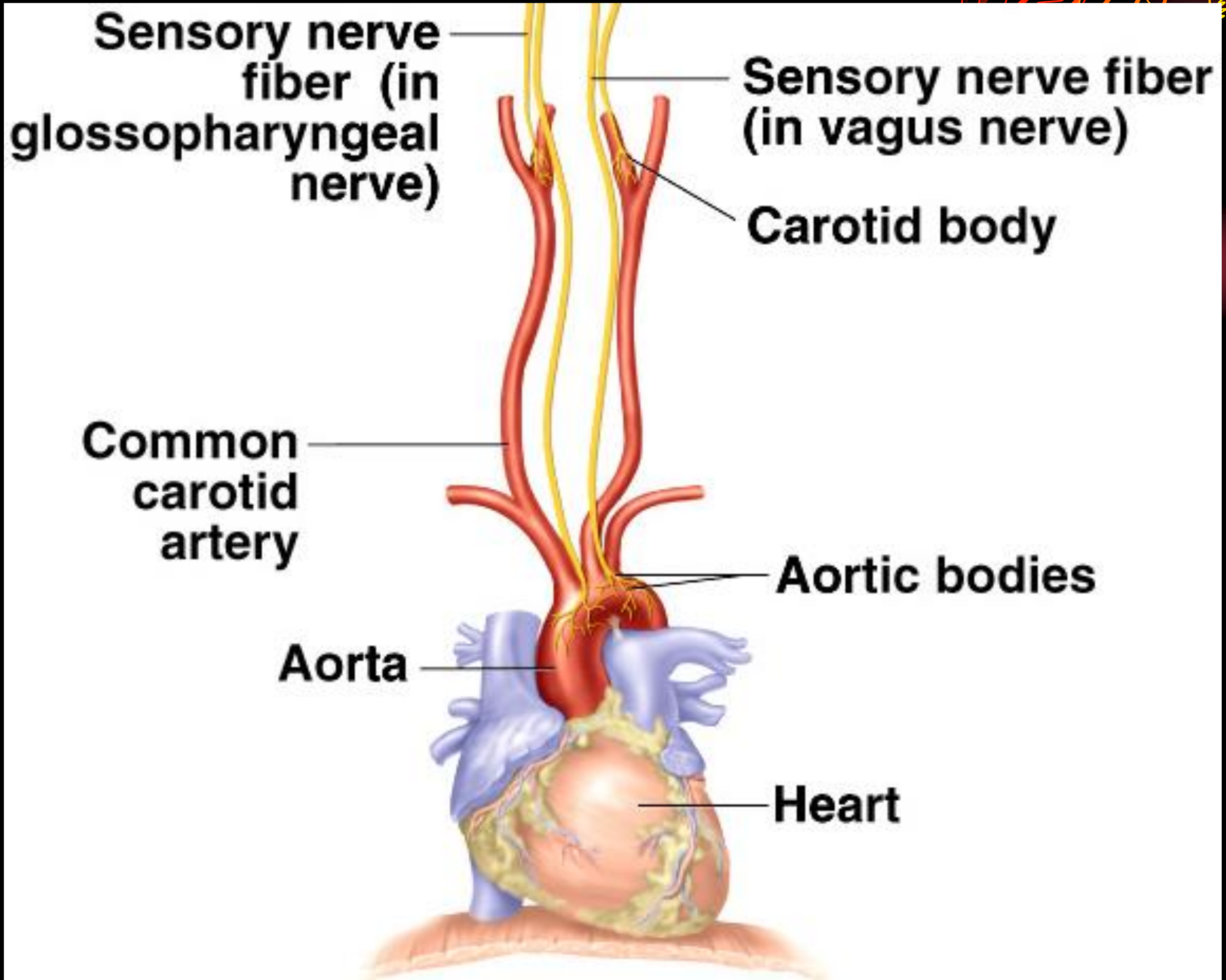


Ventral Surface

Central Chemoreceptor Stimulation

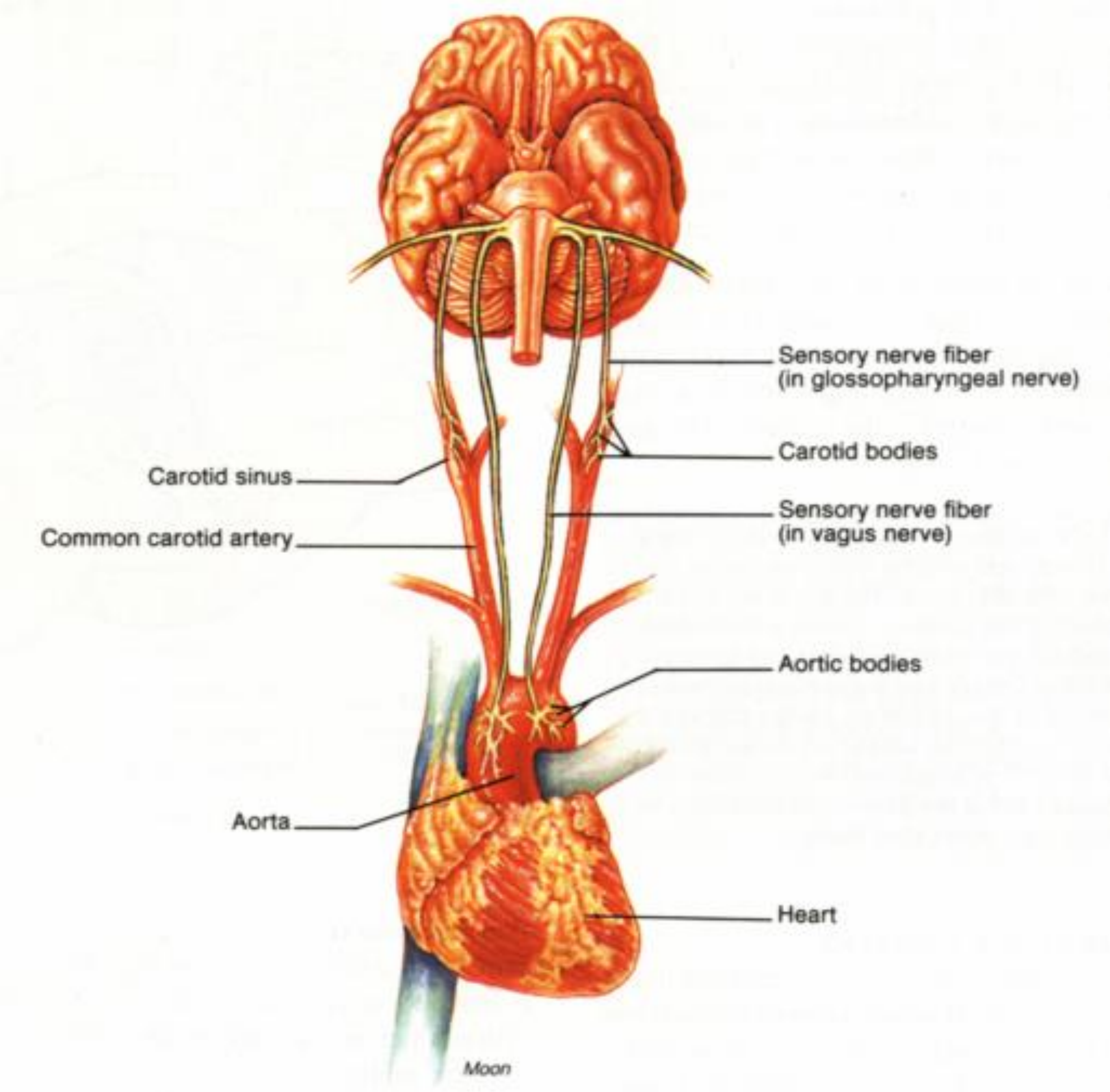


Peripheral Chemoreceptor Pathways



Peripheral Chemoreceptors

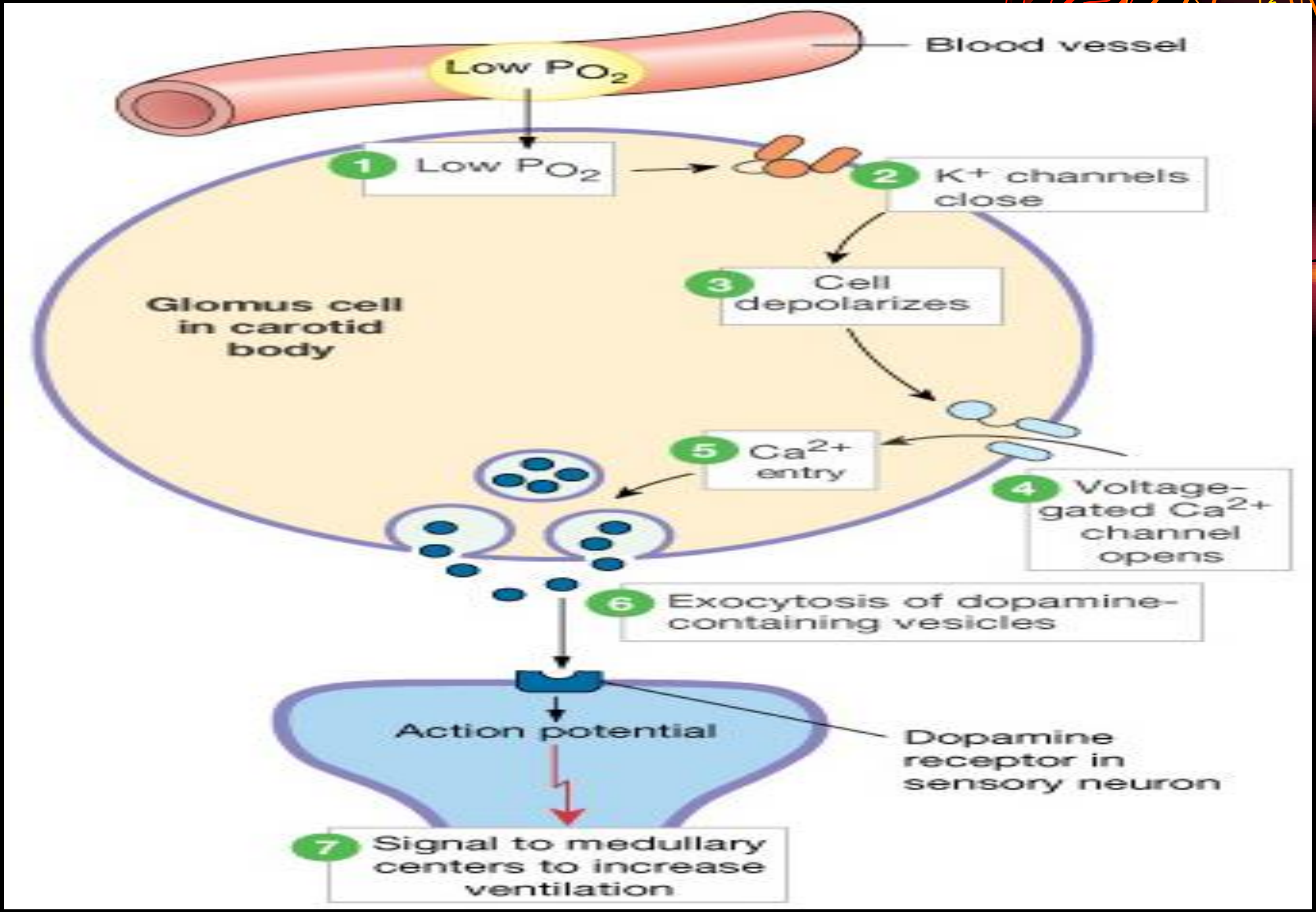
- Carotid bodies
  - Sensitive to: P_aO_2, P_aCO_2, and pH
  - Afferents in glossopharyngeal nerve.
- Aortic bodies
  - Sensitive to: P_aO_2, P_aCO_2, but <u>not</u> pH
  - Afferents in vagus


Sensory nerve fiber
(in glossopharyngeal nerve)
Carotid bodies
Carotid sinus
Common carotid artery
Sensory nerve fiber
(in vagus nerve)
Aortic bodies
Aorta
Heart
Moon

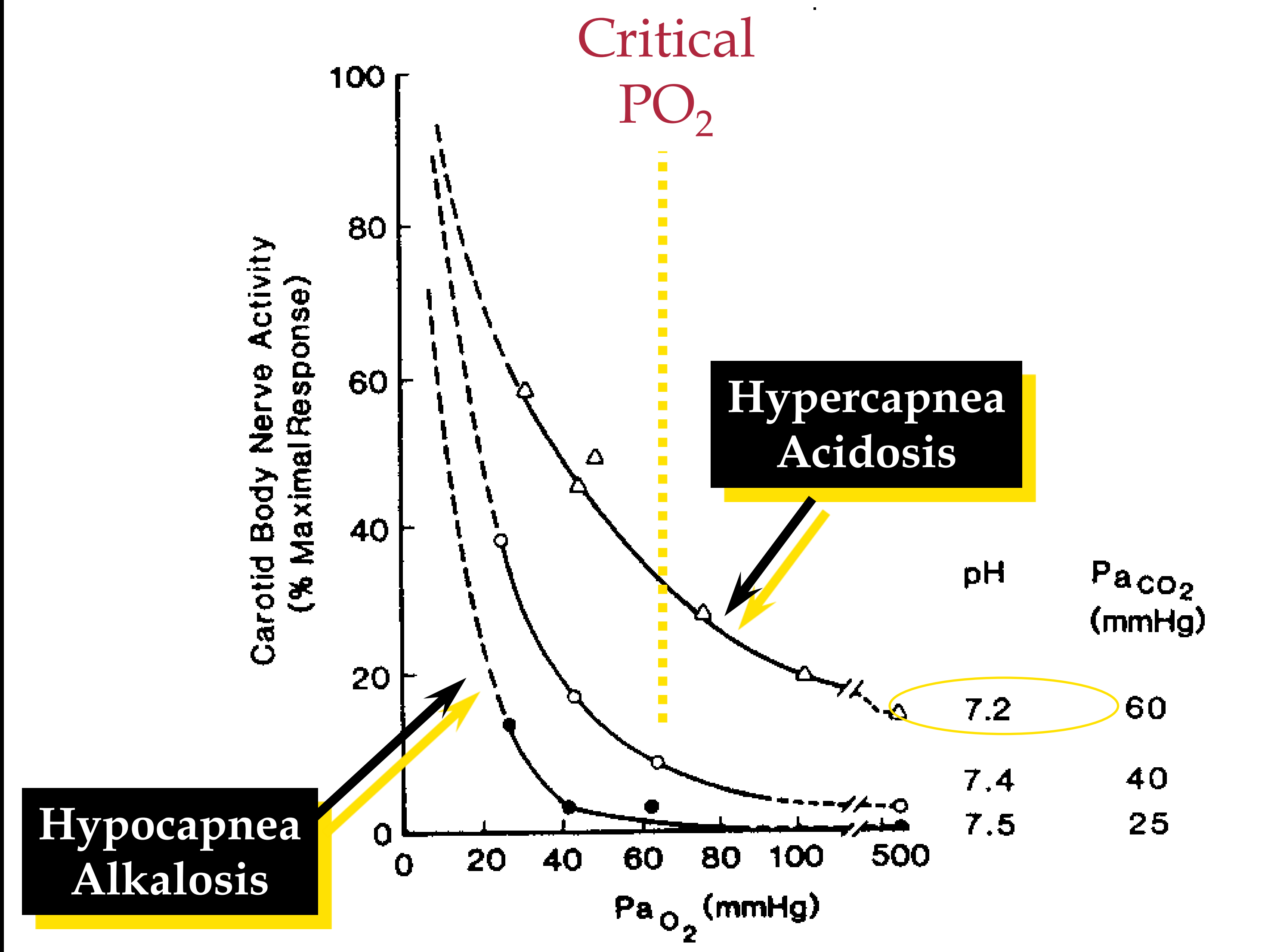
Carotid Body Function

- High flow per unit weight:
  (2 L/min/100 g)
- High carotid body VO_2 consumption:
  (8 ml O_2/min/100g)
- Tiny a-v O_2 difference
- Responsiveness begins at P_aO_2 (not the oxygen content) below about 60 mmHg.

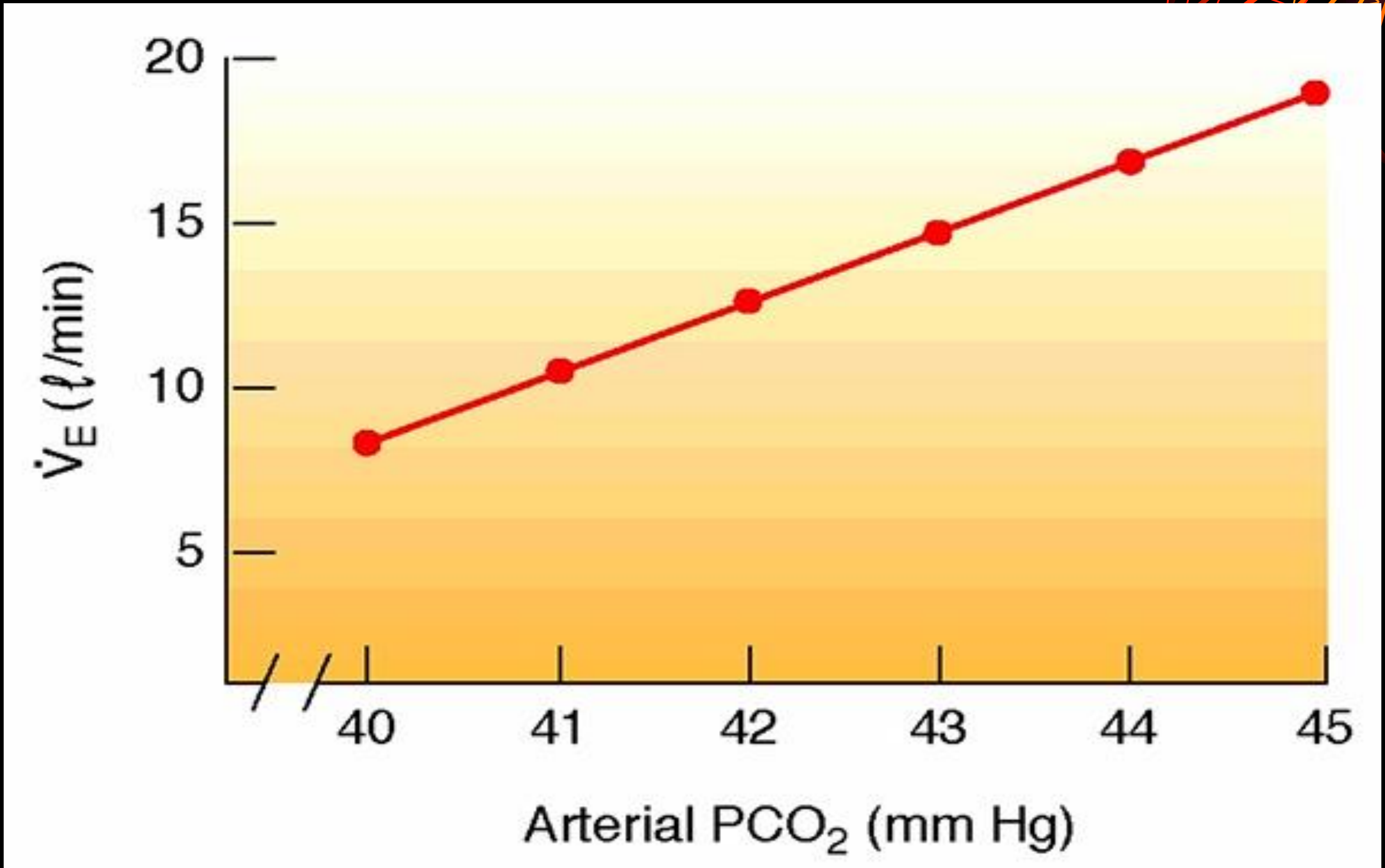
Carotid body oxygen sensor releases neurotransmitter when decrease in PO2



Carotid Body Response



Effect of Arterial PCO_2 on Ventilation



Carbon Dioxide, Oxygen and pH Influence Ventilation (through peripheral receptor)

- Peripheral chemoreceptors sensitive to P_{O2}, P_{CO2} and pH
- Receptors are activated by increase in P_{CO2} or decrease in P_{O2} and pH
- Send APs through sensory neurons to the brain
- Sensory info is integrated within the medulla
- Respiratory centers respond by sending efferent signals through somatic motor neurons to the skeletal muscles
- Ventilation is increased

Effects of Hydrogen Ions (through central chemoreceptors)

- pH of CSF (most powerful respiratory stimulus)
- Respiratory acidosis (pH < 7.35) caused by failure of pulmonary ventilation
  - hypercapnia (P_{CO_2}) > 43 mmHg
  - CO_2 easily crosses blood-brain barrier, in CSF the CO_2 reacts with water and releases H^+, central chemoreceptors strongly stimulate inspiratory center
  - corrected by hyperventilation, pushes reaction to the left by "blowing off" CO_2

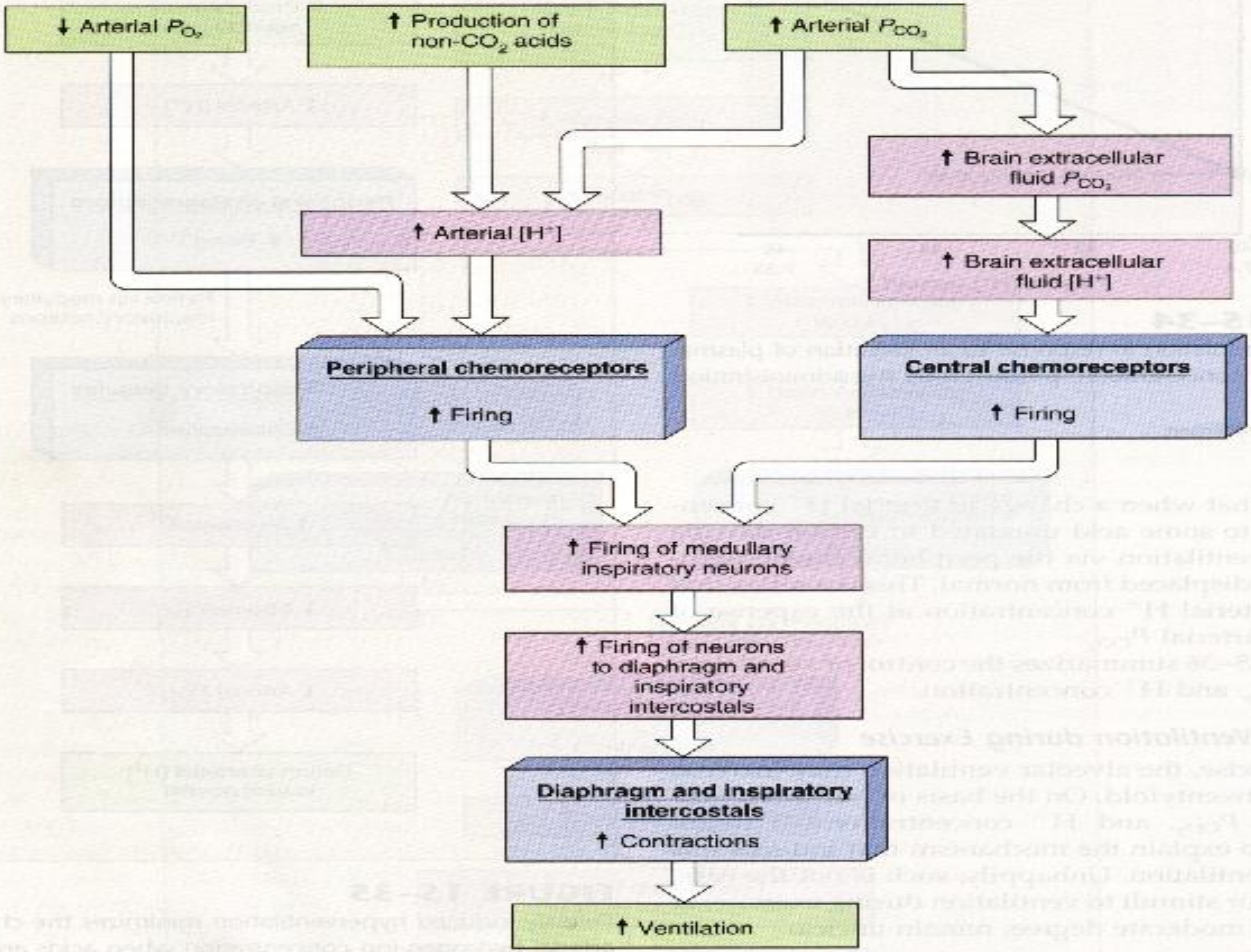
$$CO_2 \text{ (expired)} + H_2O \leftarrow H_2CO_3 \leftarrow HCO_3^- + H^+$$

Carbon Dioxide

- Indirect effects
  - through pH (central chemoreceptor)
- Direct effects
  - ↑ CO_2 may directly stimulate peripheral chemoreceptors and trigger ↑ ventilation more quickly than central chemoreceptors
- If the PCO_2 is too high, the respiratory center will be inhibited.

Oxygen

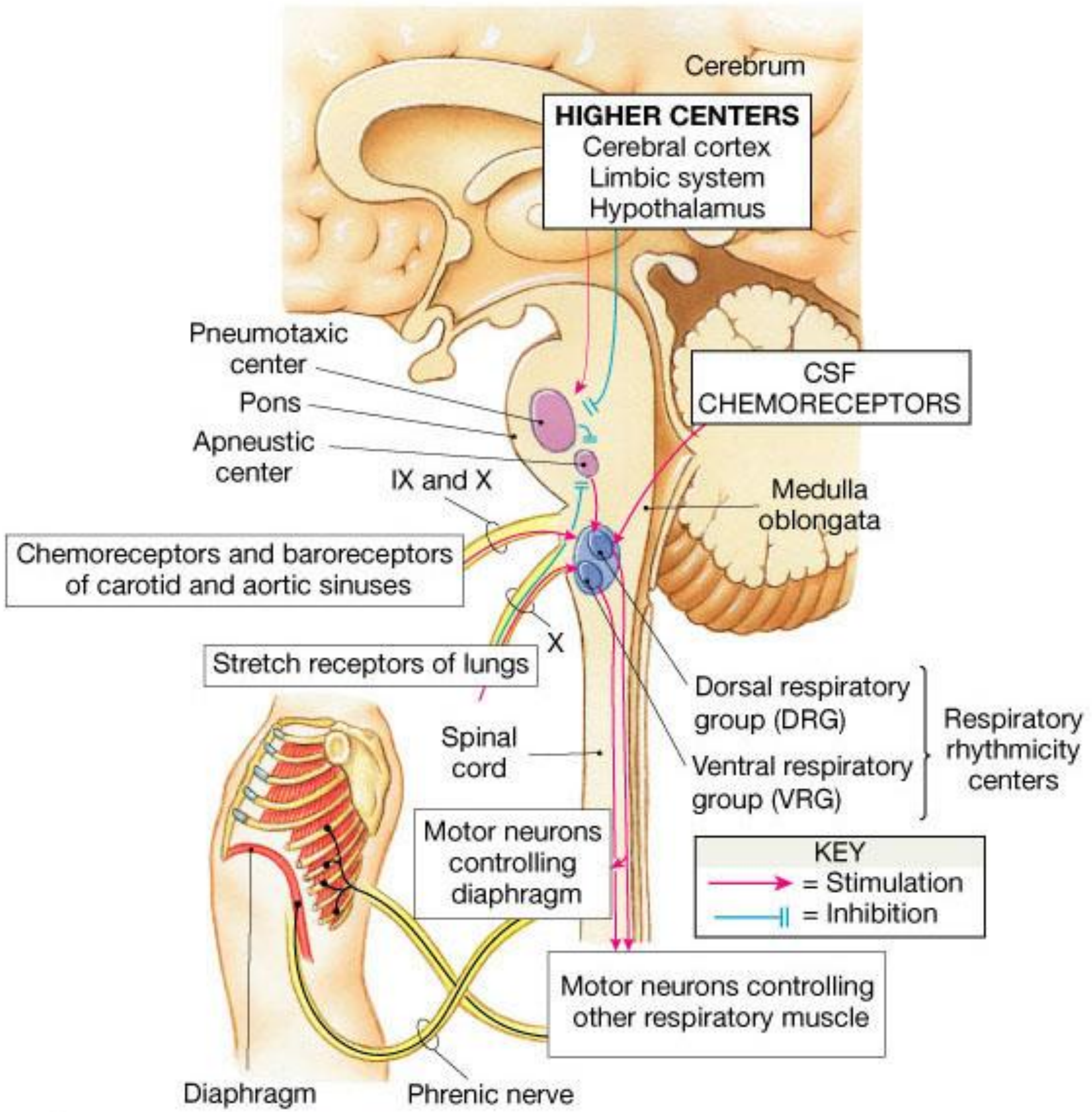
- Direct inhibitory effect of hypoxemia on the respiratory center
- Chronic hypoxemia, $PO_2 < 60$ mmHg, can significantly stimulate ventilation
  - Emphysema , pneumonia
  - high altitudes after several days


↓ Arterial P_{O_2}
↑ Production of non-CO_2 acids
↑ Arterial P_{CO_2}
↑ Brain extracellular fluid P_{CO_2}
↑ Arterial [H^+]
↑ Brain extracellular fluid [H^+]
Peripheral chemoreceptors
↑ Firing
Central chemoreceptors
↑ Firing
↑ Firing of medullary inspiratory neurons
↑ Firing of neurons to diaphragm and inspiratory intercostals
Diaphragm and inspiratory intercostals
↑ Contractions
↑ Ventilation

Neuroreceptor reflex

Hering-Breuer Reflex or Pulmonary Stretch Reflex

- Including pulmonary inflation reflex and pulmonary deflation reflex
- Receptor: Slowly adapting stretch receptors (SARs) in bronchial airways.
- Afferent: vagus nerve
- Pulmonary inflation reflex:
  – Terminate inspiration.
  – By speeding inspiratory termination they increase respiratory frequency.
  – **Sustained stimulation of SARs:** causes <u>activation of expiratory neurons</u>


Cerebrum
HIGHER CENTERS
Cerebral cortex
Limbic system
Hypothalamus
Pneumotaxic center
Pons
Apneustic center
IX and X
CSF CHEMORECEPTORS
Medulla oblongata
Chemoreceptors and baroreceptors of carotid and aortic sinuses
X
Stretch receptors of lungs
Dorsal respiratory group (DRG)
Ventral respiratory group (VRG)
Respiratory rhythmicity centers
Spinal cord
Motor neurons controlling diaphragm
KEY
= Stimulation
= Inhibition
Motor neurons controlling other respiratory muscle
Diaphragm
Phrenic nerve

Significance of Hering-Breuer

- Normal adults. Receptors are not activated at end normal tidal volumes.
  - Become Important during exercise when tidal volume is increased.
  - Become Important in Chronic obstructive lung diseases when lungs are more distended.
- Infants. Probably help terminate normal inspiration.

Factors Influencing Respiration