UNIT 1 PHYSIOLOGY

1.1 Introduction

1.2 Osmoregulation

1.3 Digestion

1.4 Respiration

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1.1 INTRODUCTION

General Physiology.

Cellular Physiology.

Neuro Physiology.

Intestinal Physiology.

Endocrinology.

Scope of Physiology

Physiology is the study of normal function within living creatures.

It is a sub-section of biology, covering a range of topics (Biological System)

organs,

anatomy,

cells,

biological compounds,

and how they all interact to make life possible.

Branches of physiology

Cell physiology- the way cells work and interact; membrane transport and neuron transmission.

Systems physiology - computational and mathematical modeling

Evolutionary physiology – adaptation and change over multiple generations

- the role of behavior in evolution,
- sexual selection, and
- physiological changes in relation to geographic variation.

Defense physiology -fight-or-flight response

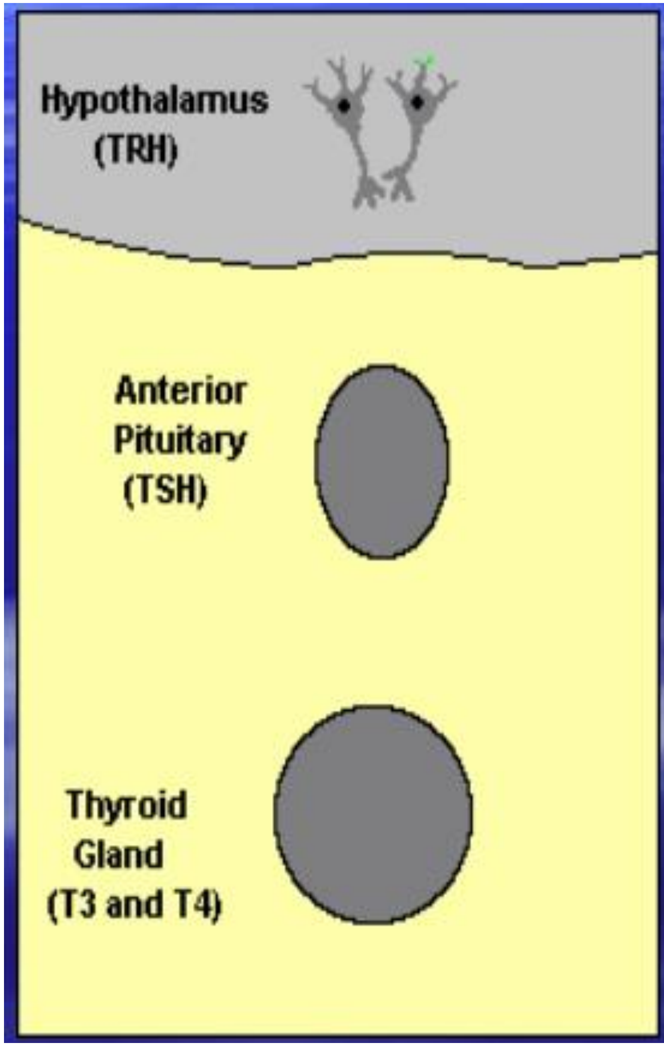
Exercise physiology

Comparative Physiology

Homeostasis

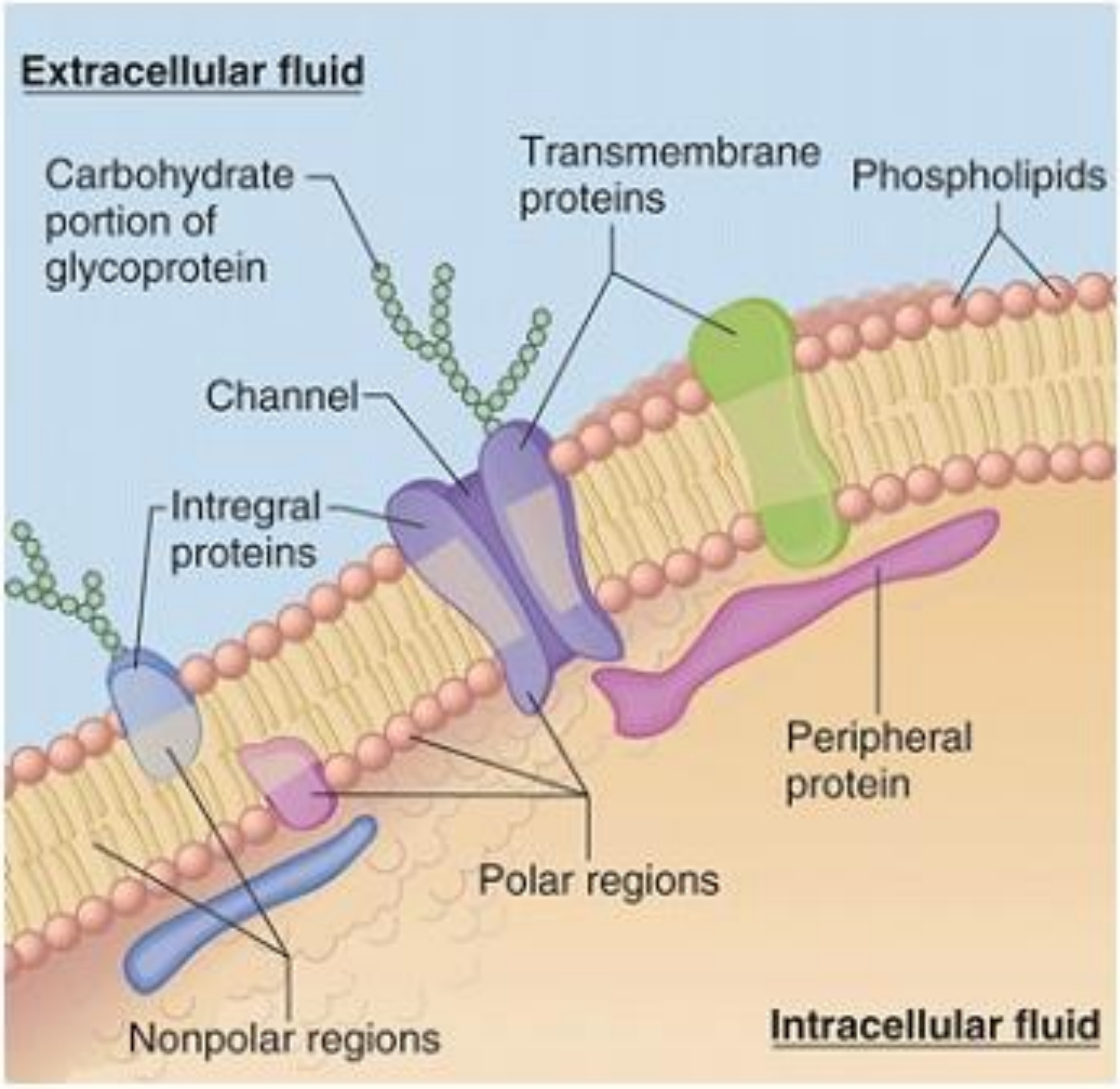
- **Homeostasis is the process by which an organism maintains the composition of the extracellular fluid (ECF) and intracellular fluid (ICF) in a steady-state condition.**
- **ECF consists of the blood plasma and interstitial fluid. The composition of the ECF is maintained by the cardiovascular, pulmonary, renal, gastrointestinal, endocrine, and nervous systems acting in coordinated fashion.**
- **ICF's composition is maintained by the cell membrane, which mediates the transport of material between between the ICF and ECF by diffusion, osmosis, and active transport.**

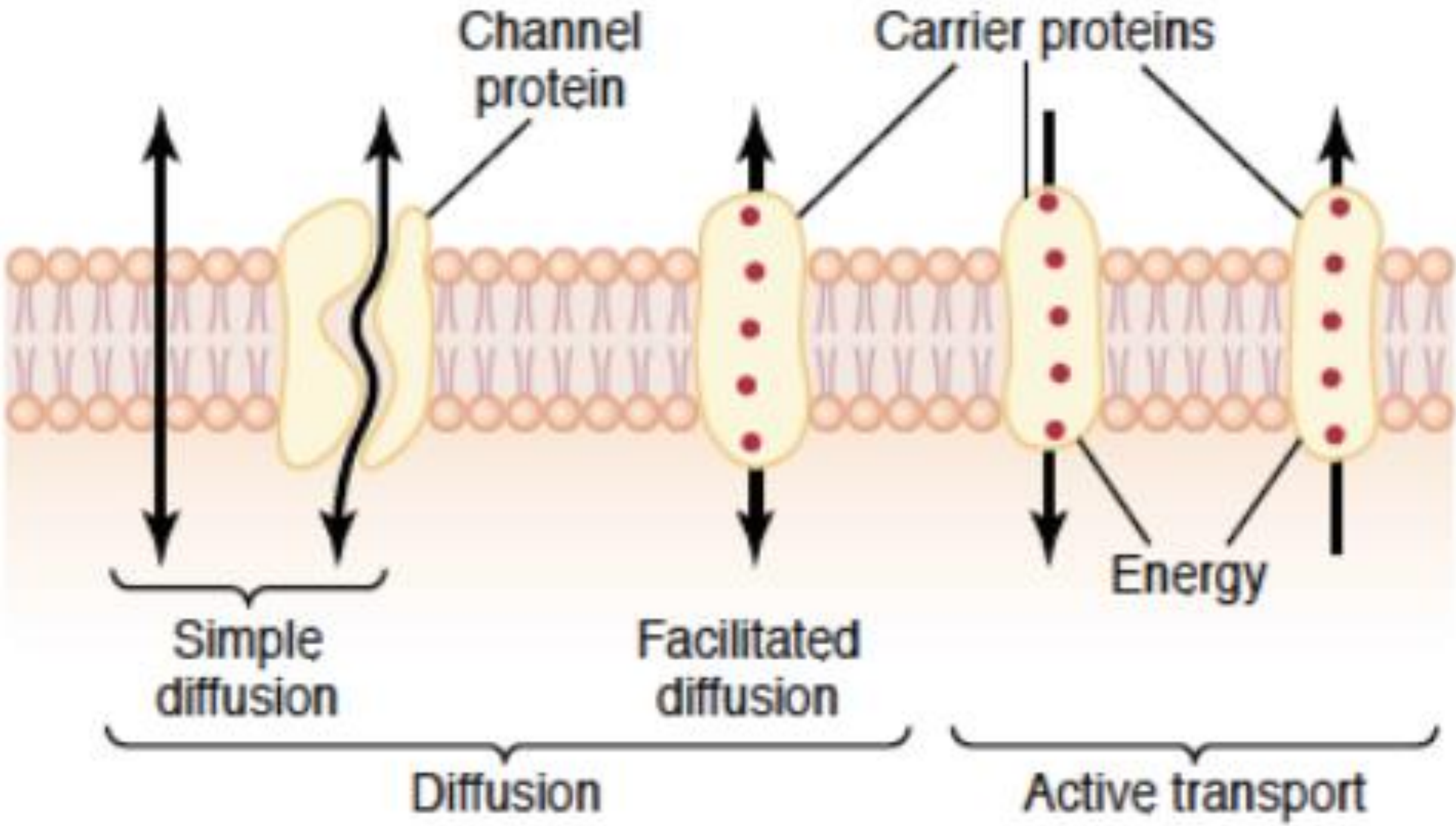
Homeostasis is maintained by mechanisms that act through negative feedback loops.



- Neurons in the hypothalamus secrete thyroid releasing hormone (TRH) which stimulates cells in the anterior pituitary to secrete TSH
- TSH binds to receptors on epithelial cells in the thyroid gland, stimulating synthesis and secretion of thyroid hormones, which affect probably all cells of the body
- When blood concentrations of thyroid hormones increase above a certain threshold, TRH secreting neurons in the hypothalamus as inhibited and stop secreting TRH.
- This is an example of "negative feedback"

CELLULAR PHYSIOLOGY




Channel protein
Carrier proteins
Energy
Simple diffusion
Facilitated diffusion
Diffusion
Active transport

Sodium-Potassium Pump

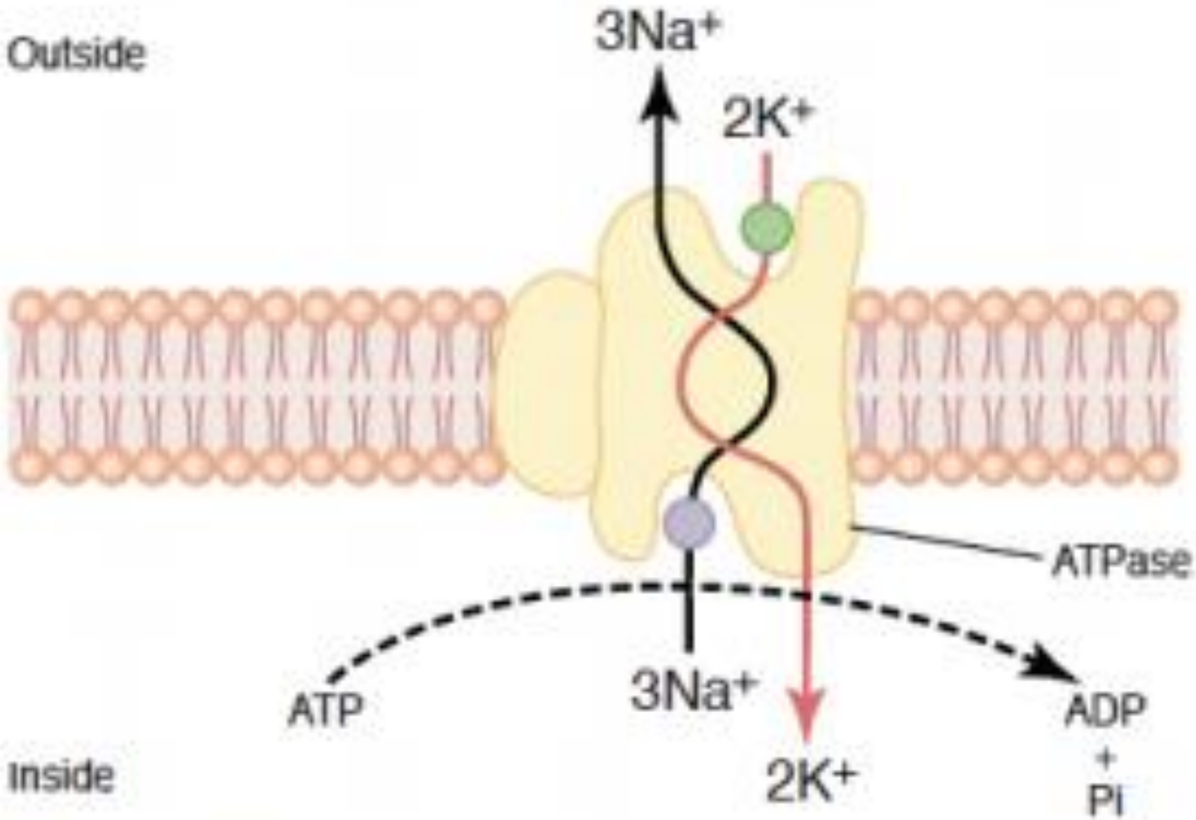
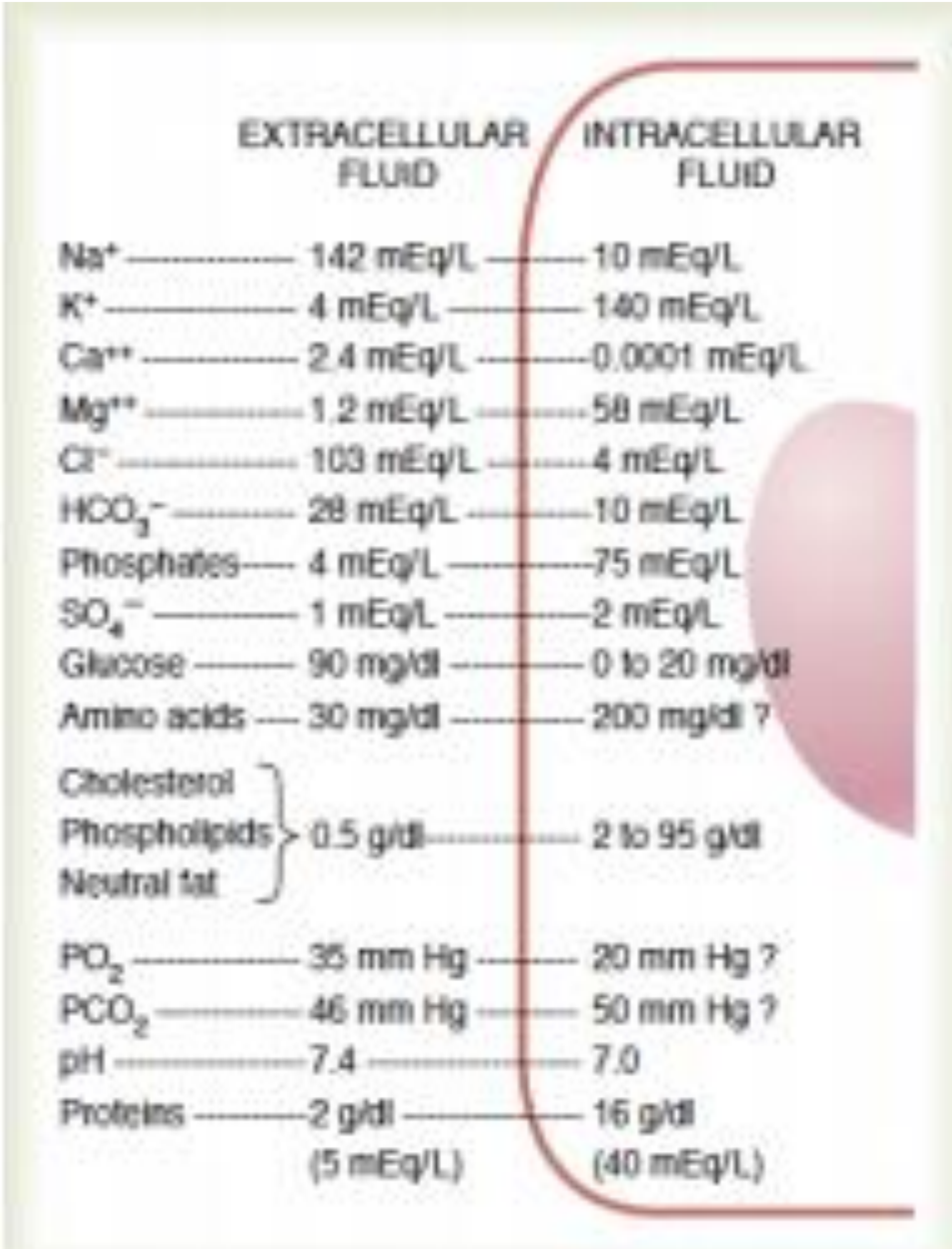


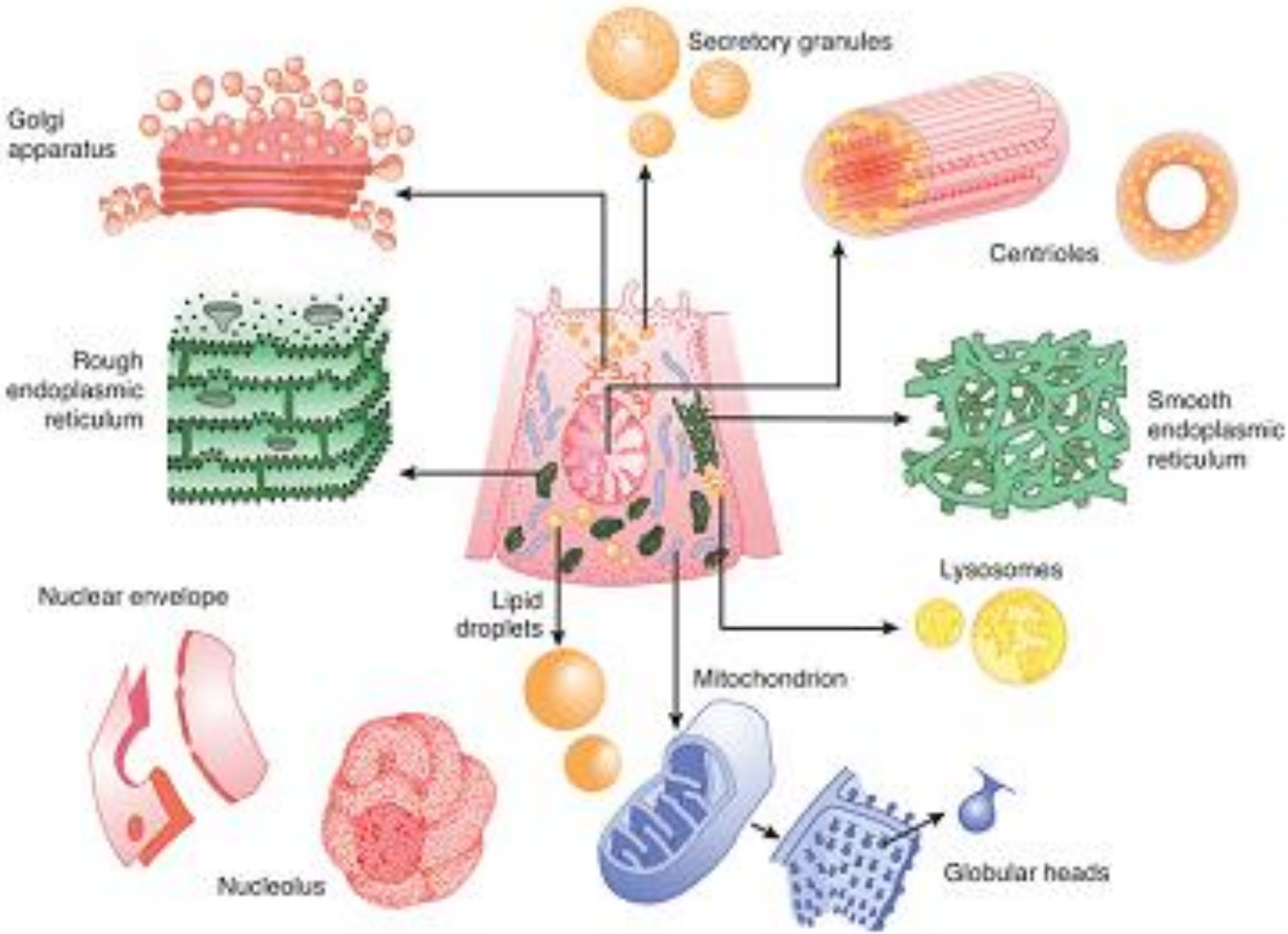
Figure 4–11

Postulated mechanism of the sodium-potassium pump. ADP, adenosine diphosphate; ATP, adenosine triphosphate; Pi, phosphate ion.

Intracellular Volume Regulation

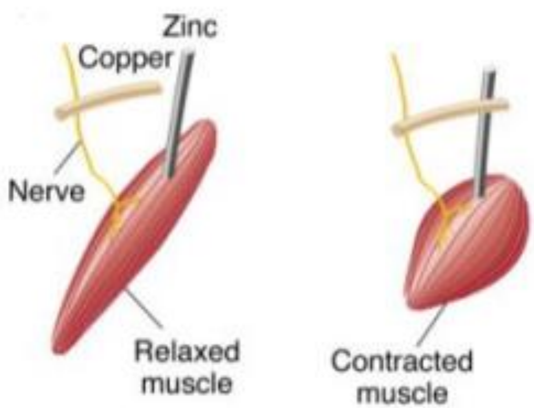


Cellular contents



Neurophysiology

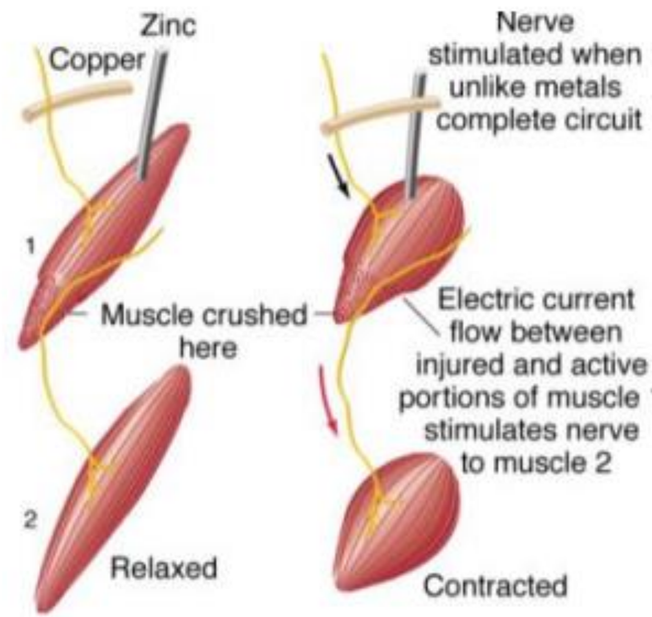
All animal cells have electric potential differences (voltages) across plasma membranes



Luigi Galvani (1791)

"Animal electricity"

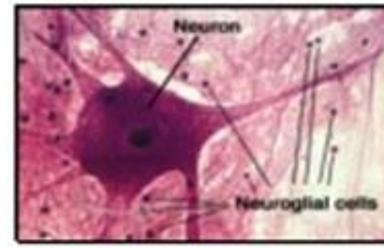
Electrical "fluid" passed through metal rods from muscle to nerve; discharge from muscle caused contraction



Carlo Matteucci (1840)

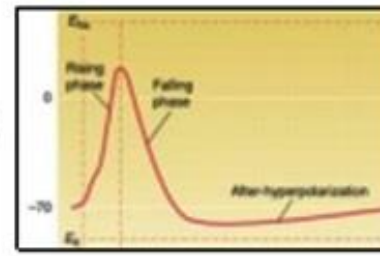
Demonstrated that excitable tissues produce electric current

Neurophysiology is a branch of physiology and neuroscience that is concerned with the study of the functioning of the nervous system.



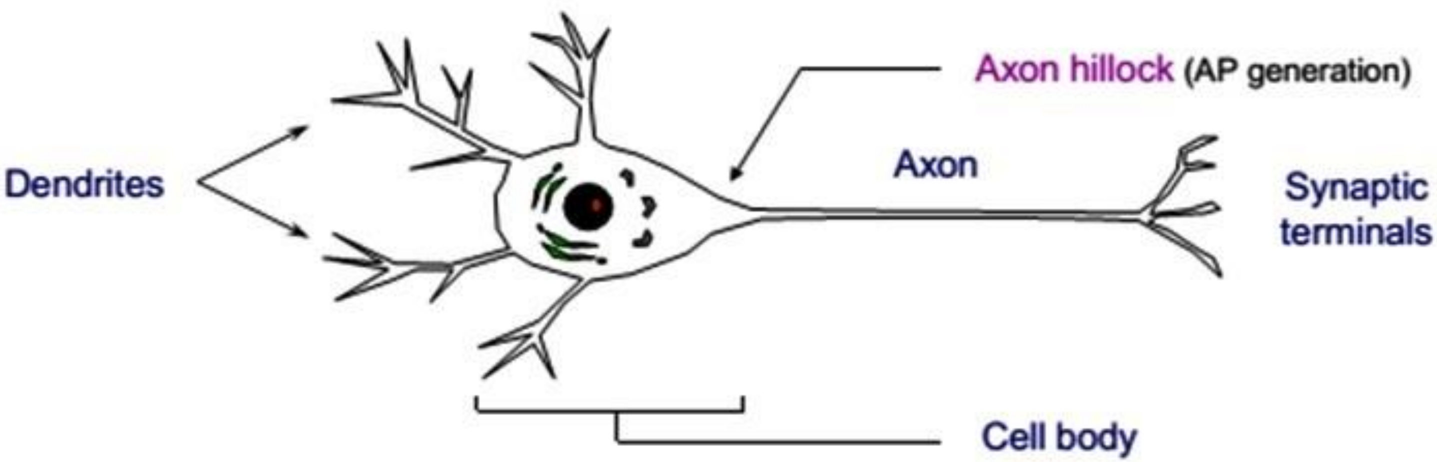
Neurons:

- Specialized "excitable" cells
- Allow rapid communication throughout body



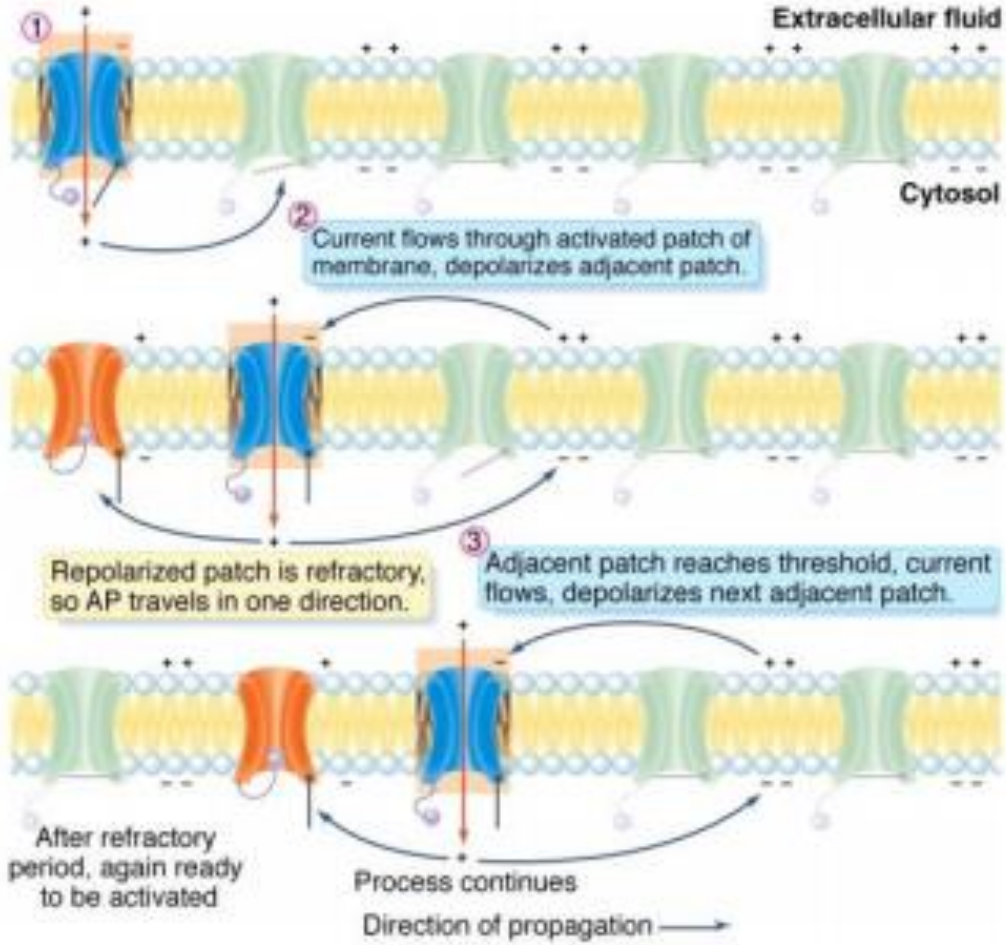
Neuron Anatomy:

1) Dendrites: Receive information (environment / other neurons)
2) Cell body (soma): Integrates information / initiate response
3) Axon: Conducts action potential (AP – electrical impulse)
4) Synaptic terminals: Transmit signal (other neurons / effector organs)



Propagation of Action Potentials:

Propagation of APs down a nerve occurs by the spread of local currents from active to adjacent inactive regions



* Only showing Na^+ channels

Randall et al. (Eckert: Animal Physiology, 5th ed.) – Figure 6.4

Propagation of Action Potentials:

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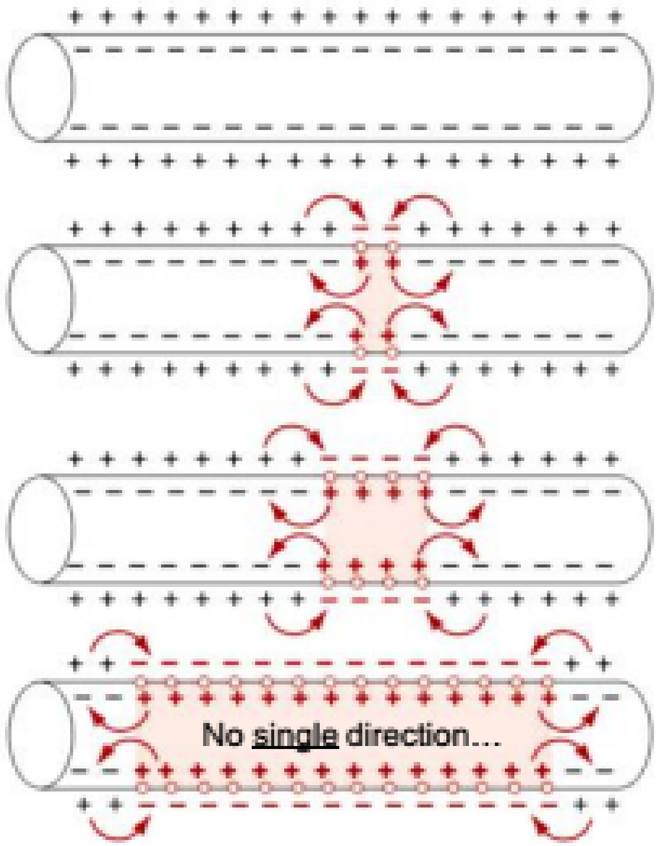


1) Rest

2) Stimulation (mechanical, chemical, electrical)

3) Propagation (positive feedback system)

- Opening of neighboring voltage-gated Na^+ and K^+ channels

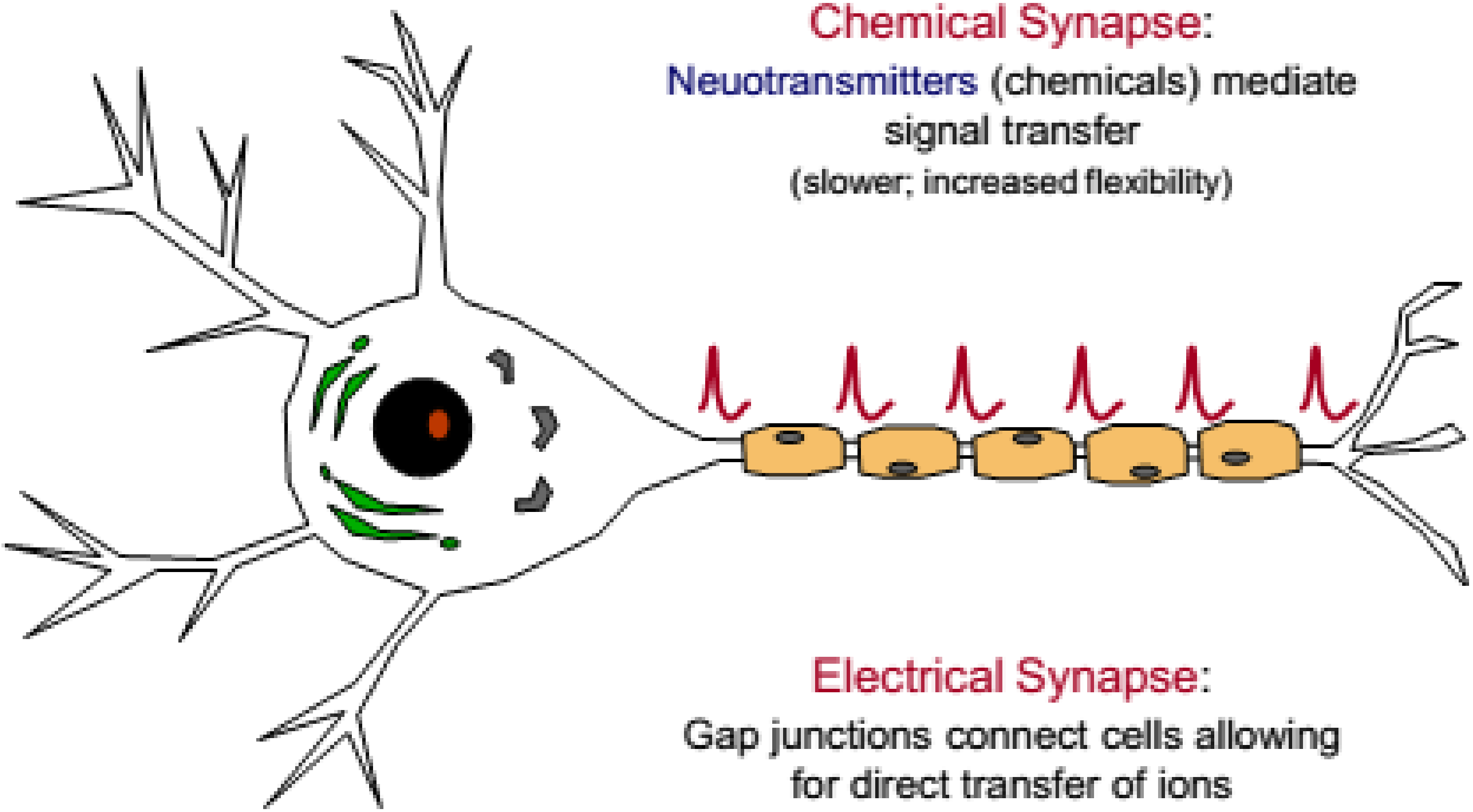
Approximately 100,000 – 50 million impulses can be fired before a cell needs to re-establish concentration gradients

Na^+ / K^+ pumps stimulated by an increase in interior Na^+ levels ($[change]^3$)

Guyton & Hall (Textbook of Medical Physiology, 12th ed.) – Figure 5.11

How Do Neurons Communicate Together?

Synapse (*Gr* – "to clasp") : Point of junction between neighboring neurons or a neuron and effector organ



Chemical Synapse:

Neuotransmitters (chemicals) mediate signal transfer

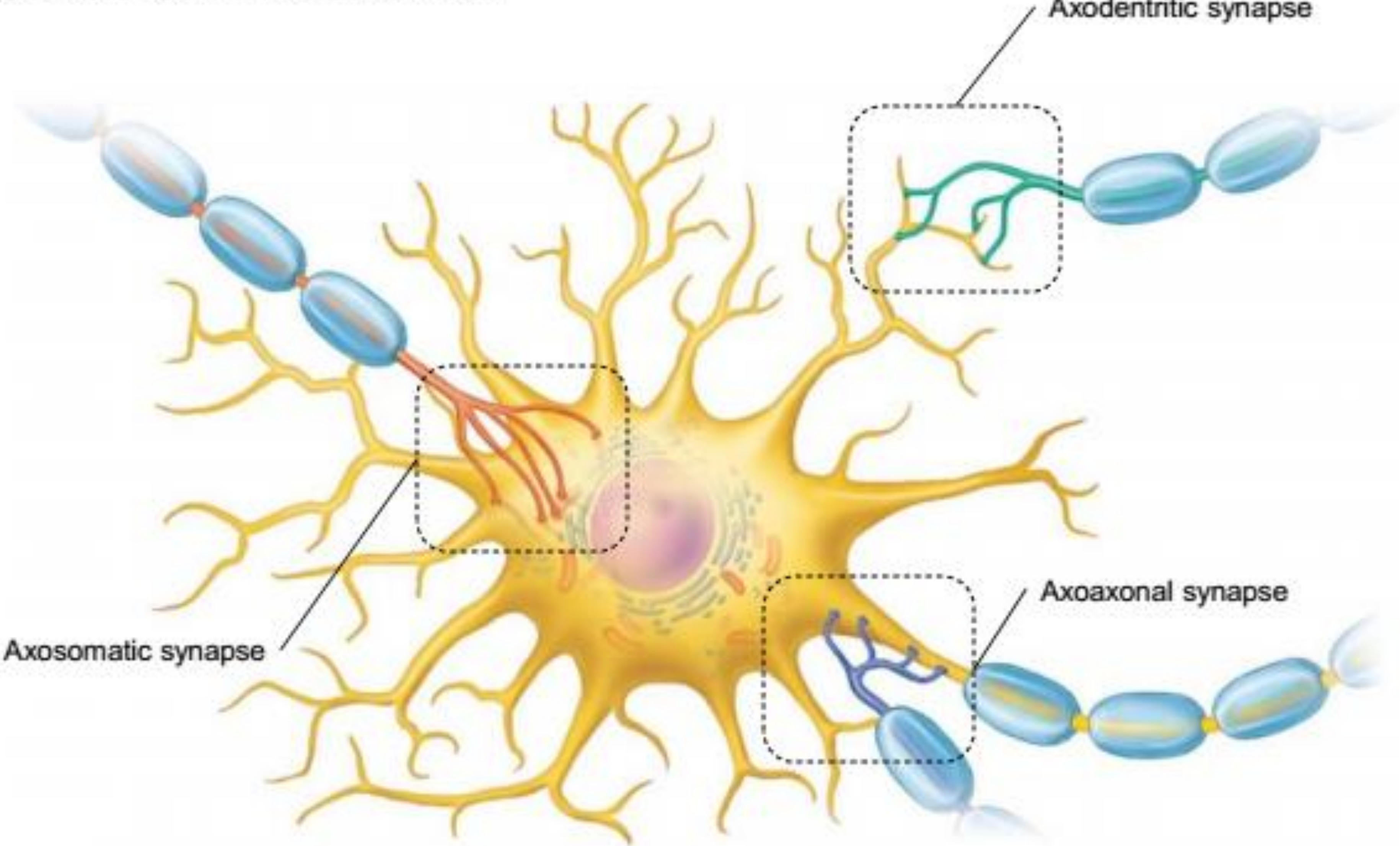
(slower; increased flexibility)

Electrical Synapse:

Gap junctions connect cells allowing for direct transfer of ions

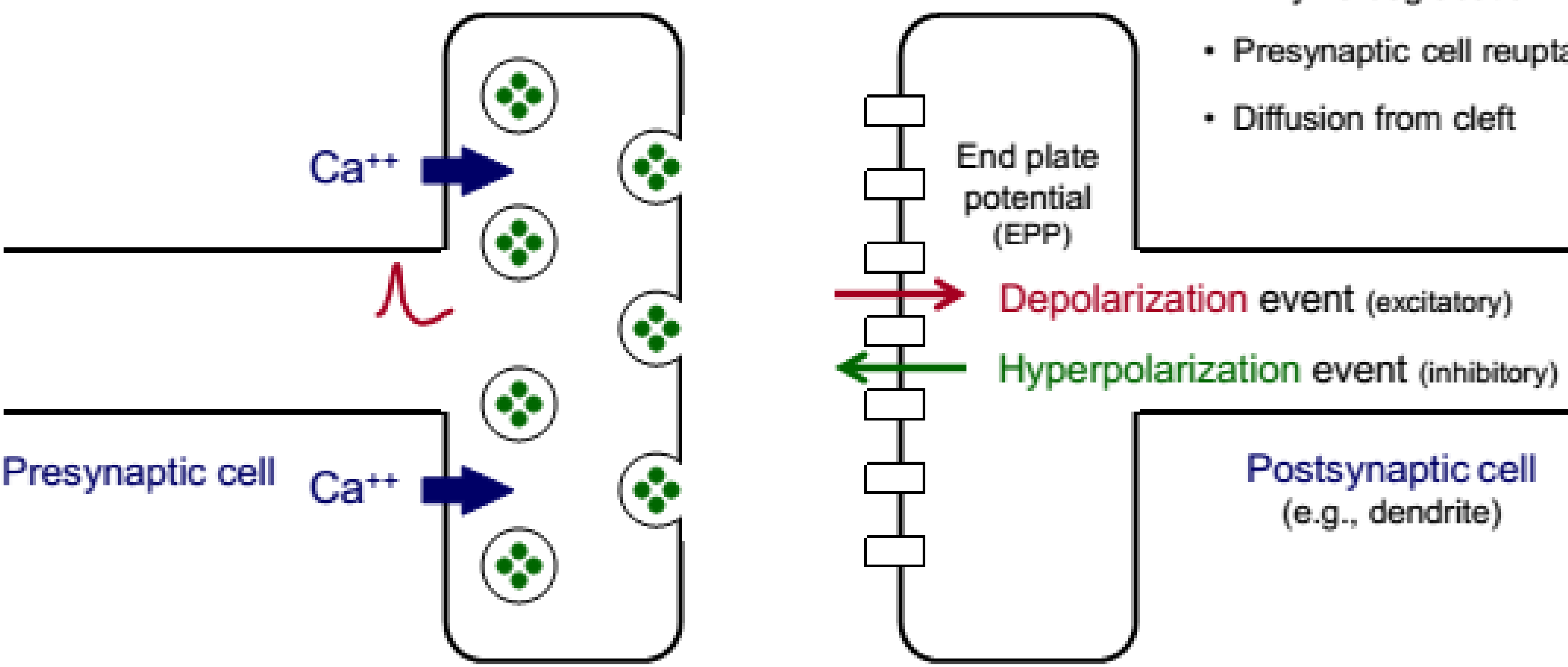
(allows for rapid, coordinated signaling)

Types of Synaptic Connections:



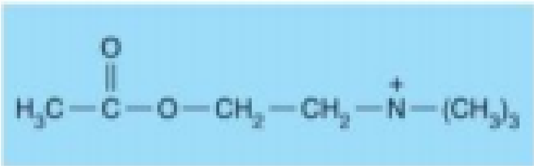
Events at a Chemical Synapse:

1) Action potential arrives at synaptic terminal
2) Ca^{++} voltage gates open; Ca^{++} enters cell
3) Synaptic vesicles fuse with plasma membrane
4) Neurotransmitter released into synaptic cleft (exocytosis)
5) Neurotransmitter binds with post-synaptic receptors
6) Neurotransmitter removal
   - Enzyme degradation
   - Presynaptic cell reuptake
   - Diffusion from cleft



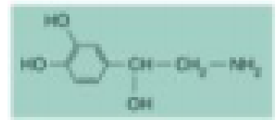
Types of Neurotransmitters (based on structure):

- Synthesized by presynaptic cell
- Released by presynaptic cell (when stimulated)
- Stimulates post-synaptic cell (when applied)



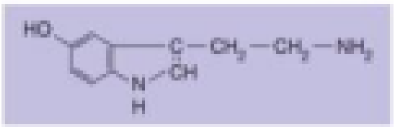
1) Acetylcholine

- Widespread in system
  - CNS / PNS
  - Neuromuscular junction



Norepinephrine

Dopamine



Serotonin

2) Biogenic Amines (amino-acid derivatives)

- Broadly distributed in brain
- Emotional behavior ("feel good" effects)

GABA (gamma-aminobutyric acid)

3) Amino Acids

- Located primarily in CNS
- Inhibitory effect

Glutamate: Excitatory NT

Glycine: Inhibitory NT

GABA: Inhibitory NT

Endorphins

4) Peptides

- Located primarily in CNS

Endorphins: Natural opiates

Substance P: Pain mediator

Endocannabinoid

5) Gases / Lipids

- Located in CNS / PNS

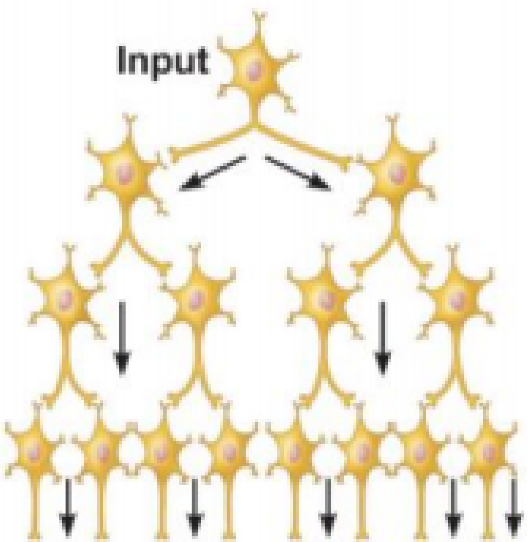
Nitric Oxide(NO): Muscle relaxation

Endocannabinoid: Memory

functional capabilities

Basic Concepts of Neural Integration:

Circuit: Pattern of synaptic connections in a neuronal pool

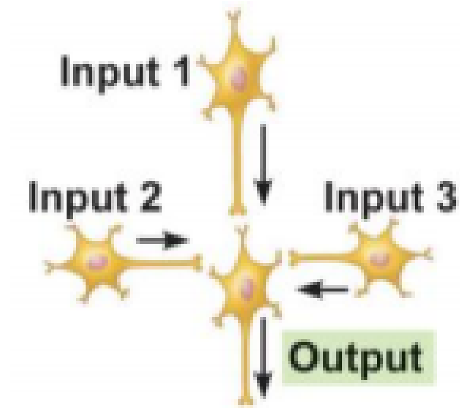


Diverging Circuit

(1 neuron → > 1 neurons)

Amplifies signal

(e.g., motor output)

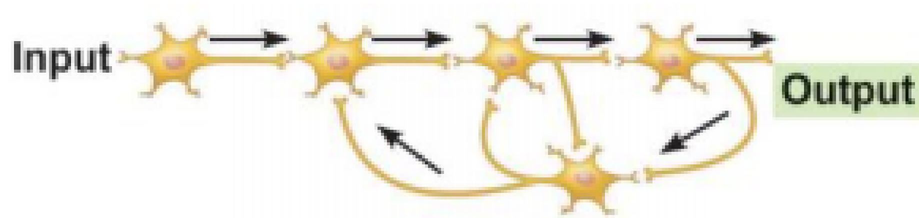


Converging Circuit

(> 1 neuron → 1 neurons)

Concentrates signal

(e.g., sensory input)



Reverberating Circuit

(1 neuron → 1 neurons)

(positive feedback)

Prolongs signal

(e.g., repetition activity)

Intestinal Physiology

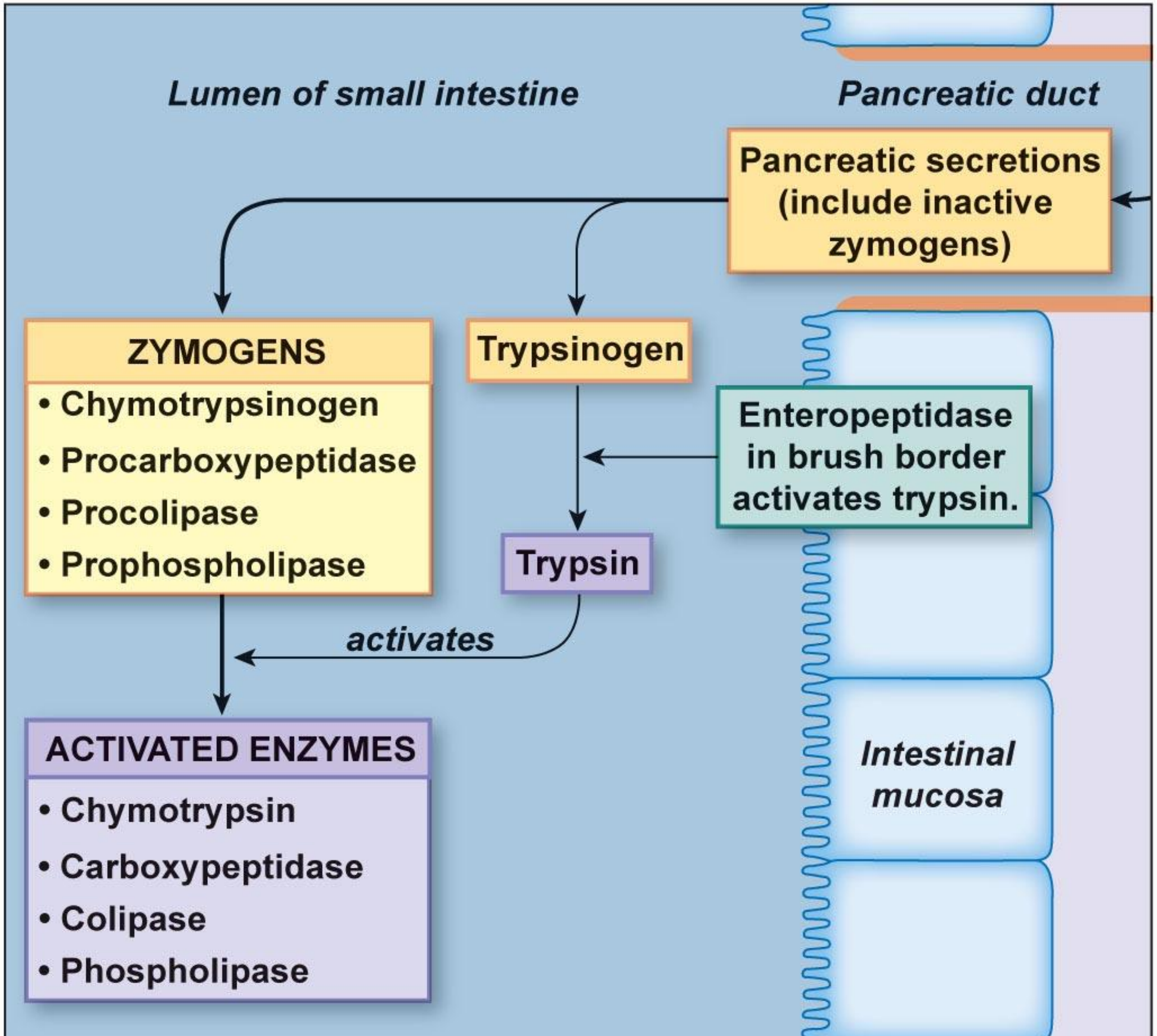
The final products of the cephalic and gastric phase is

- Digestion of proteins
- Formation of chyme
- Controlled entry of chyme into the intestine
  - Starts the intestinal phase which contains loops that
    - Feed back to further control gastric emptying
    - Feed forward to promote digestion, secretion, motility and absorption of nutrients
    - Signals are hormonal & neural

- Hormonal and neural aspects of the intestinal phase
  - entrance of chyme into duodenum gets the enteric nervous system going, secreting:
    - Secretin
      - slows gastric emptying & gastric acid production
      - Stimulates bicarbonate (HCO_3^-) production from pancreas to buffer acidic chyme
    - cholecystokinin (CCK)
      - Secreted in response to lipids and slows gastric motility and gastric acid secretion
      - Acts hormonally on the hypothalamus,
    - Incretin hormones (GIP and GLP-1)
      - GIP (gastric inhibitory peptide)
      - GLP-1 (glucagon-like peptide1)
        - » Slow gastric acid and emptying
        - » stimulate insulin release from pancreas

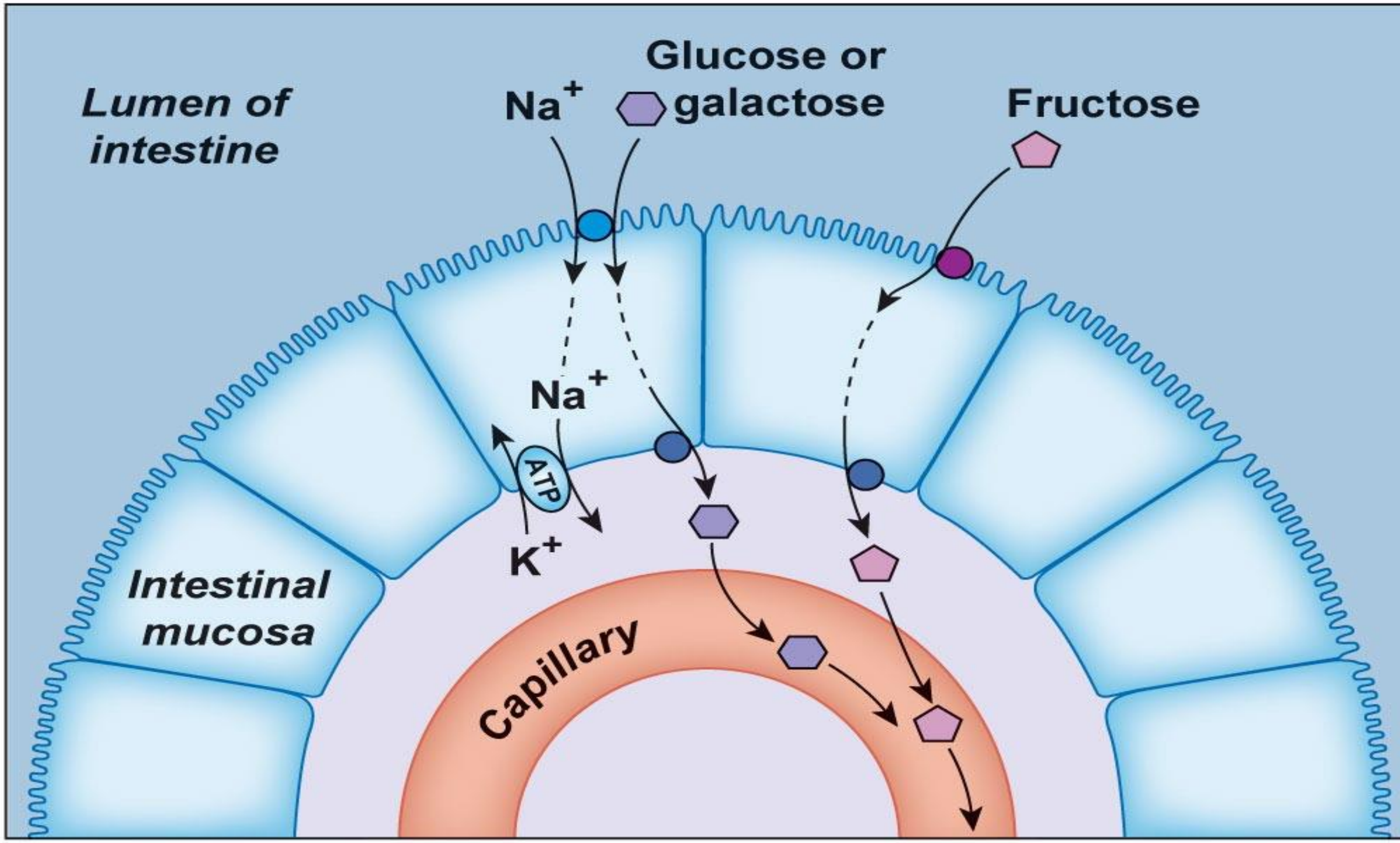
- Major processes occurring in the intestinal phase
  - Buffering
    - Via pancreatic exocrine secretion
  - Digestion
    - By pancreatic exocrine secretion
      - Trypsinogen, chymotrypsinogen, procarboxypeptidase, procolipase and prophospholipase
    - By bile release from gallbladder (stimulated by CCK)
      - Bile emulsifies the lipids, increasing surface area for pancreatic lipases
    - By intestinal mucosal enzymes (brush border enzymes) that are “anchored” to apical surface
      - Peptidases, disaccharidases, enteropeptidase
  - Absorption
    - Most of the water & nutrients are absorbed in the small intestine

- Activation of pancreatic proteolytic enzymes



- **The large intestines main processes are**
  - Concentrating waste
    - Removal of water
      - through feces
  - Movement & defecation
    - Ileocecal valve controls chyme entrance into colon
      - Relaxes in sequence with intestinal peristalsis as well as when gastric emptying starts (gastrocolic reflex)
        - » CCK, serotonin and gastrin are potential initiators of the gastrocolic reflex
    - Defecation reflex
      - Increases abdominal pressure, relaxes anal sphincters
  - Digestion and absorption
    - Digestion mainly through bacterial action which produces
      - Lactate and fatty acids which are absorbable by simple diffusion
      - Bacterial action also produces vitamin K
      - By product of bacterial fermentation is gas (CO_2, methane & HS)

Absorption - Carbohydrate absorption

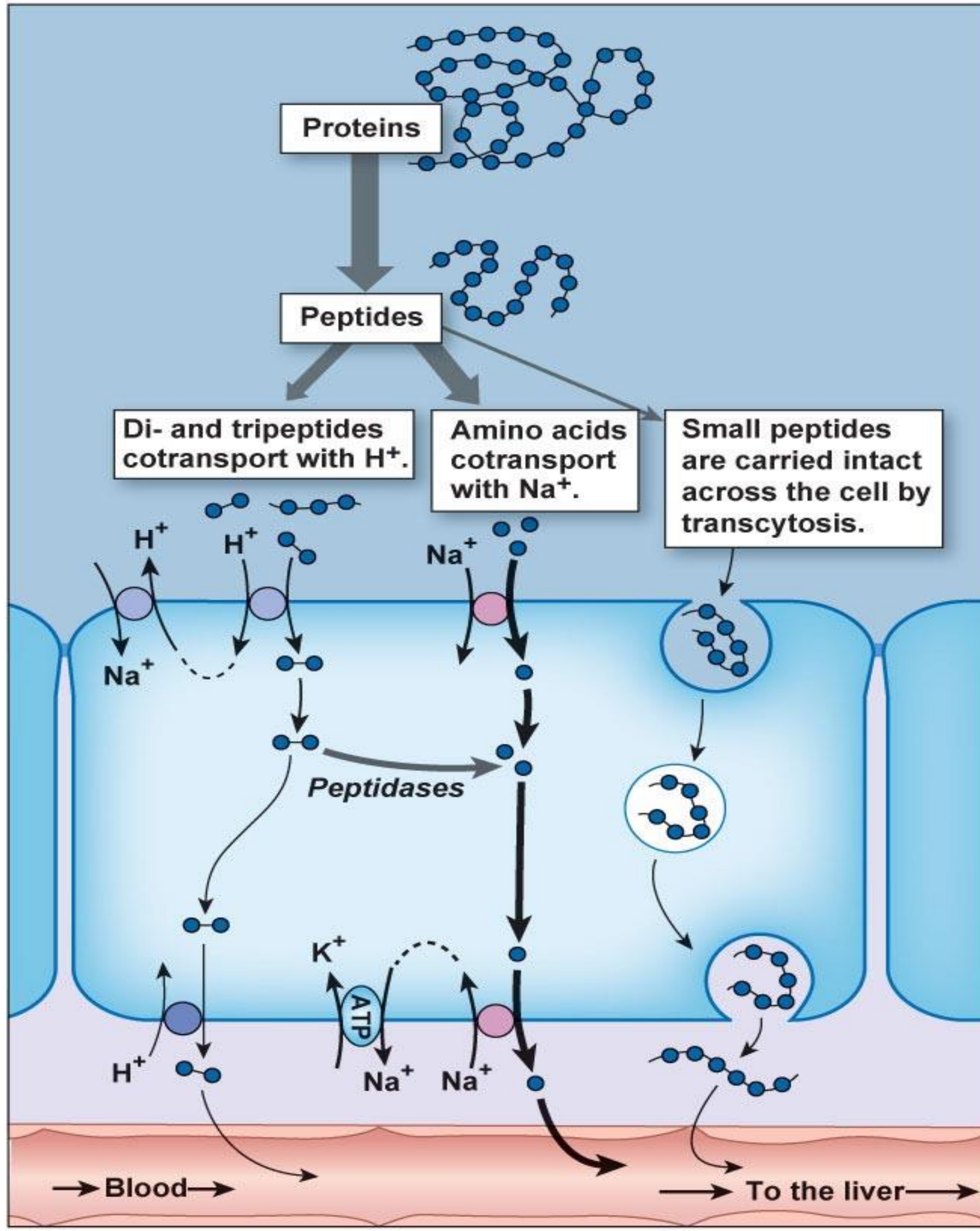


Glucose enters the cell with Na^+ on the SGLT symporter and exits on GLUT2. Fructose enters on GLUT5 and exits on GLUT2.

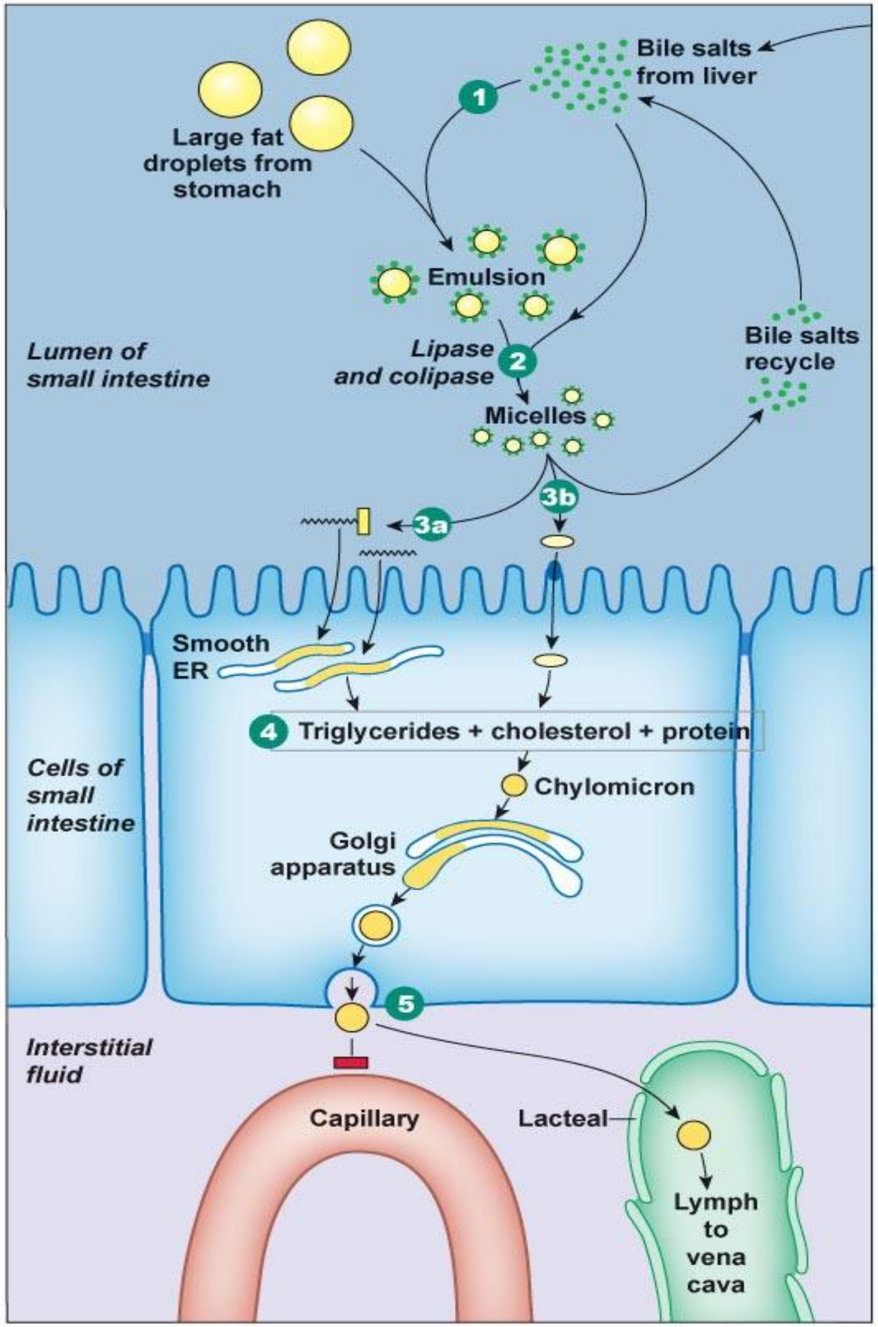
KEY

- SGLT
- GLUT2
- GLUT5

Protein absorption



Lipid digestion & absorption



1. Bile salts from liver coat fat droplets.
2. Pancreatic lipase and colipase break down fats into monoglycerides and fatty acids stored in micelles.
3a. Monoglycerides and fatty acids move out of micelles and enter cells by diffusion.
3b. Cholesterol is transported into cells by a membrane transporter.
4. Absorbed fats combine with cholesterol and proteins in the intestinal cells to form chylomicrons.
5. Chylomicrons are released into the lymphatic system.

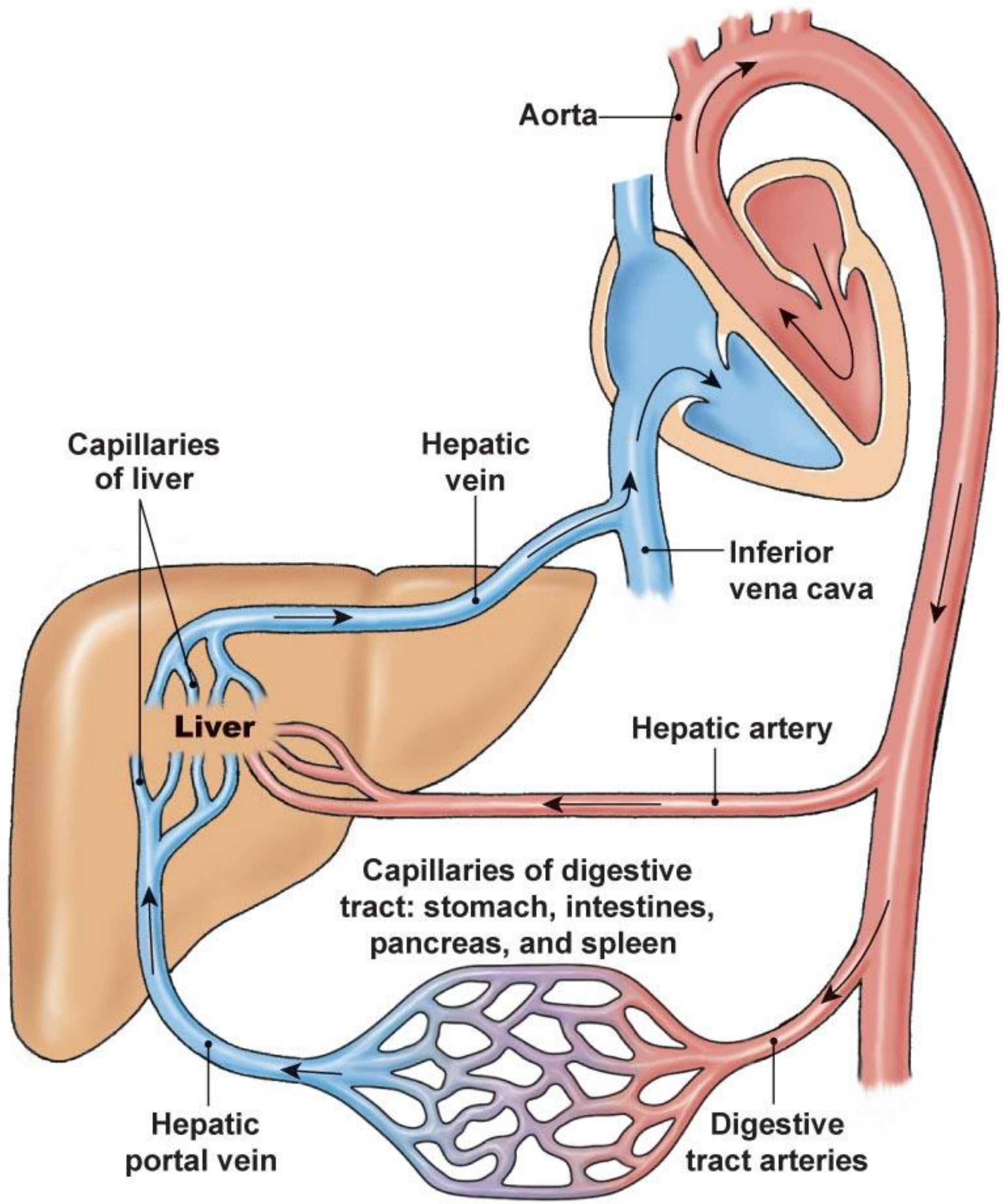
Absorbed nutrients

and water

are

returned via the

hepatic portal system



Endocrinology

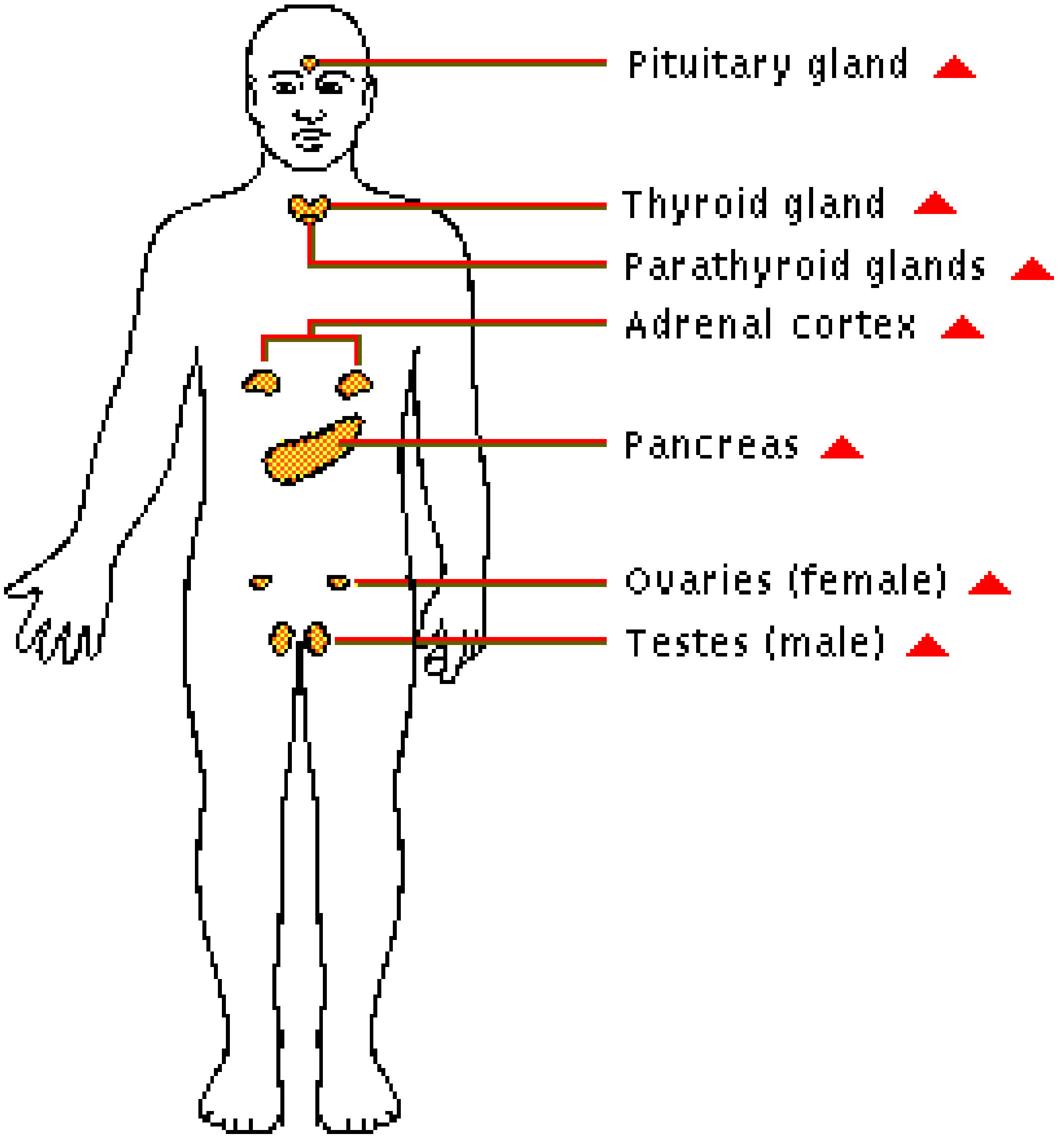
- the study of hormone and glandular abnormalities (diabetes, thyroid problems, and circus performers)

Overview of the Endocrine System

- System of ductless glands that secrete hormones
  - Hormones are “messenger molecules”
  - Circulate in the blood
  - Act on distant target cells
  - Target cells respond to the hormones for which they have receptors
  - The effects are dependent on the programmed response of the target cells
  - Hormones are just molecular triggers
- Basic categories of hormones
  - Amino acid based: modified amino acids (or *amines*), peptides (short chains of amino acids), and proteins (long chains of amino acids)
  - Steroids: lipid molecules derived from cholesterol

Other endocrine organs

- endothelial vascular cells
- adipocytes
- heart
- bone
- Liver
- kidney
- ????



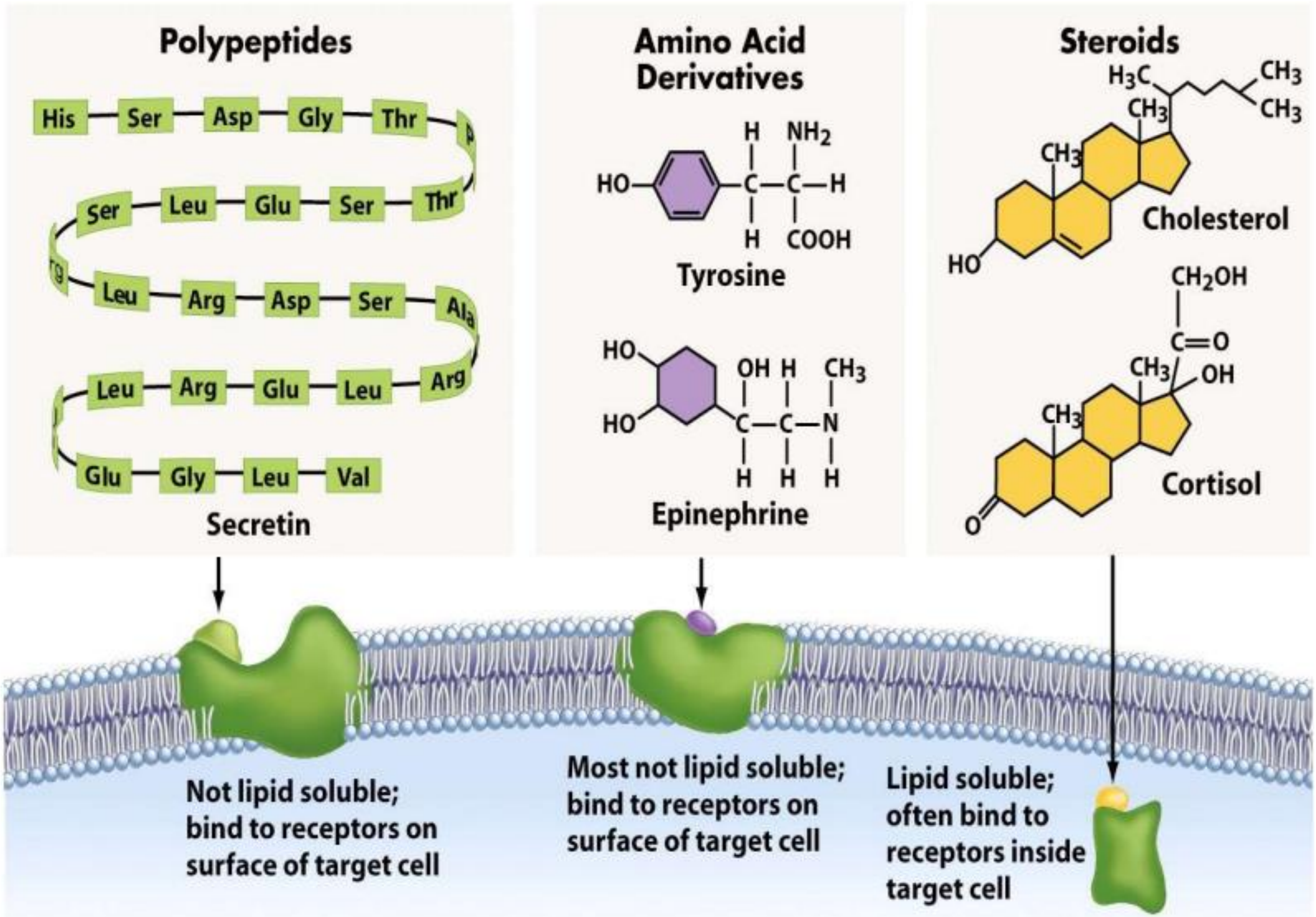
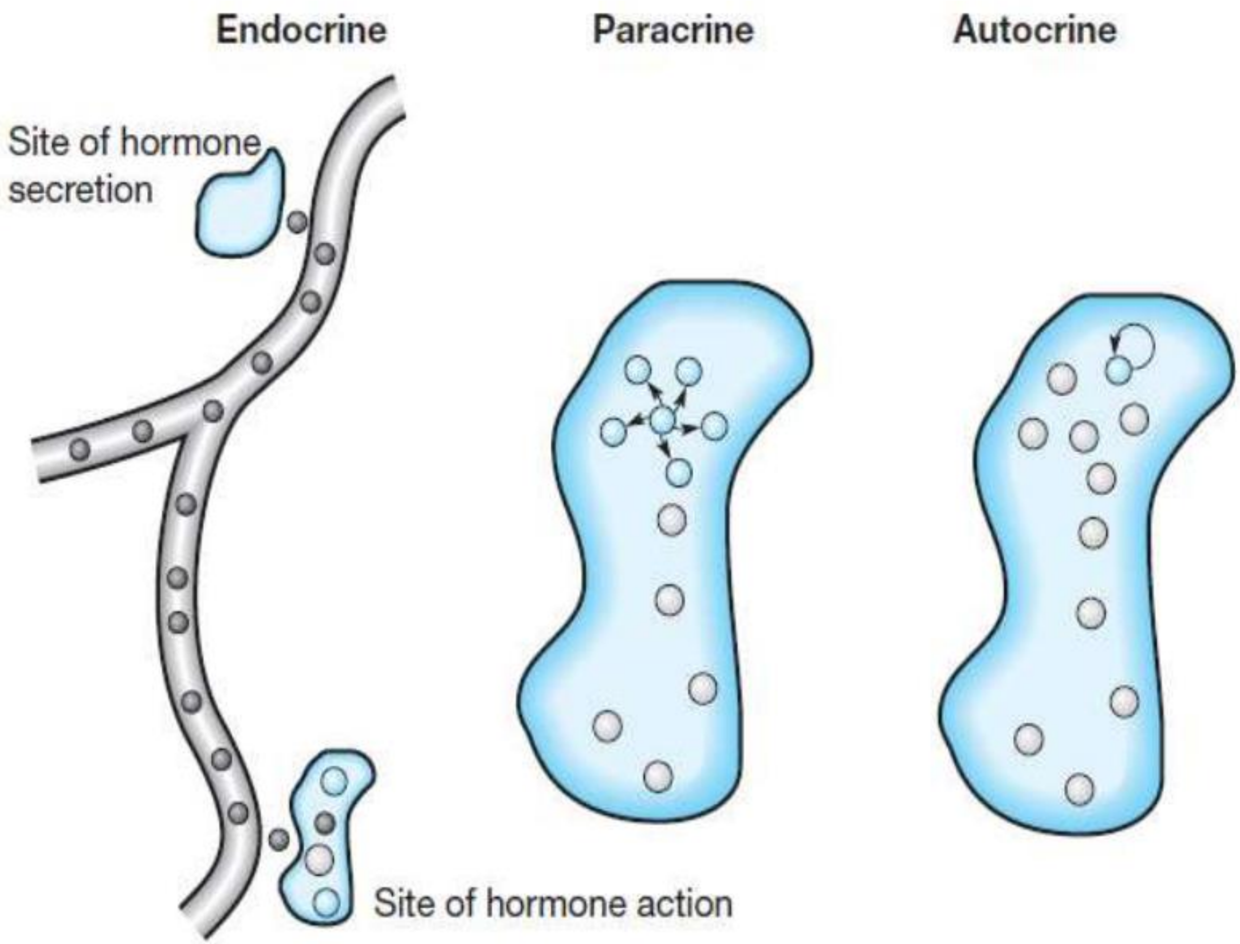


Figure 47-3 Biological Science, 2/e

Endocrine- hormones that have a biological effect far away.

Paracrine- hormones that have a biological effect nearby.

Autocrine- hormones that have a local effect

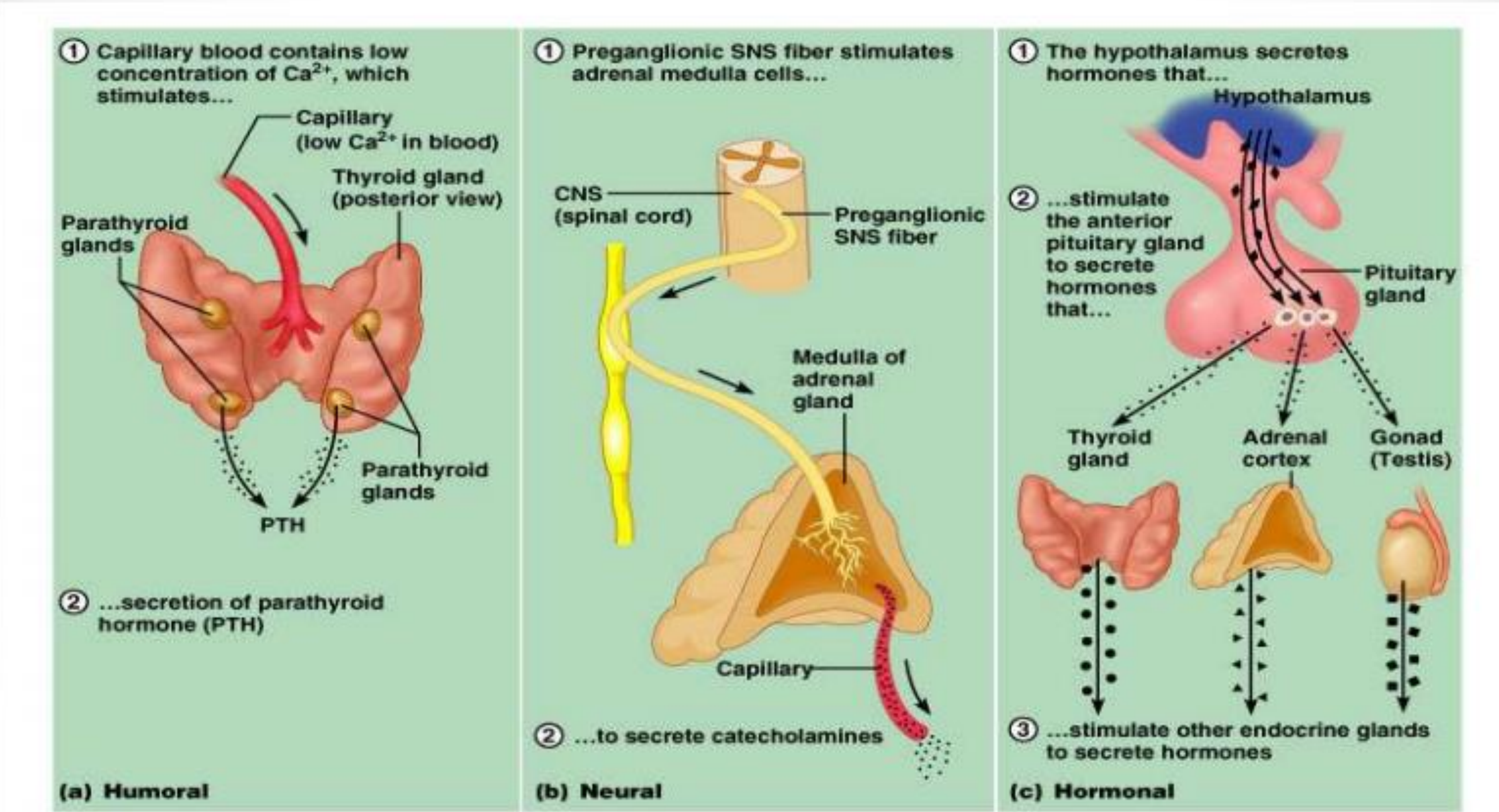


Mechanisms of hormone release

(a) Humoral: in response to changing levels of ions or nutrients in the blood

(b) Neural: stimulation by nerves

(c) Hormonal: stimulation received from other hormones



Function

- Maintain Internal Homeostasis
- Support Cell Growth
- Coordinate Development
- Coordinate Reproduction
- Facilitate Responses to External Stimuli

Site Produced (Endocrine Gland)	Hormone	Major Function* Is Control of:
Adipose tissue cells	Leptin	Food intake; metabolic rate
Adrenal:		
Adrenal cortex	Cortisol	Organic metabolism; response to stress; immune system
	Androgens	Sex drive in women
	Aldosterone	Sodium, potassium, and acid excretion by kidneys
Adrenal medulla	Epinephrine Norepinephrine	Organic metabolism; cardiovascular function; response to stress
Gastrointestinal tract	Gastrin Secretin Cholecystokinin Glucose-dependent insulinotropic peptide (GIP)† Motilin	Gastrointestinal tract; liver; pancreas; gallbladder
Gonads:		
Ovaries: female	Estrogen Progesterone	Reproductive system; breasts; growth and development; influences gametes
	Inhibin	FSH secretion
	Relaxin	? Relaxation of cervix and pubic ligaments
Testes: male	Testosterone	Reproductive system; growth and development; sex drive; influences gametes
	Inhibin	FSH secretion
	Müllerian-inhibiting hormone	Regression of Müllerian ducts

Heart	Atrial natriuretic factor (ANF, atriopeptin)	Sodium excretion by kidneys; blood pressure
Hypothalamus	Hypophysiotropic hormones:	Secretion of hormones by the anterior pituitary
	Corticotropin releasing hormone (CRH)	Secretion of adrenocorticotropic hormone (stimulation)
	Thyrotropin releasing hormone (TRH)	Secretion of thyroid-stimulating hormone (stimulation)
	Growth hormone releasing hormone (GHRH)	Secretion of growth hormone (stimulation)
	Somatostatin (SS)	Secretion of growth hormone (inhibition)
	Gonadotropin releasing hormone (GnRH)	Secretion of luteinizing hormone and follicle-stimulating hormone (stimulation)
	Dopamine (DA, also called prolactin-inhibiting hormone, PIH)	Secretion of prolactin (inhibition)
	Posterior pituitary hormones	See posterior pituitary
Kidneys	Renin (an enzyme that generates angiotensin)	Aldosterone secretion; blood pressure
	Erythropoietin	Erythrocyte production
	1,25-dihydroxyvitamin D_3	Plasma calcium
Leukocytes, macrophages, endothelial cells, and fibroblasts	Cytokines‡ (these include the interleukins, colony-stimulating factors, interferons, tumor necrosis factors)	Immune defenses
Liver and other cells	Insulin-like growth factors (IGF-I and II)	Cell division and growth
Pancreas	Insulin Glucagon Somatostatin	Organic metabolism; plasma glucose
Parathyroids	Parathyroid hormone (PTH, PH, parathormone)	Plasma calcium and phosphate
Pineal	Melatonin	? Sexual maturity; body rhythms

Pituitary glands:		
Anterior pituitary	Growth hormone (GH, somatotropin)	Growth, mainly via secretion of IGF-I; protein, carbohydrate, and lipid metabolism
	Thyroid-stimulating hormone (TSH, thyrotropin)	Thyroid gland
	Adrenocorticotropic hormone (ACTH, corticotropin)	Adrenal cortex
	Prolactin	Breast growth and milk synthesis; may be permissive for certain reproductive functions in the male
	Gonadotropic hormones: Follicle-stimulating hormone (FSH) Luteinizing hormone (LH)	Gonads (gamete production and sex hormone secretion)
	β-lipotropin and β-endorphin	Unknown
Posterior pituitary[§]	Oxytocin	Milk let-down; uterine motility
	Vasopressin (antidiuretic hormone, ADH)	Water excretion by the kidneys; blood pressure
Placenta	Chorionic gonadotropin (CG)	Secretion by corpus luteum
	Estrogens	See Gonads: ovaries
	Progesterone	See Gonads: ovaries
	Placental lactogen	Breast development; organic metabolism
Thymus	Thymopoietin	T-lymphocyte function
Thyroid	Thyroxine (T_4)	Metabolic rate; growth; brain development and function
	Triiodothyronine (T_3)	
	Calcitonin	Plasma calcium
Multiple cell types	Growth factors[‡] (e.g., epidermal growth factor)	Growth and proliferation of specific cell types

Scope of physiology

Physiology is the science of the **functional activities of the human body**.

Physiology covers a wide range (observations on humans and experiments on animals and model systems) in order to **understand principles**.

Physiology is the science most directly relevant to **human medicine** in all its specialties and to understanding all environmental factors affecting human life.

It is also a pure science of great challenge because of the complexity of its problems and its extensive interaction with mathematical, physical, biochemical, and engineering sciences, as well as with other branches of biology.

Within the prescribed curriculum, one may specialize in cellular and molecular physiology, theoretical and mathematical physiology, and organ systems and integrative phenomena, including neuroscience and behavioral physiology.

Osmoregulation

- Osmo-conformers
- Osmo-regulators
- Osmoregulation in shark
- Osmoregulation in marine and fresh water teleosts
- Osmoregulation in terrestrial mammals (camel and kangaroo rats)

Osmoregulation is the process in which a **suitable internal medium is maintained for normal life activities** by regulating the movement of **water and salts** between the body fluid and the animal medium (external).

- **Water entry**
- By drinking
- Along with food
- By oxidative reaction (metabolic water)
- By osmosis from surrounding medium
- **Water exit**
- Urine
- Respiration
- Sweat (skin) by osmosis and by exocytosis

Depending upon the concentration **(body fluid and environment) -** animals are classified into 3 types.

- **Isotonic or iso-osmotic animals:**
  - animals whose body fluid concentration is similar to that of the external medium.
  Ex. Marine protozoon's , Endoparasites.

- **Hypotonic or Hypo-osmotic Animals:**
  - whose body concentration is less than that of the environment
  Ex. Marine animals.

- **Hypertonic or Hyper-osmotic Animals:**
  - whose body fluid concentration is more than that of environment.
  Ex. Fresh water animals.

Osmotic conformers

hagfish, skates and sharks

- animals which are **osmotically labile** (dependent)

- body fluid concentration change with in the medium

- **having a high tissue tolerance**,

animal can survive

- as long as their basic metabolic functions proceed effectively

Osmo-regulators

- Freshwater fish, protists like the paramecium… etc

animals which are **osmotically stable** (independent)

- maintain their internal osmotic concentration at constant level

(no effect of external environments)

In general

osmoconformers can tolerate greater variations in their **internal environment** than osmoregulators

and

osmoregulators can tolerate greater variations in their **external environment**, than osmo-confermers.

Table 8.9 : Concentrations of major solutes (in millimoles per litre) in sea water and in the blood plasma of some aquatic vertebrates

	Habitat	Solute			Osmotic concentration (mOsm/litre[-1])
		Na	K	Urea[a]	
Sea water		~450	10	0	~1000
Cyclostomes					
Hagfish (*Myxine*)	Marine	549	11		1152
Lamprey (*Petromyzon*)	Marine				317
Lamprey (*Lampetra*)	Fresh water	120	3	<1	270
Elasmobranchs					
Ray (*Raja*)	Marine	289	4	444	1050
Dogfish (*Squalus*)	Marine	287	5	354	1000
Fresh-water ray (*Potamotrygon*)	Fresh water	150	6	<1	308
Coelacanth (*Latimeria*)	Marine	197	7	350	954
Teleosts					
Goldfish (*Carassius*)	Fresh water	115	4		259
Toadfish (*Opsanus*)	Marine	160	5		392
Eel (*Anguilla*)	Fresh water	155	3		323
	Marine	177	3		371
Salmon (*Salmo*)	Fresh water	181	2		340
	Marine	212	3		400
Amphibians					
Frog (*Rana*)	Fresh water	92	3	~1	200
Crab-eating frog (*R. cancrivora*)	Marine	252	14	350	830[b]

a When no value is listed for urea, the concentration is of the order of 1 mmol per liter and osmotically insignificant. Values for ray, dogfish, and coelacanth include trimethylamine oxide

b Values for frogs kept in a medium of about 800 mOsm per liter, or four-fifths of normal sea water

Osmoregulation in marine elasmobranchs

Example - sharks

- body fluid salt concentration = roughly1/3rd the level of the sea-water

- maintain osmotic equilibrium - by adding organic compounds (**urea**).

-equal or slightly above the sea-water

urea is abnormal for other vertebrates ….. **normal for shark.**

urea excreted through kidney….**shark kidney actively reabsorbs**

- urea can pose problems in the body functioning by destabilizing the protein- enzymes .

- **trim-ethylamine (TMAO), betaine and sarcosine** inhibits the effect of urea on enzymes.

- **sodium concentration** much lower than that of sea-water …….Na intrude in

- **sodium excretion** ……………kidney and **rectal gland**

- elasmobranch **blood** is usually slightly more **concentrated** than sea-water

- inflow of water via the gills
- water is used for the formation of urine and for the secretion of rectal gland

Osmoregulation
in
marine and fresh water
teleosts

Adaptation

sea-water fish body surface- relatively permeable to ions,
fresh water fish body surface- relatively impermeable

Marine teleosts

body (**hyposmotic)** < medium (**hyperosmotic**)

- **losing body water (gill surfaces and urine)**

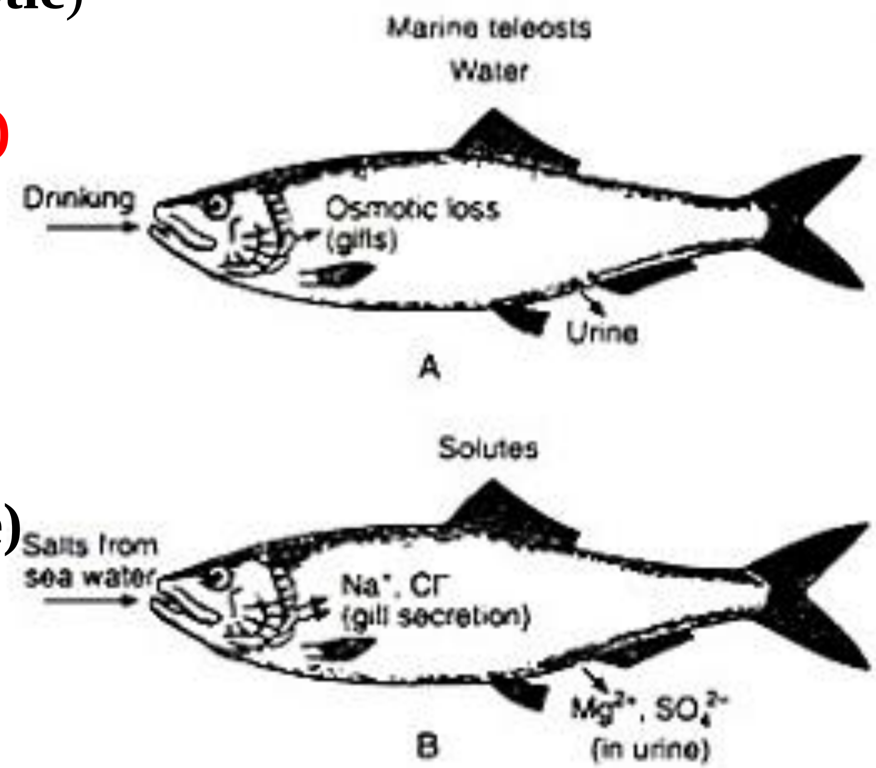
To compensate water loss

- by **drinking sea-water/general body surface**

restore the water + **Salts ingested** and **absorbed (intestine)**
impose another problem

- **elimination** of excess salt Na & cl – by **chloride cells** (Gills + opercular cover) (active transport)

- **Kidney-** excretion of divalent ions (**magnesium and sulfate)**

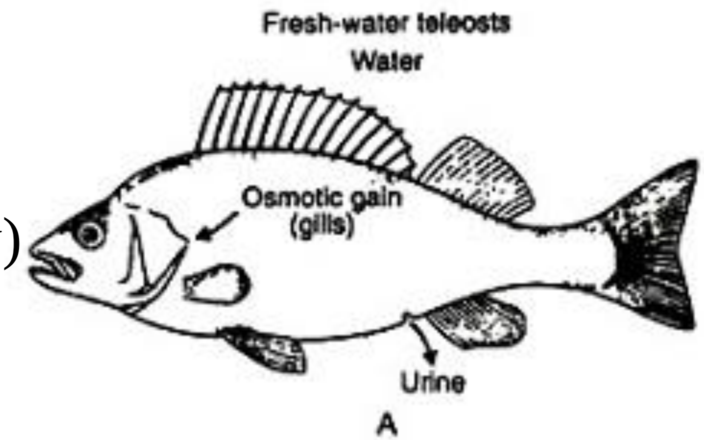


Fresh water teleosts

Blood (**hyperosmotic** ~300 mOsm/litre)
> medium (**hyposmotic)**

- problem is the **osmotic water inflow** **(gills)**

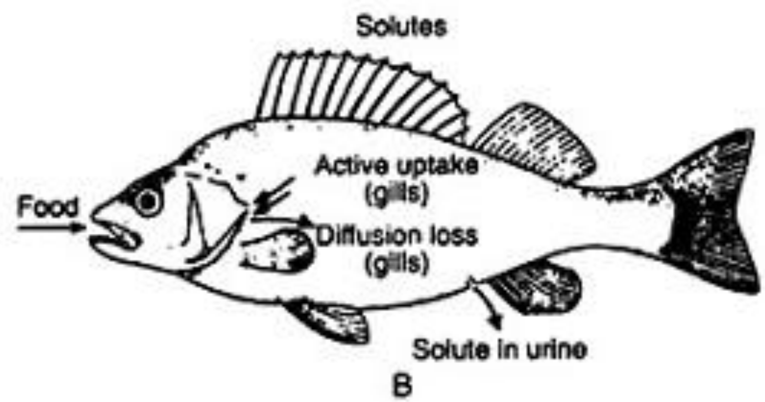
(freshwater **teleosts skin** is **less permeable)**



- **water** is excreted + solute too
  - as **urine (**dil,**1/3rd** of body weight per day)
    2 to 10 mmol/litre of solutes
  - **through gills (**slightly permeable to ions**)**

To compensate solute loss

- **food**
- **gills (active transport)**
- ~~**skin**~~ plays only a minor role in active absorption



Osmoregulation in terrestrial mammals (camel and kangaroo rats)

CAMEL

- the camel has often to survive on limited quantities of water for long periods of time.
- very low rate of water use & restricting water loss as soon as its intake is reduced.

1) **hump** fat - complete **oxidation = water**.
2) **stomach-** glandular sac areas "**water sacs**" - fluid secretion
3) Water is lost from the body by **evaporative cooling**, in the **urine** and in the **feces**.
4) Fecal water loss is also small in camel. Final reabsorption of water occurs in the colon.

- camel **exhales**, **water vapor becomes trapped** in their nostrils.
- Camels **eating green herbage**.
- camels' **thick coats**.
- **lighter** color **summer coat-** reflecting light & to avoid sunburn.
- long legs- keeping its body farther from the ground.

- The **rumen** helps maintain water balance

1. Water storage
2. Prevention of haemolysis and osmotic tissue shock during rapid rehydration

- **Camel's kidneys**

1. a long loop of henle

both concentrating urine and reducing its flow

2. a well-developed medulla (medulla: cortex is 4:1)

3. renal corpuscles have a smaller diameter

- **Anti-diuretic hormone (ADH)- regulate the volume of urine excreted** and **its concentration**.

➢ ADH (hypothalamus) → released to blood

in response to increased blood osmolarity

➢ Larger release of ADH = fast renal response

(increased re-absorption of water)

(small volume of more concentrated urine being excreted).

Unique features of blood

- In dehydration blood viscosity is normal.
- Constant- Blood **composition** and **volume**
- **haemoglobin** function - remains normal

- Erythrocytes- **oval shaped** and **non-nucleated**
  - **resist osmotic variation** without rupturing;
    (swell to twice their initial volume following rehydration)
  - **flow quicker** in a dehydrated state

- **long life span of Erythrocytes on dehydration**.
  - **hydrated** camels is **90 to 120 days**.
  - **chronically dehydrated** during summer (40°C mean during day; 20°C mean at night) - life span extends to **150** days.

Erythrocyte turnover is water and energy expensive.

-extending the life span of erythrocytes reduces energy and water expenditure.

Kangaroo rats

- desert dwelling rodents
- sustain themselves with minimal water intake (seeds and certain vegetation for hydration)

- specific adaptations
  - Behavioral
  - Dietary
  - Morphological

- **prefer living sandy or soft soiled areas**

➢ allows them to burrow the ground

➢ **stay buried in the ground during the day** (greatest temperatures)

  - to conserve water by not perspiring.

- **active during the night** **(**coolest temperatures)

- **sand bathing**
  - in **removing oils from the hair**

    excessively oiled - reduces the insulating effects

- **oil is deficient**
  - Dorsal glands secretions are applied evenly

    (to aid in prevention of water loss and insulation)

- Process occurs upon awakening and once more before dawn.

- **water supply**

➢ **oxidative reactions** in its cells

- About 90% of the daily **water supply** is generated

➢ From **food-** remaining 10% of water.

- structural + behavioral adaptations = can survive in the desert **without ever drinking water**.

- **Kidney Function**
  - the loop of Henle **- long and densely packed within the renal medulla** (increase water reabsorption)
  - long loops- **countercurrent exchange** increased

Active transport

(increase in urine concentration)

  - concentrate urea to 3,500 mmol/l (humans 400 mmol/l).

- **Feces water absorbed – in large intestine and rectum**.

- **Lacking sweat glands -** lose little water by evaporation from the body surface.

1.3 DIGESTION

We need food for cellular utilization:

→nutrients as **building blocks** for synthesis

→sugars, etc to break down for **energy**

most food that we eat cannot be directly used by the body

→too large and complex to be absorbed

→chemical composition must be modified to be useable by cells

digestive system functions to altered the chemical and physical composition of food so that it can be absorbed and used by the body; ie

Functions of Digestive System:

1. physical and chemical digestion
2. absorption
3. collect & eliminate nonuseable components of food

Anatomy of the Digestive System

organs of digestive system form essentially:
a long continuous tube open at both ends

→ **alimentary canal** (gastrointestinal tract)

mouth→pharynx→esophagus→stomach→
small intestine→large intestine

attached to this tube are assorted **accessory organs** and structures that aid in the digestive processes

salivary glands
teeth
liver
gall bladder
pancreas
mesenteries

The GI tract (digestive system) is located mainly in **abdominopelvic cavity**

surrounded by **serous membrane**
= visceral peritoneum

this serous membrane is continuous with parietal peritoneum and extends between digestive organs as **mesenteries**
→ hold organs in place, prevent tangling

The **wall** of the alimentary canal consists of 4 layers:

outer

serosa:
visceral peritoneum,
mainly fibrous and areolar CT
with some pockets of adipose CT

muscularis
several layers of smooth muscle

submucosa
blood vessels, lymphatic vessels, nerves,
connective tissue

inner

mucosa:
small band of muscle tissue, **muscularis mucosa**
mucus membrane lining
contains **goblet cells** that secrete mucous for
protection

these layers are modified within various organs

→ some have muscle layers well developed

→ some with mucous lining modified for secretion
of digestive juices

→ some with mucous lining modified for absorption

1. <u>Mouth (Buccal Cavity, Oral Cavity)</u>

bordered above by **hard** and **soft palate**

forms partition between mouth and nasal passages

uvula

is suspended from rear of soft palate
blocks nasal passages when swallowing

tongue

lines ventral border of mouth cavity
is skeletal muscle covered with mucous membrane

contains taste buds

frenulum is thin fold of mucous membrane on ventral surface of tongue that anchors the tongue to the floor of the mouth

short frenulum → "tongue tied"

Teeth

two sets

deciduous (=baby teeth) (20)

begin at 6 months; shed 6-13 yrs

permanent teeth (32)

each tooth has a

crown (above gum)
neck is where crown, gum and root meet
root (below gum)

imbedded in socket

kinds of teeth modified for specific functions

incisors – 4+4; cut, knip
canines – 2+2; holding onto prey
premolars – 4+4; cutting, crushing
molars – 6+6; chewing, grinding, crushing

each tooth is composed of several layers:

enamel

very hard
outer surface
on upper exposed crown only
resists bacterial attack
cannot regenerate if damaged

dentin

below enamel
less hard, similar to bone matrix
decays quickly of enamel is penetrated

pulp

living portion of tooth
consists of blood vessels, nerves

cementum

on root of tooth only
outer surface
holds root into socket in jaws

Salivary Glands

3 Pairs of **salivary glands**:

sublingual
submandibular
parotid

largest, below ears
mumps = acute infection of parotid gland

secrete **saliva** (enzymes and mucous for digestion)

2. <u>Pharynx (throat)</u>

already discussed

3. <u>Esophagus</u>

collapsible tube ~ 10” long

extends from pharynx to stomach

→gets food through thorax to abdominal cavity

posterior to trachea and heart

pierces diaphragm

uses peristalsis to move food to stomach

→ can swallow upsidedown

drains into stomach through the cardiac orifice surrounded by the **lower esophageal sphincter**

4. <u>Stomach</u>

muscular sac just below diaphragm and liver

alimentary canal expands to form stomach

50 mL when empty; up to 1.5 L after meal

Major functions of stomach:

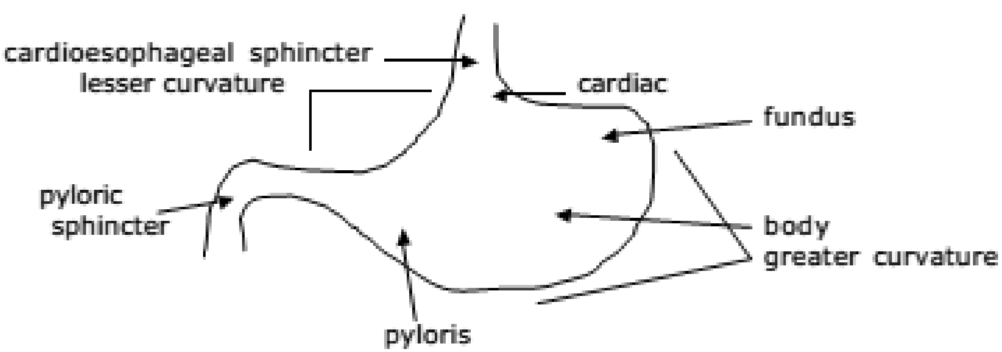
1. **physical digestion** – churning action

2. **chemical digestion** – esp proteins

3. limited **absorption** (some water, alcohol, certain drugs)

divided into 4 regions:

cardiac
fundus
body
pyloris



Muscle layers are very well developed in stomach

circular
longitudinal
oblique

Help to break up food by churning action

results in milky white liquid = **chyme**

sphincter muscles close both stomach openings:

cardioesphageal sphincter
(=lower esophageal sphincter)

heartburn →doesn't close properly

pyloric sphincter

cholic in babies → doesn't open properly
given smooth muscle relaxers

mucosal lining of stomach is folded into **rugae** to allow for expansion with a meal

within the mucous lining of stomach are glandular tubes called **gastric pits**

→within gastric pits are numerous microscopic **gastric glands**:

→ secrete **mucous** for protection

→ secretes various **digestive enzymes**

→ secretes **HCl**

5. Small Intestine

longest part of alimentary canal:

→ 1" diameter x 10' long (living) or 20' long (cadaver)

Major functions of small intestine:

1. **most chemical digestion** of food (duodenum)

2. secretes **hormones** which direct secretion of digestive juices by stomach, gall bladder, pancreas

3. most **absorption** of digested foodstuffs (jejunum & ileum)

small intestine fills most of abdominal cavity

held in place by **mesenteries** (=serous membranes) subdivided into 3 functional regions:

duodenum

~10" long
uppermost
drains pyloric stomach
receives ducts from gall bladder and pancreas

jejunum

~4'
central portion

mostly in umbilical region
especially rich blood supply
most digestion and absorption occurs here
absorbs most nutrients, water & salts

ileum

~5'
mainly in hypogastric region
joins to caecum of large intestine
absorbs and reclaims bile salts and some additional nutrients

mucosal lining of the small intestine is folded into **plicae**

the intestinal mucosa also contains small finger-like projections = **villi**

~1mm tall

each villus contains absorptive epithelial cells and goblet cells

core of villus is filled with areolar tissue of lamina propria

within this is an arteriole, capillary bed, venule and lymphatic capillary = **lacteal**

6. <u>Large Intestine</u>

2.5″ diameter x 6′ long

valve-like sphincter separates small from large intestine = **ileocecal valve**

Major functions of large intestine:

1. **absorb additional water** as needed by body
2. **absorb** small amount of **additional nutrients**

   some Vit K and B's made by bacteria in lg intestine

3. collects, concentrates and **rids body of undigested wastes**

subdivided into 3 regions:

cecum

blind ended sac that extends from point of attachment to small intestine

contains appendix → ~3.5" (9cm) long
significant source of lymphocytes

colon

subdivided into:

ascending colon
transverse colon
descending colon
sigmoid colon

rectum

last 7-8"

ends at **anus**

held shut by two **anal sphincters**:

internal anal sphincter of smooth muscle
external anal sphincter of skeletal muscle

Accessory Organs of Digestive Tract

A. Liver

is the largest gland in body

lies immediately under the diaphragm

consist of 2 **lobes** separated by **falciform ligament**

receives blood from the **Hepatic Artery** and the **Hepatic Portal Vein**

B. <u>Gall Bladder</u>

lies on undersurface of liver
3-4" long and 1.5" wide

liver produces 0.6 – 1.2L of bile/day

bile travels up **Cystic Duct** to **gall bladder** for storage

can hold 30-50 ml of bile

gall bladder stores and concentrates bile

When needed bile travels down **Cystic Duct** to **Common bile Duct** to the **duodenum**

C. Pancreas

most digestion is carried out by pancreatic enzymes

6-9 " long

composed of 2 kinds of glandular tissue:

endocrine → secretes hormones

islets = 2% of total mass of pancreas

their secretions pass into circulatory system
secrete **insulin** and **glucagon**

exocrine → digestive function

pancreatic digestive secretions average ~2L/day

→ mainly on demand, in short timespans

pancreatic secretions are collected in **pancreatic duct** and usually a smaller accessory pancreatic duct that both drain into the duodenum

Anatomy of the Digestive System

organs of digestive system form essentially: a long continuous tube open at both ends → **alimentary canal** (gastrointestinal tract)

mouth → pharynx → esophagus → stomach → small intestine → large intestine

attached to this tube are assorted **accessory organs** and structures that aid in the digestive processes

salivary glands

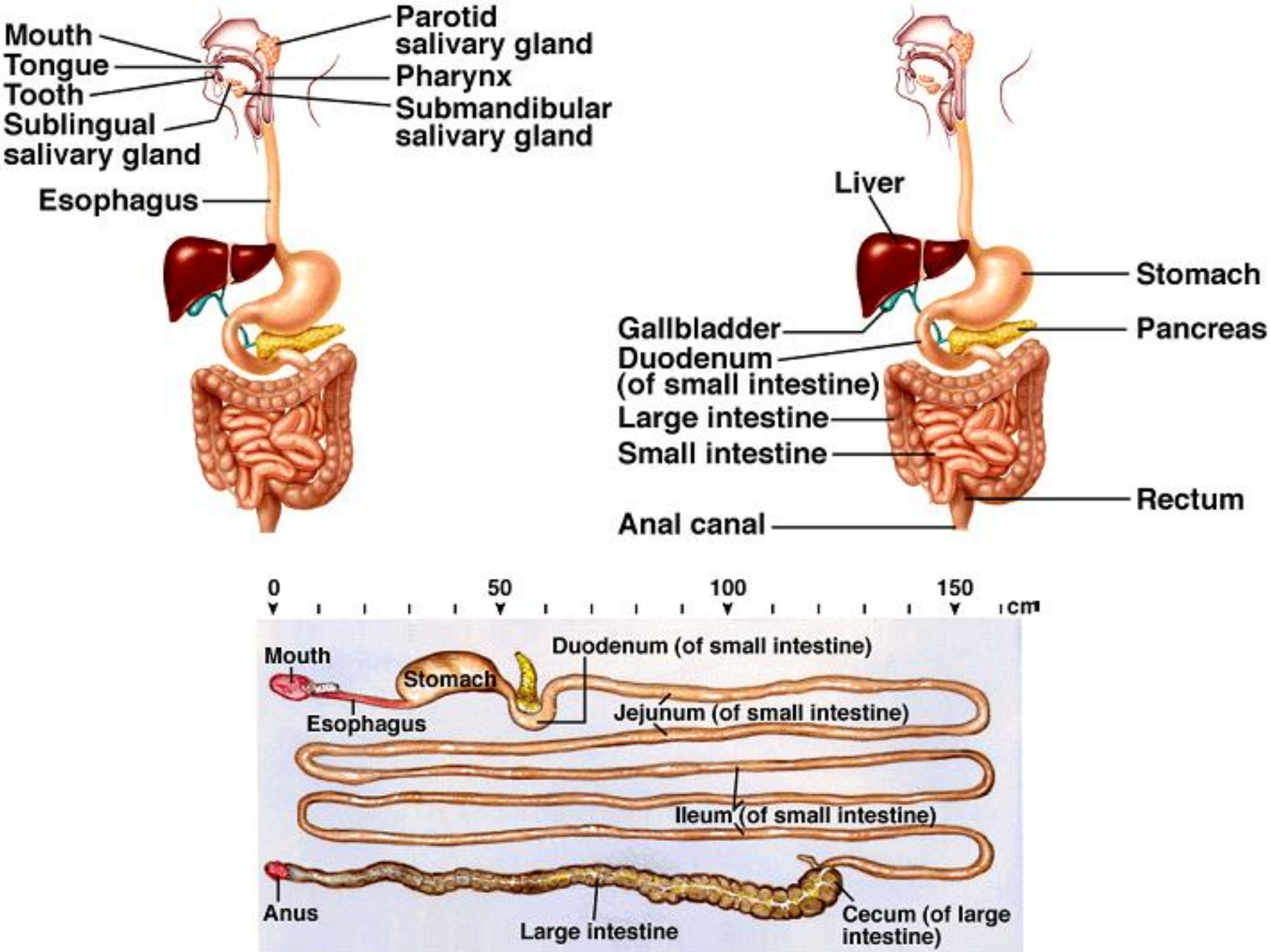
teeth

liver

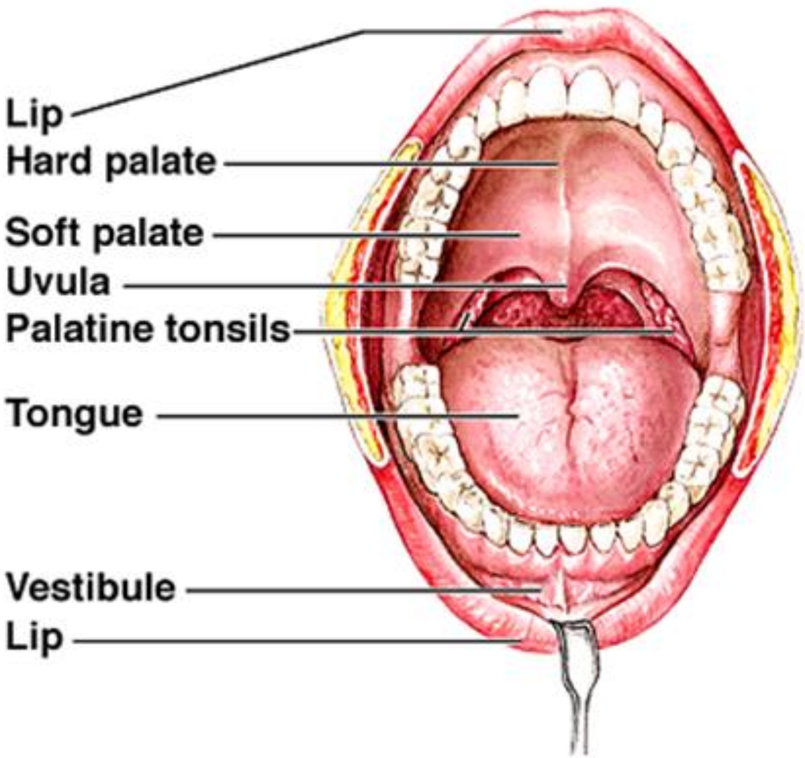
gall bladder

pancreas

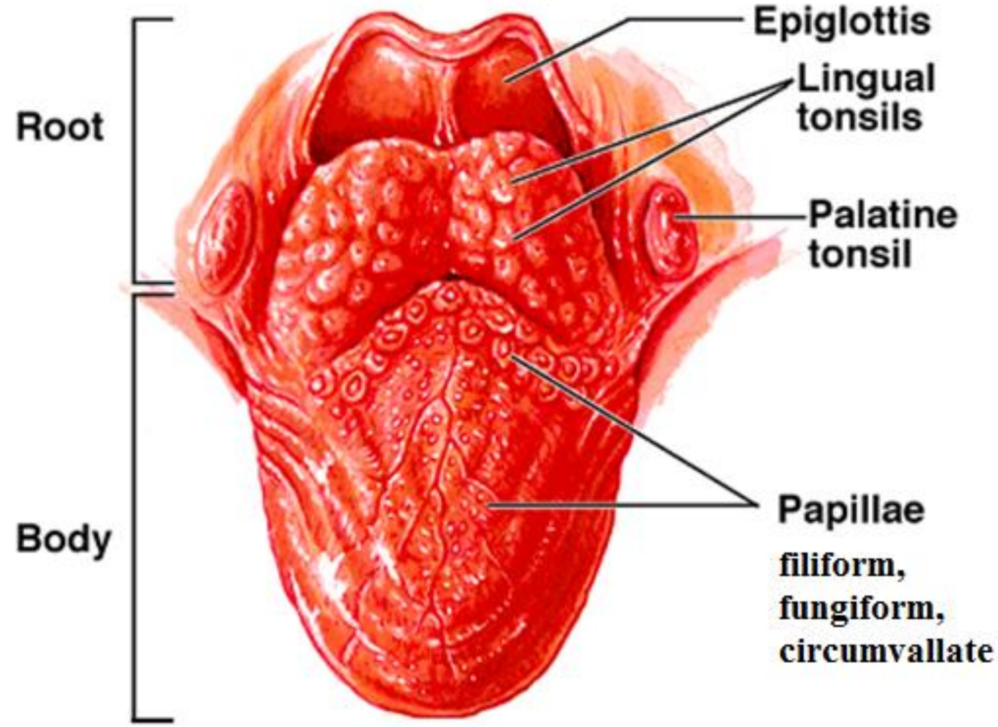
mesenteries


Mouth
Tongue
Tooth
Sublingual salivary gland
Esophagus
Parotid salivary gland
Pharynx
Submandibular salivary gland
Liver
Stomach
Gallbladder
Pancreas
Duodenum (of small intestine)
Large intestine
Small intestine
Rectum
Anal canal
0
50
100
150
cm
Mouth
Stomach
Duodenum (of small intestine)
Esophagus
Jejunum (of small intestine)
Ileum (of small intestine)
Anus
Large intestine
Cecum (of large intestine)

Mouth



Tongue Surface



Dentition

Same type of teeth → homodont (non-mammalian vertebrates)

Different type of teeth (i, c, p, m) → **heterodont**

Only one set of teeth throughout life → Monophyodont

Two successions of teeth (deciduous and permanent) → **Diphyodont**

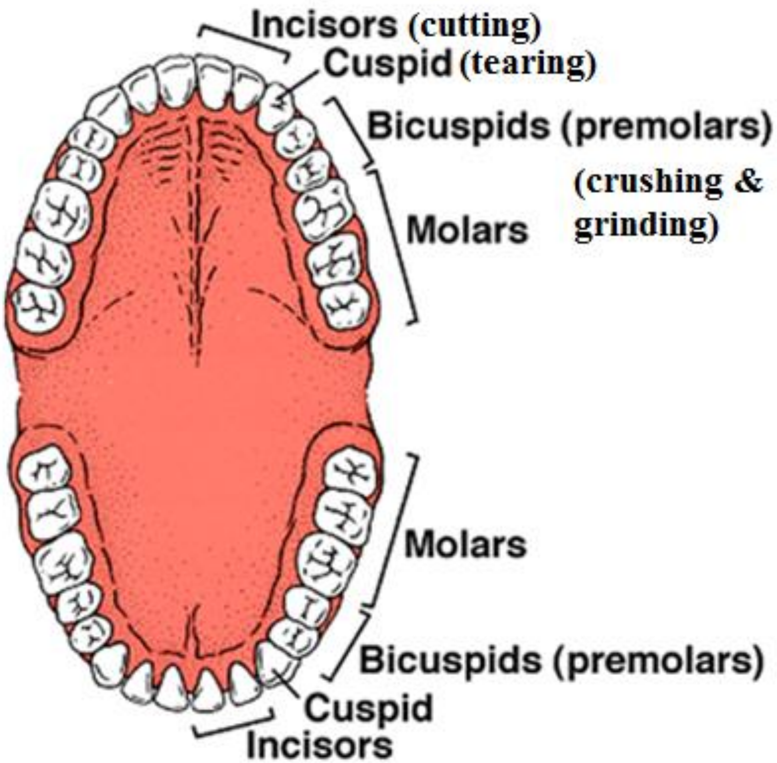
Continuous discarded and replaced by new throughout life → Polyphyodont

Top surface of the jaw bones (fish & amphibians) → Acrodont

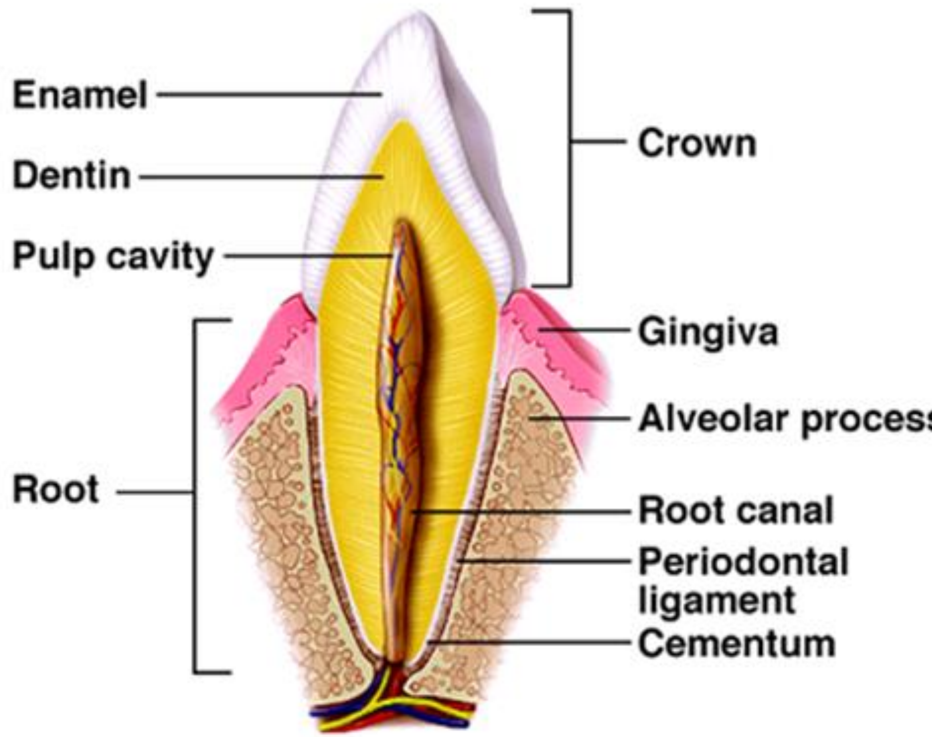
Inner side and upper side of the jaw bones (lizards & urodeles) → Pleurodont

Tooth firmly fixed in a socket of the jaw bone (mammals) → **Thecodont**
(peg & socket attachment)

Secondary Teeth

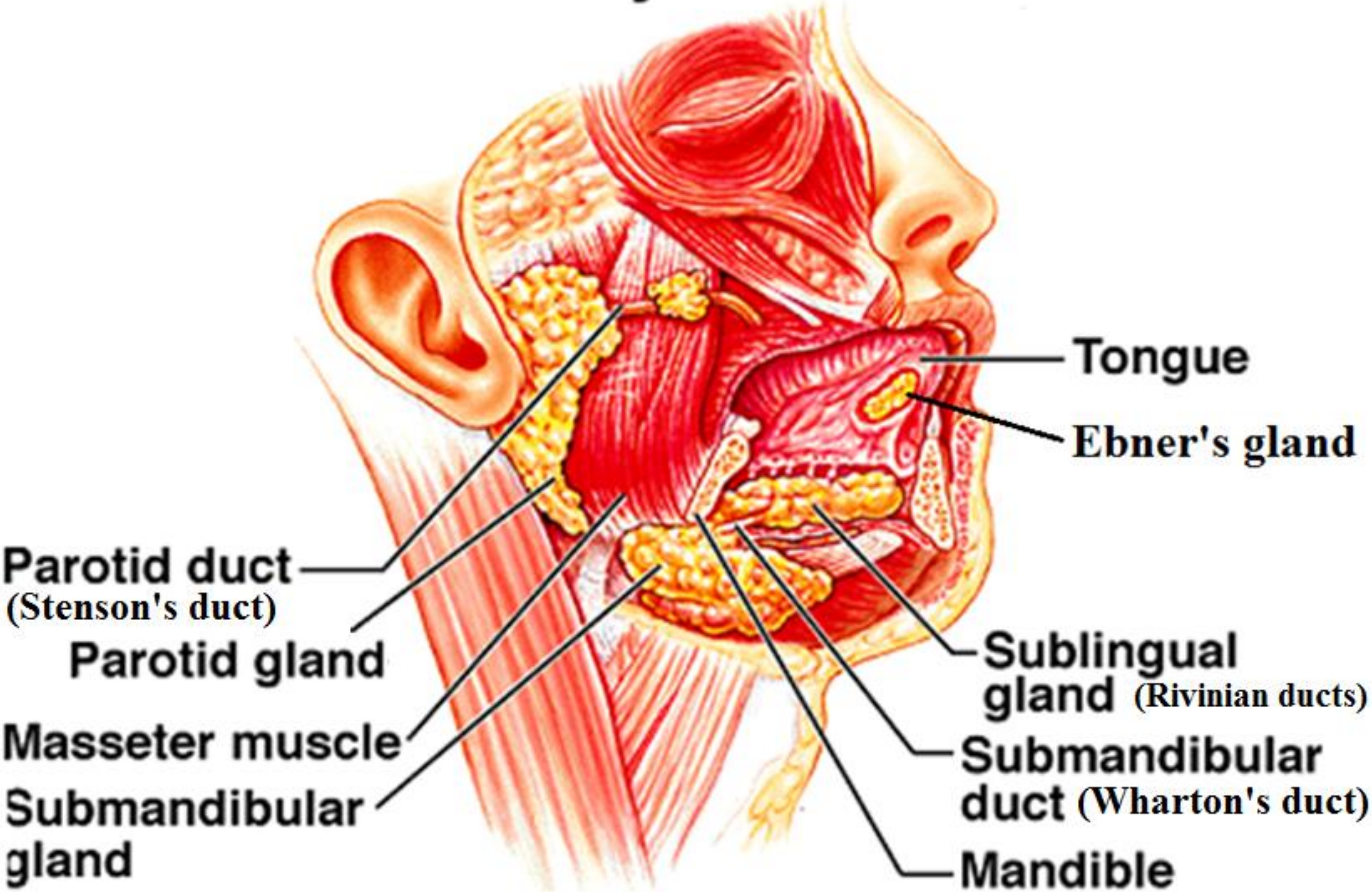


Cuspid Tooth

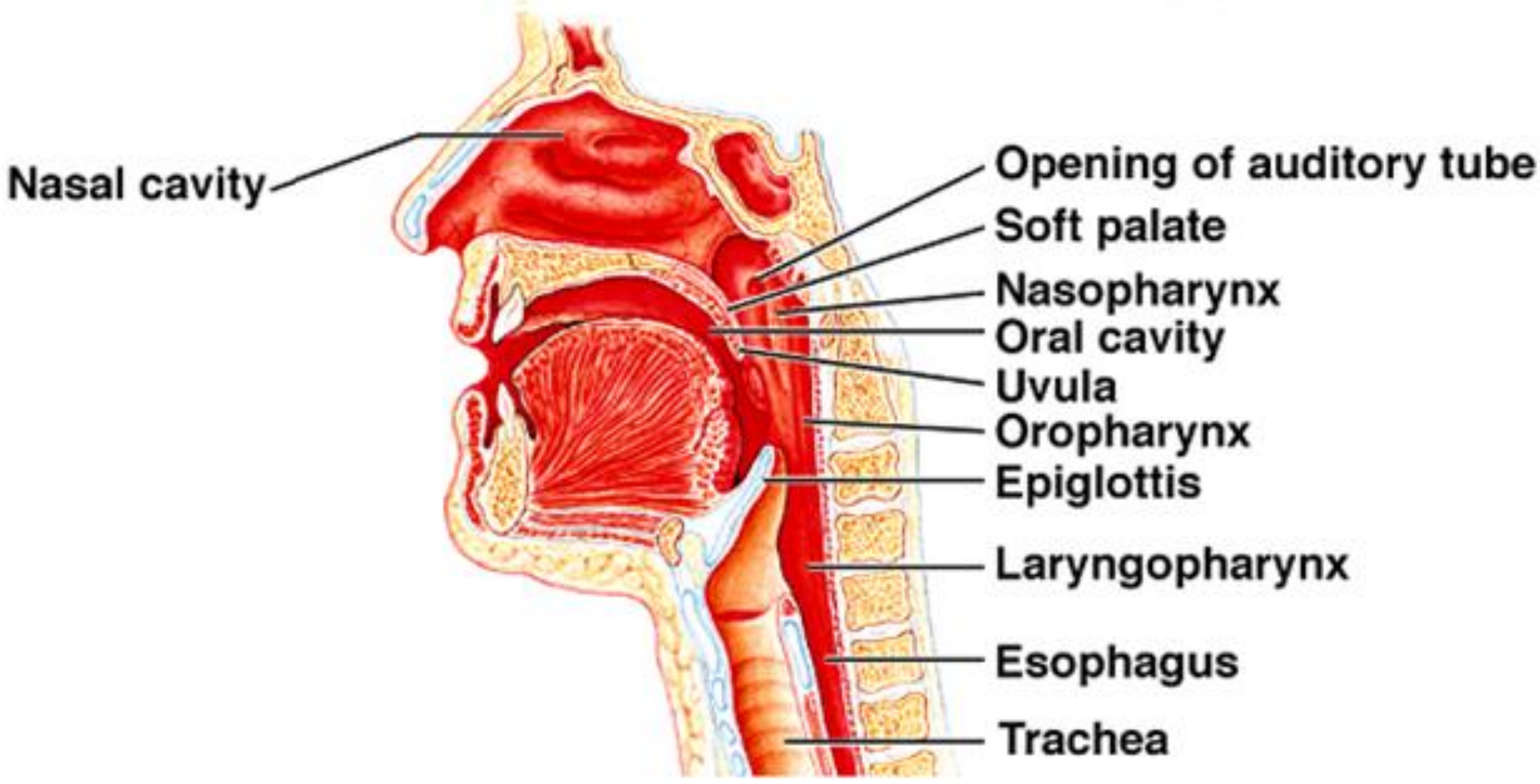


Dental formula
i 2/2, c 1/1, p 2/2, m 3/3 = 16x2 = 32

Salivary Glands

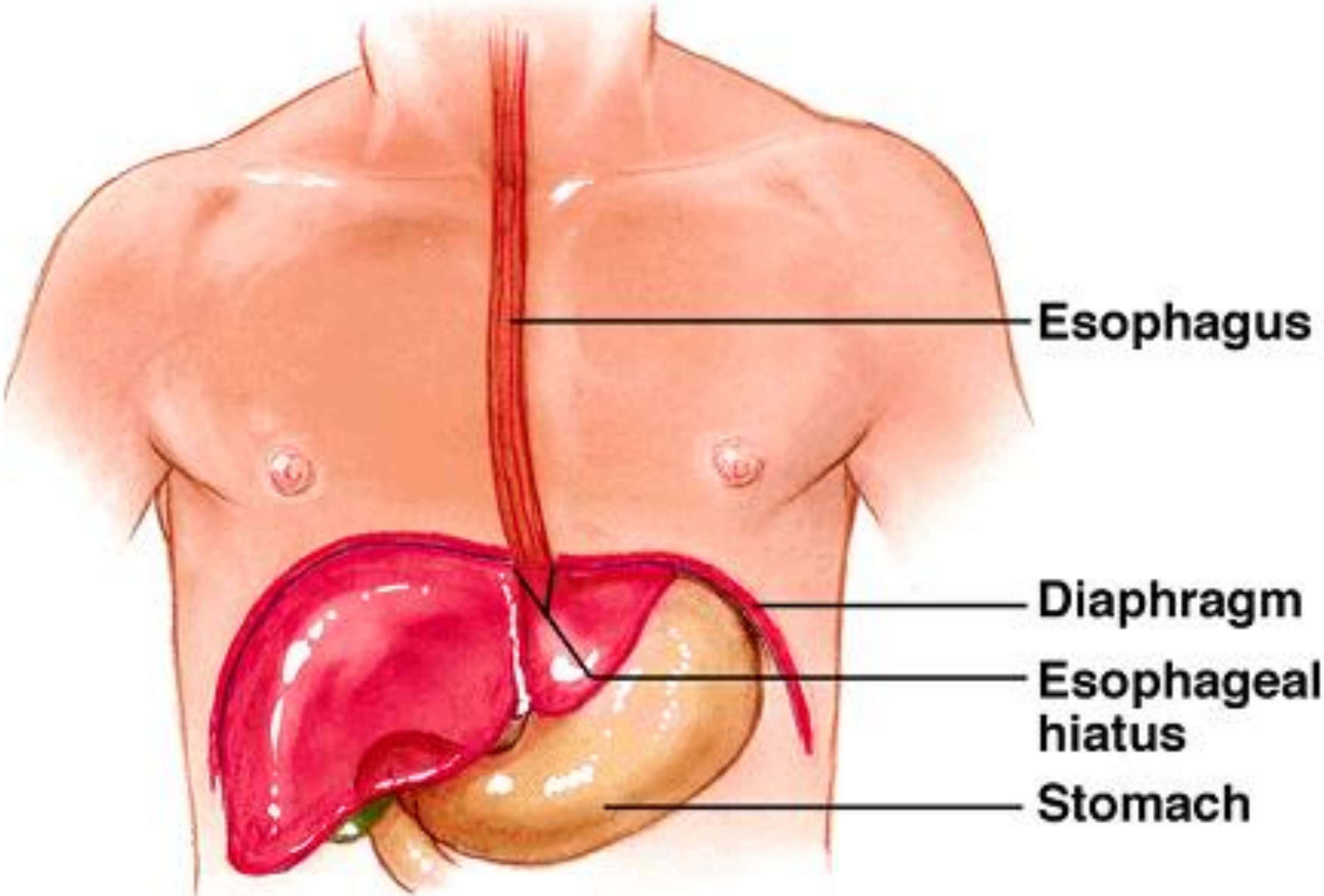


Pharynx

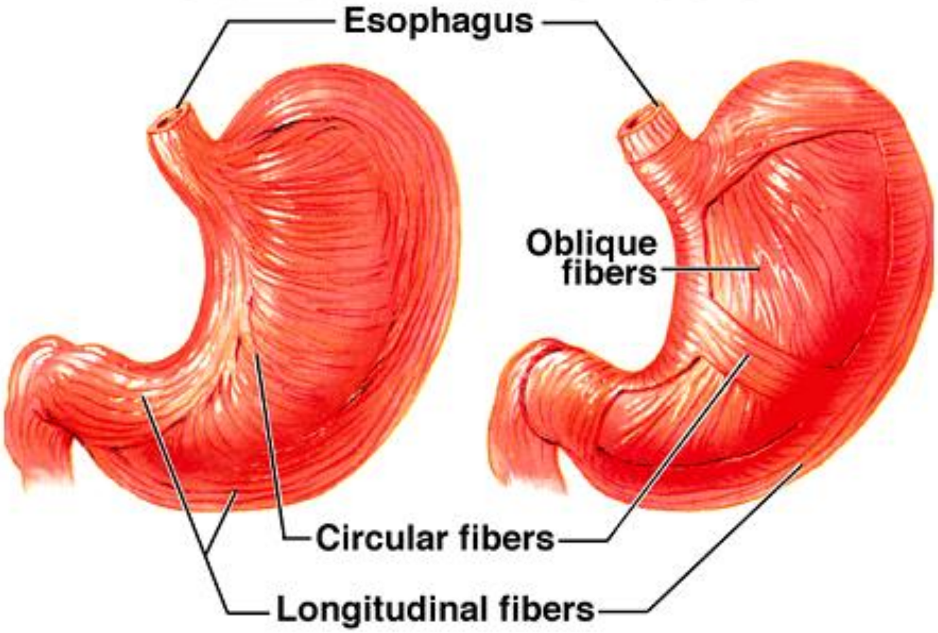


Nasal cavity
Opening of auditory tube
Soft palate
Nasopharynx
Oral cavity
Uvula
Oropharynx
Epiglottis
Laryngopharynx
Esophagus
Trachea

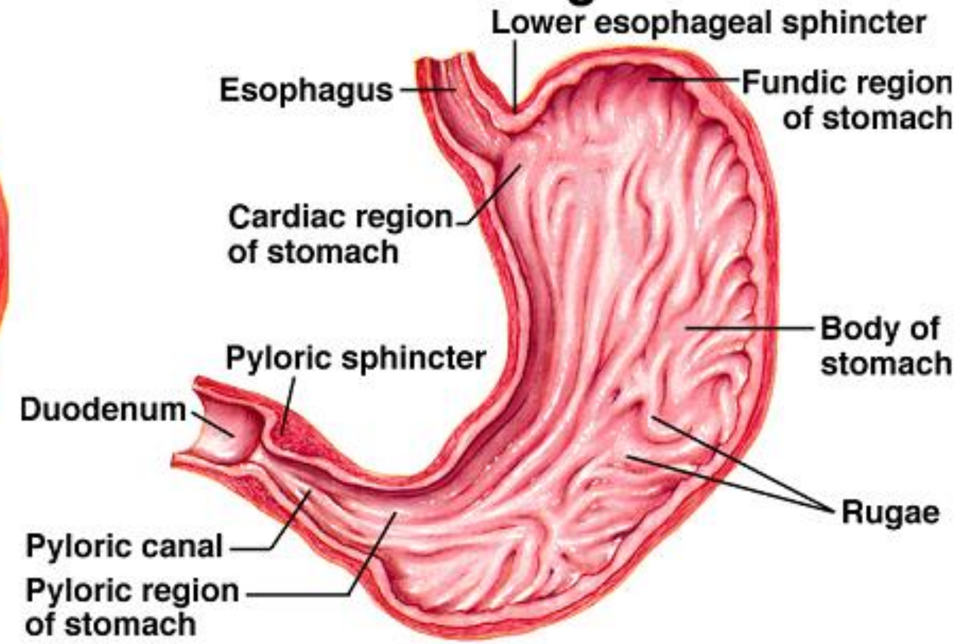
Esophagus



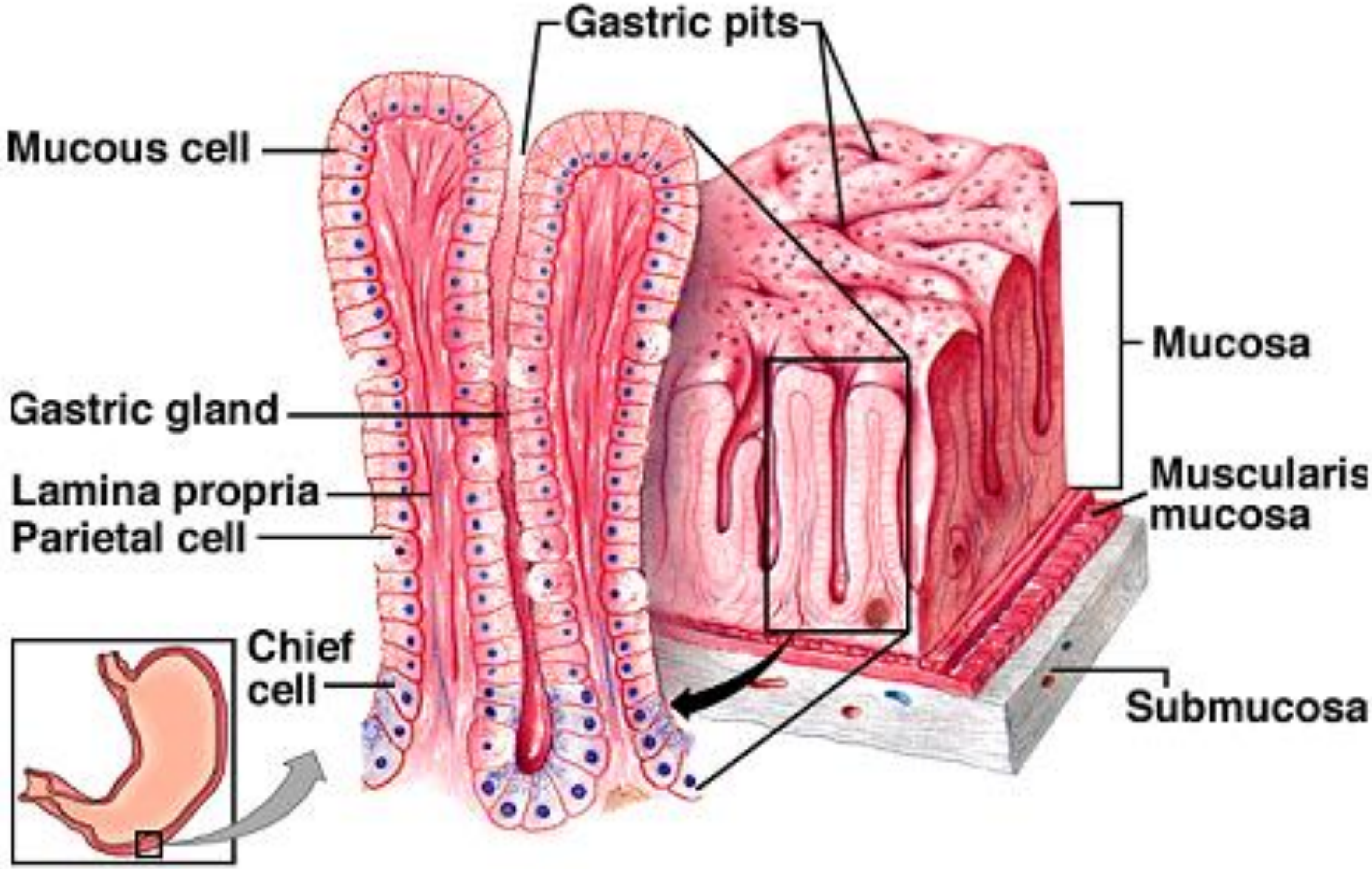
Stomach Muscle Fibers



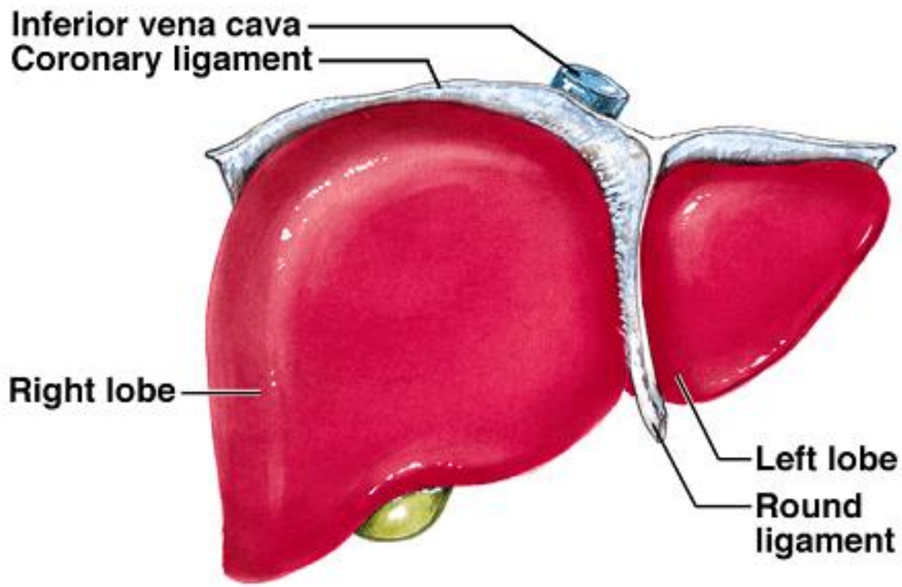
Stomach Regions



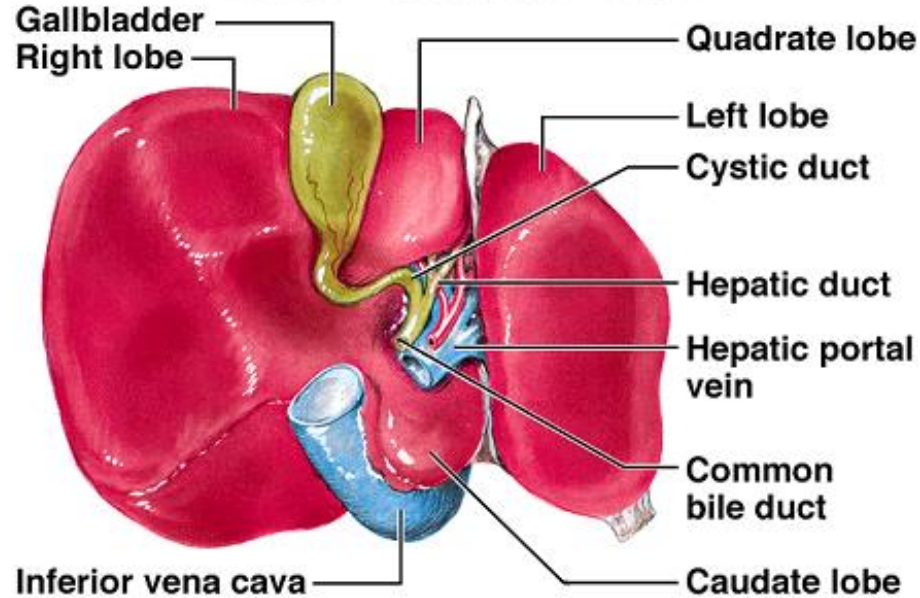
Gastric Gland and Mucosa



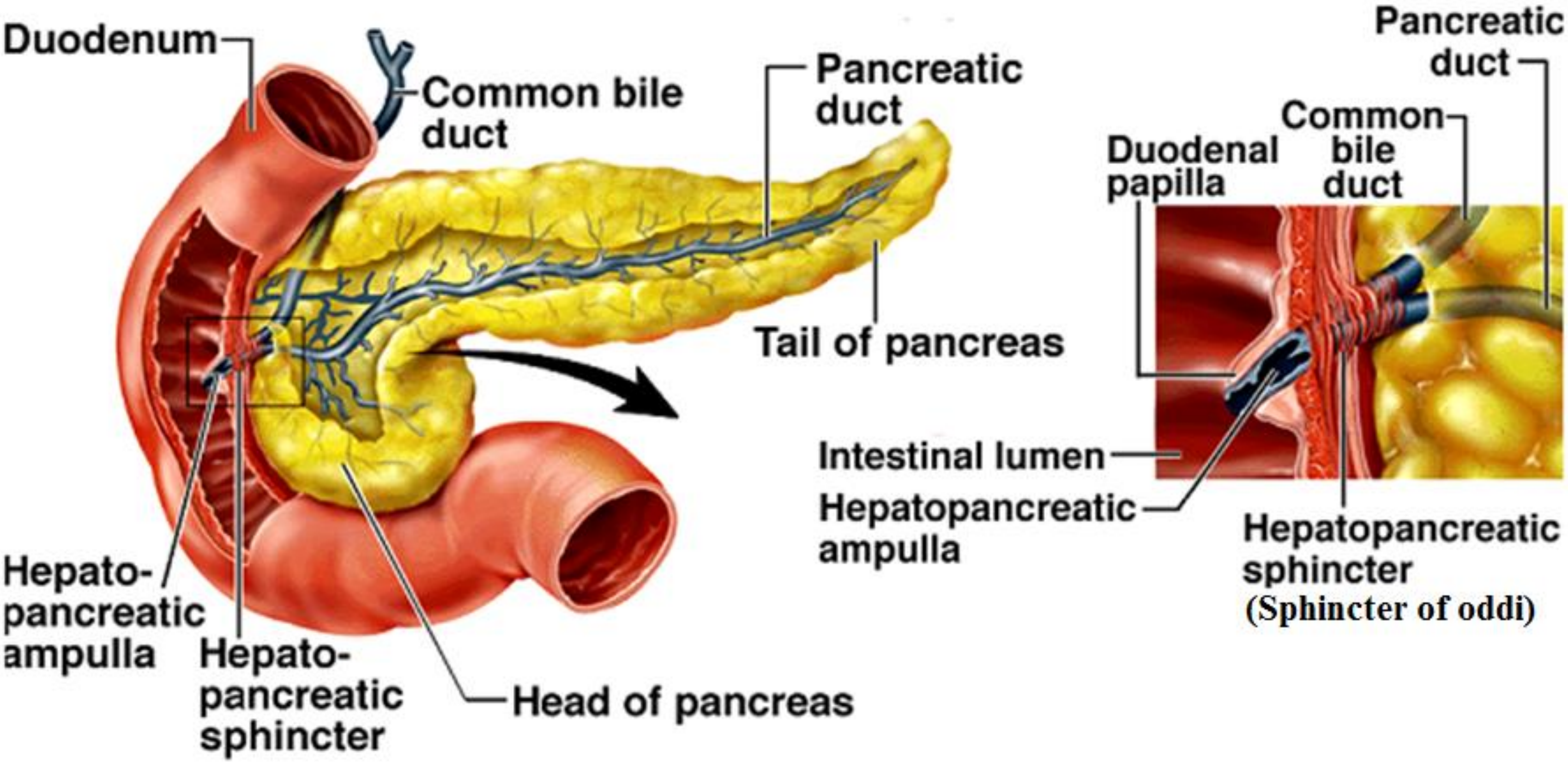
Liver—Anterior View



Liver—Inferior View



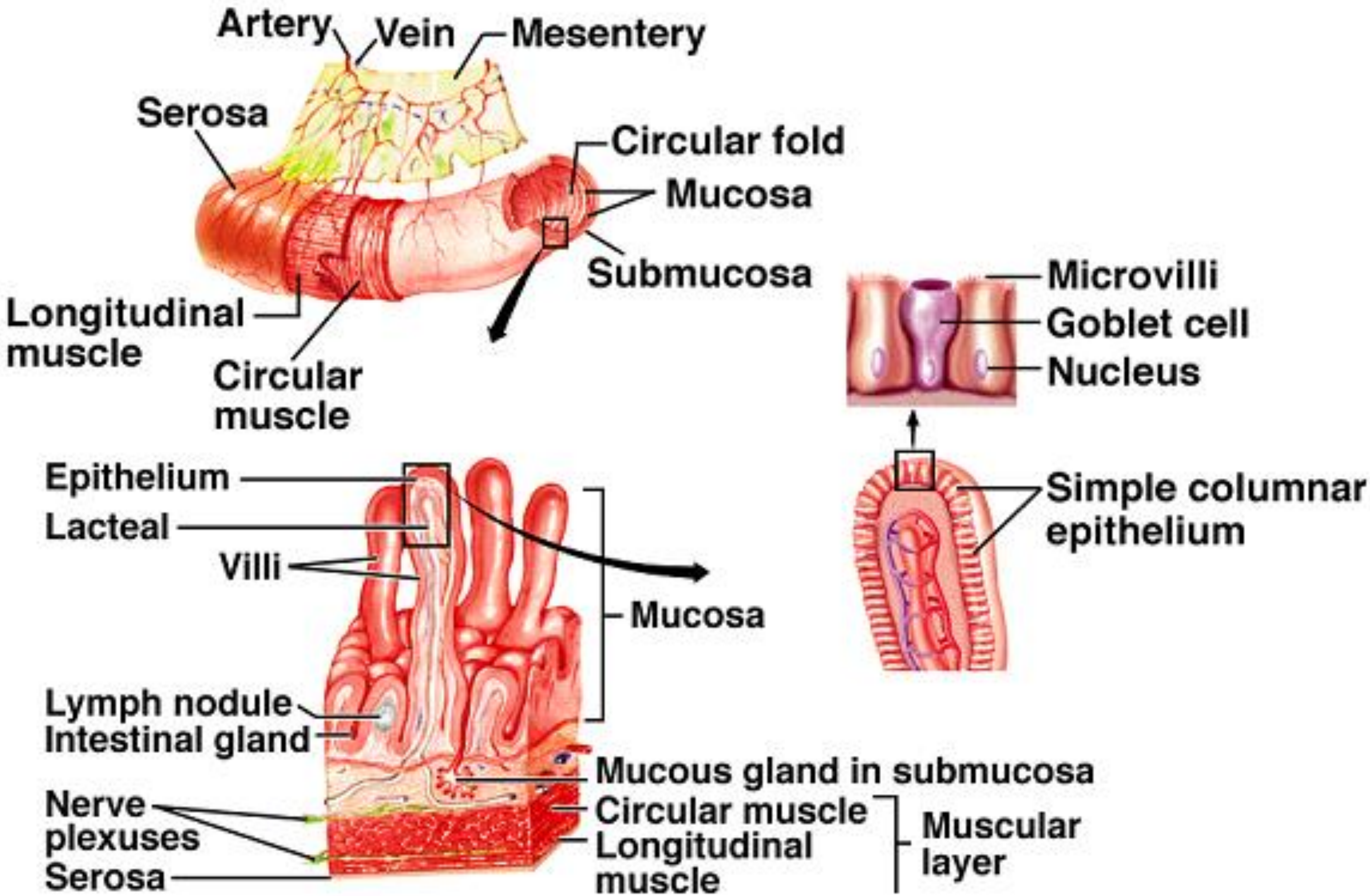
Pancreas and Duodenum



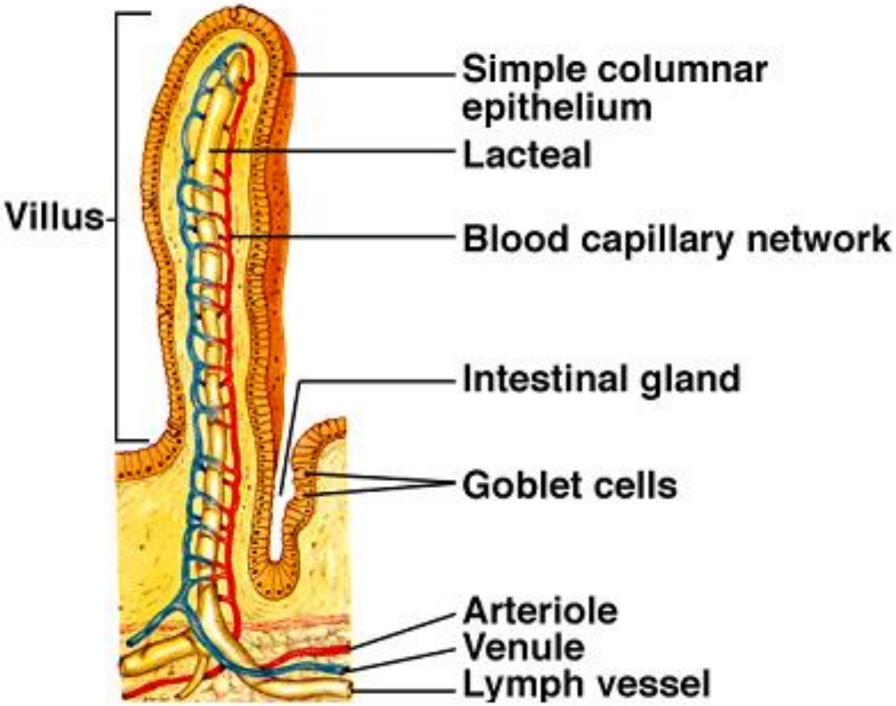
Structure of the Wall

4 layers in the wall of the alimentary canal:

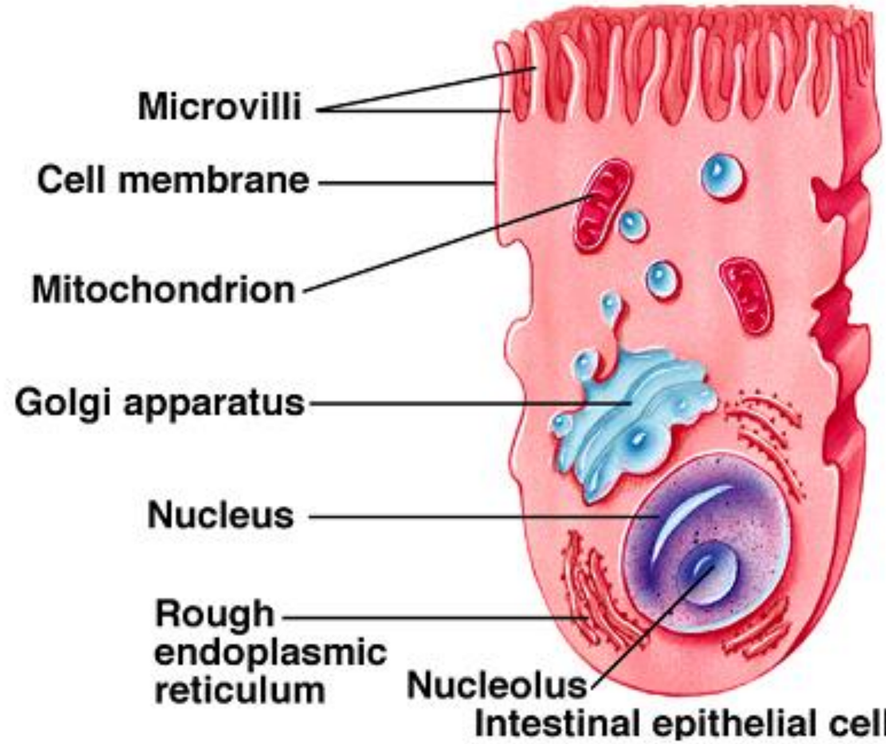
1) **mucosa** (inner layer)**-** epithelium, connective tissue, smooth muscle, has folds to increase surface area, glands for secretion of mucus & digestive enzymes, mucosa carries on secretion & absorption
2) **submucosa-** loose connective tissue, glands, blood & lymphatic vessels, nerves, submucosa nourishes tissues & carries absorbed materials away
3) **muscular layer-** 2 coats of smooth muscle = circular & longitudinal fibers that provide movements for the tube
4) **serosa layer** (outer)- visceral peritoneum, serous cells protect underlying tissues & secrete serous fluid to reduce friction within the abdominal cavity


Artery
Vein
Mesentery
Serosa
Circular fold
Mucosa
Submucosa
Longitudinal muscle
Circular muscle
Microvilli
Goblet cell
Nucleus
Simple columnar epithelium
Epithelium
Lacteal
Villi
Mucosa
Lymph nodule
Intestinal gland
Mucous gland in submucosa
Nerve plexuses
Circular muscle
Longitudinal muscle
Muscular layer
Serosa

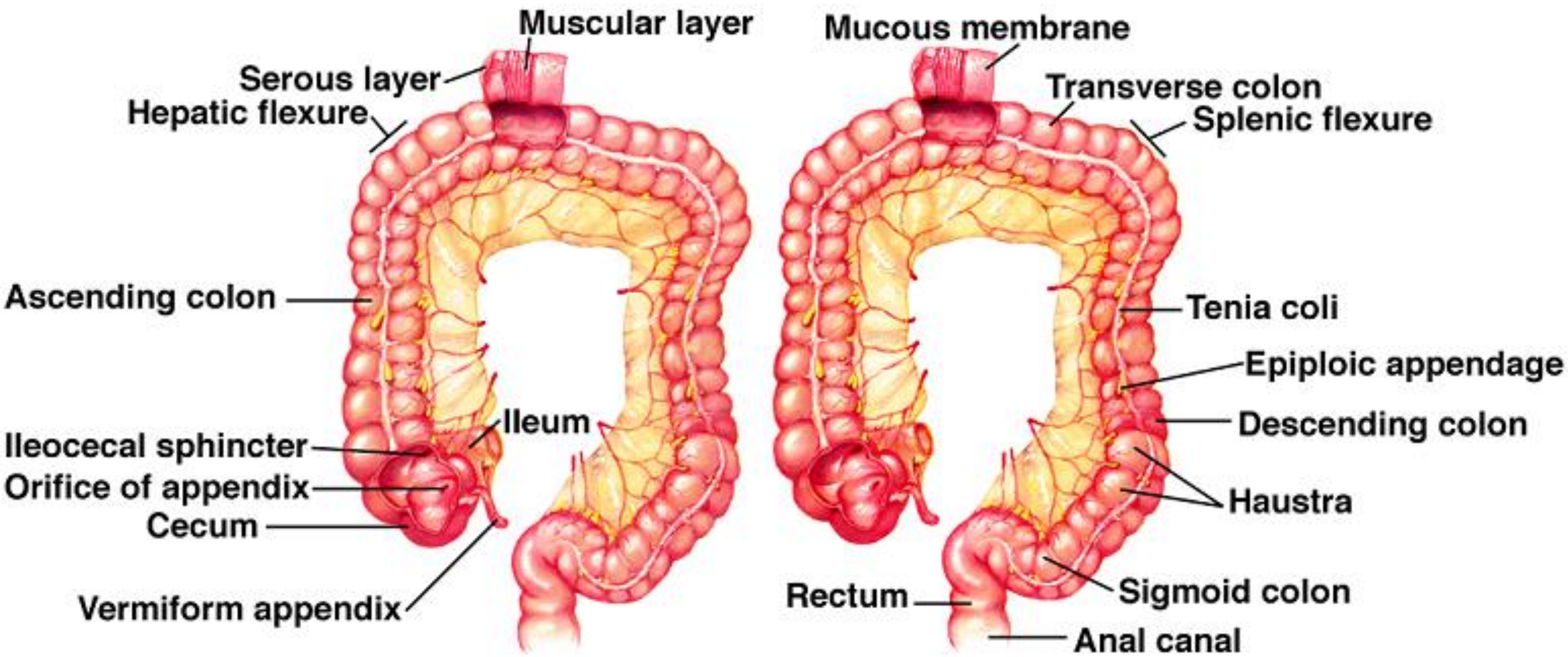
Intestinal Villus



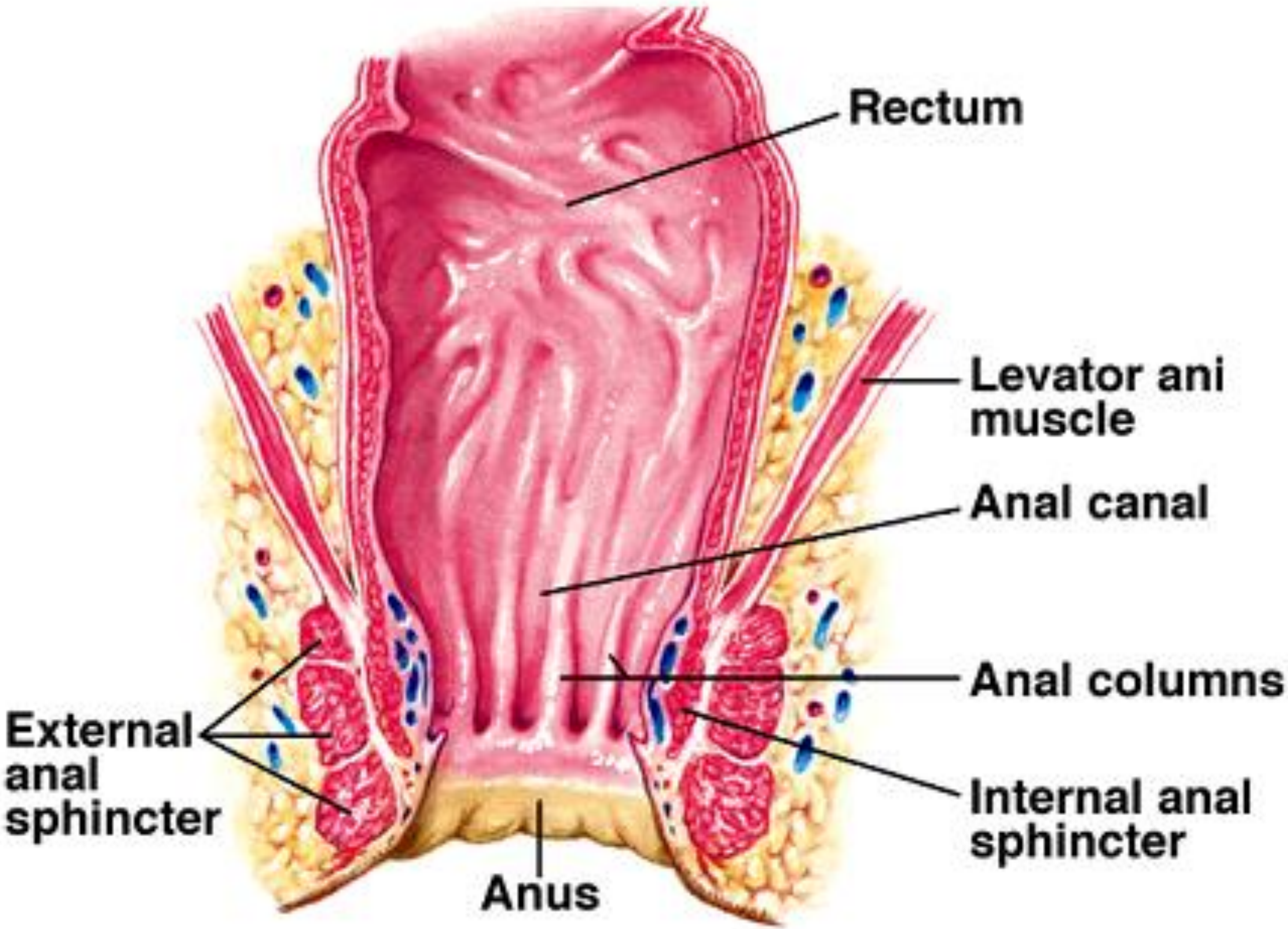
Microvilli



Large Intestine



Rectum and Anal Canal



Mechanical and Enzymatic digestion

1. Mechanical digestion

i. Mastigation:

The teeth are admirably designed for chewing.

- anterior teeth (incisors): strong cutting action,
  posterior teeth (molars): grinding action.
- important to broke indigestible cellulose membranes of the food

chewing aids the digestion

Digestive enzymes act only on the surfaces of food particles;

- the rate of digestion is dependent on the total surface area exposed to the digestive secretions.

grinding the food - prevents excoriation of the gastrointestinal tract and increases the ease of emptying – from stomach into the small intestine- then into all succeeding segments of the gut.

ii. Swallowing (deglutition):

complicated mechanism because the pharynx- serves respiration and swallowing both.

Tongue helps in mixing of saliva with the food - semisolid form (bolus) - then swallowed through Oesophagus to the stomach.

Peristalsis movement of alimentary canal also helps in swallowing.

iii. Churning in stomach:

The wall of stomach undergoes **periodic movement as well as contraction** producing churning movement called **peristalsis**, which results in breakdown of complex food into simpler form.

The bolus after mixing with gastric juice, turn into fine soluble form known as **chime**.

Chemical digestion………. Digestion of Carbohydrates

in the mouth

Starch & Glycogen + water —salivary amylase (ptyalin), pH 6.8 - 7.2→ dextrins → maltose

in the stomach

blocked by the acid medium → do not under go any change

in the intestine

Starch & Glycogen + water —pancreatic amylase (amylopsin), pH 6.8 - 7.2→ dextrins → maltose

Maltose —maltase, pH 7.1 - 8.2→ glucose + glucose

Lactose —lactase, pH 7.1 - 8.2→ glucose + galactose

Sucrose —sucrase, pH 7.1 - 8.2→ glucose + fructose

Note: cellulose cannot be digest since glucose monomers are held at β (1 - 4) glycosidic bonds

Digestion of Proteins

in the mouth

no protease in saliva $\longrightarrow$ do not under go any change

in the stomach

Pepsinogen (inactive) $\xrightarrow[\text{pH 1.5 - 2.0}]{\text{HCL}}$ pepsin [acid - pepsin mixture (APM) = endopeptidase]

Proteins $\xrightarrow[\text{pH 1.5 - 2.0}]{\text{pepsin}}$ proteoses, peptones & polypeptides

Prorennin (inactive) $\longrightarrow$ rennin (chymosin)

Casein $\xrightarrow{\text{rennin}}$ paracasein

Paracasein $\xrightarrow{Ca^{2+}}$ calcium paracaseinate

Calcium paracaseinate $\xrightarrow{\text{pepsin}}$ proteoses, peptones & polypeptides

> **Note:** liquified, acidic pulpy food content of the stomach is called **chyme**

in the intestine

Proteins
- Pancreatic proteases → Trypsin, Chymotrypsin] endopeptidase; Carboxypeptidase] exopeptidase
- Intestinal proteases (= peptidases) → Aminopeptidase, Tripeptidase, Dipeptidase

Trypsinogen (inactive)	enterokinase	trypsin (active)
Proteins	trypsin, pH 7.1 - 8.2	proteoses, peptones & polypeptides
Chymotrypsinogen (inactive)	trypsin	chymotrypsin (active)
Proteins	chymotrypsin, pH 7.1 - 8.2	Polypeptides
Proteins	carboxypeptidase, pH 7.1 - 8.2	tripeptides, dipeptides, amino acids
proteoses, peptones & polypeptides	aminopeptidase, pH 7.1 - 8.2	tripeptides, dipeptides, amino acids
Tripeptides	tripeptidase, pH 7.1 - 8.2	amino acids
Dipeptides	dipeptidase, pH 7.1 - 8.2	amino acids

Note: complete protein digestion → end product amino acids

Digestion of Fats

in the mouth

Lingual lipase in saliva (inactive)

in the stomach

Lingual lipase in saliva (inactive) $\xrightarrow{\text{HCL}}$ active and hydrolyzes triglycerides

in the intestine

i) emulcification of fats by bile salts

ii) Emulcified fats $\xrightarrow[\text{pH 7.1 - 8.2}]{\text{pancreatic lipase (steapsin)}}$ fatty acids + glycerol

iii) bile salts + fatty acids + glycerol $\longrightarrow$ micelles

Note: absorbed lipids in lacteal of a villus is called **chyle**

Absorption

- ➢ process by which the end products of digestion pass through the intestinal mucosa into the blood or lymph.

- ➢ carried out by **passive, active or facilitated transport** mechanisms.

- Water moves by osmosis

- small fat soluble substances are able to diffuse through cell membranes

  e.g. fatty acids and glycerol

- while others are generally transported inside the villi

Passive transport:

Small amounts of

monosaccharides like glucose,

amino acids and

some electrolytes like chloride ions

are generally absorbed by **simple diffusion**.

The passage of these substances into the blood depends upon the **concentration gradients**.

Active transport:

- occurs against the concentration gradient and hence requires energy.
- nutrients like amino acids,

  monosaccharides like glucose,

  electrolytes like Na+

  are absorbed into the blood by this mechanism.

- Some substances like

  glucose and amino acids

  are absorbed with the help of **carrier proteins** (**facilitated transport**).

- Fatty acids and glycerol being insoluble, **cannot be absorbed** into the blood.

  They are first incorporated into small droplets (**micelles**) → move into the intestinal mucosa → reformed into very small protein coated fat globules (**chylomicrons**) → transported into the **lymph vessels** (**lacteals**) in the villi → into the blood stream → finally reach the tissues (utilise for their activities)

  This process is called **assimilation**.

Defaecation

- The digestive wastes, solidified into faeces in the **rectum**

➢ initiate a neural reflex causing an urge or desire for its removal

- The egestion of faeces to the outside through the anal opening (defaecation) is a voluntary process and is carried out by a mass peristaltic movement.

Digestive hormones

- at least five hormones that aid and regulate the digestive system

Gastrin - is in the stomach

- Secretion of gastrin is stimulated by food arriving in stomach.
- Stimulates the gastric glands to secrete **pepsinogen** (an inactive form) and **hydrochloric acid**.
- The secretion is inhibited by low pH.

Secretin - is in the duodenum

- signals the secretion of **sodium bicarbonate** in the pancreas and it **stimulates** the **bile secretion** in the liver.
- This hormone responds to the acidity of the chyme.

Cholecystokinin (CCK) - is in the duodenum

- secreted in response to **fat** in chyme
- stimulates to release digestive enzymes in **pancreas**
- stimulates to emptying of bile in the **gall bladder**.

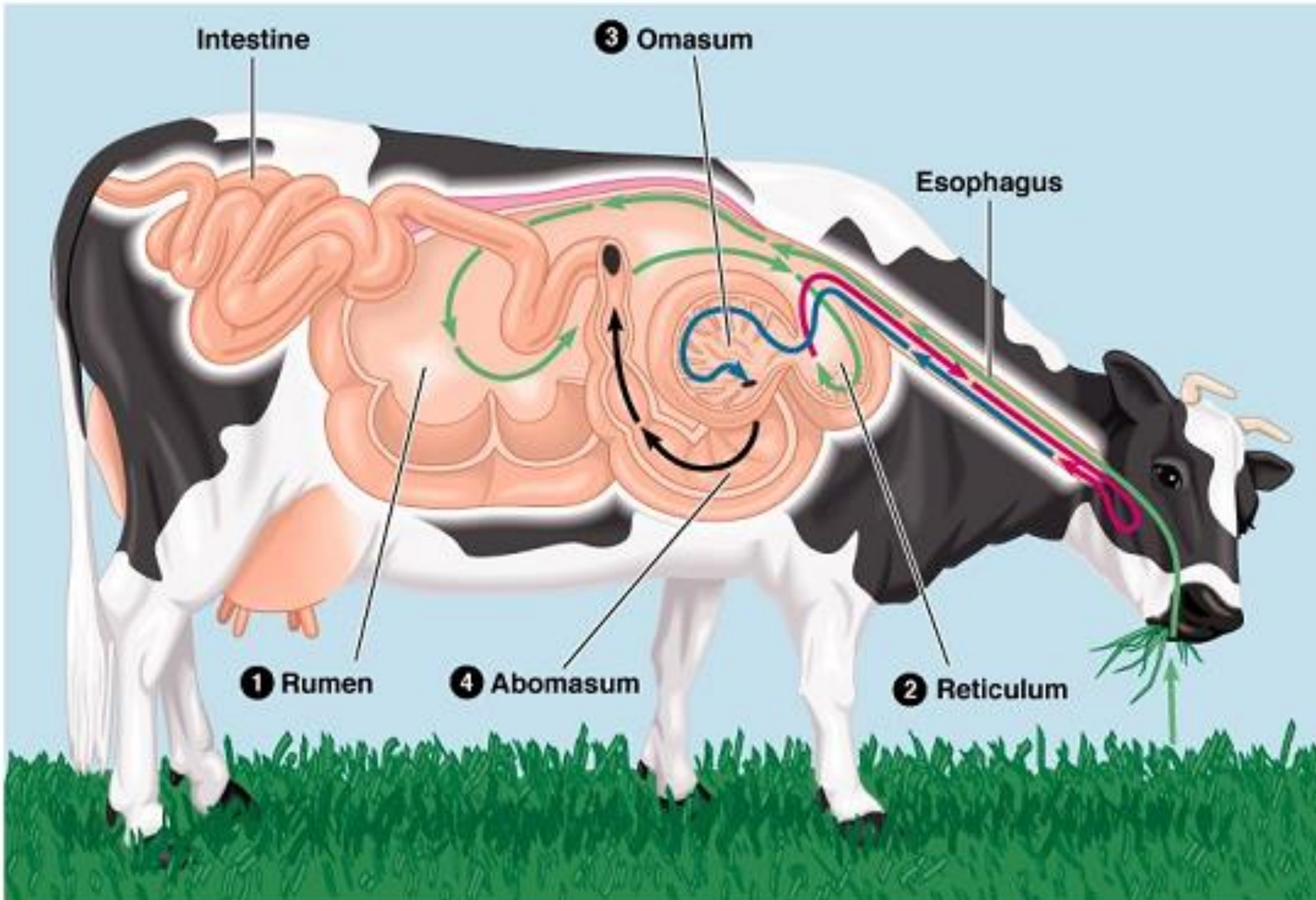
Gastric inhibitory peptide (GIP) - is in the duodenum

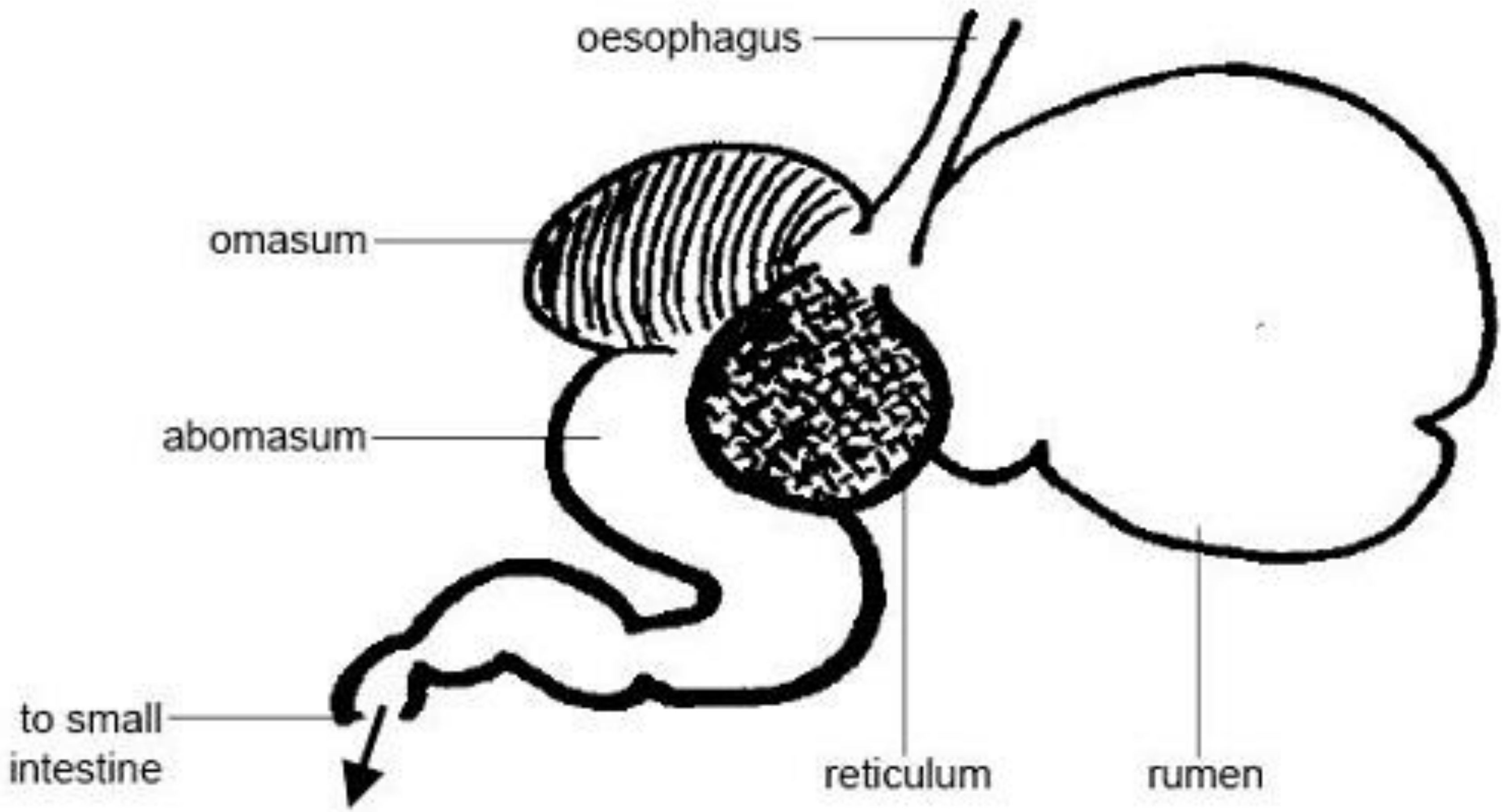
- decreases the stomach churning **in turn** slowing the emptying in the stomach
- to induce insulin secretion

Motilin - is in the duodenum

- increases the migrating myoelectric complex component of gastrointestinal motility
- stimulates the production of pepsin

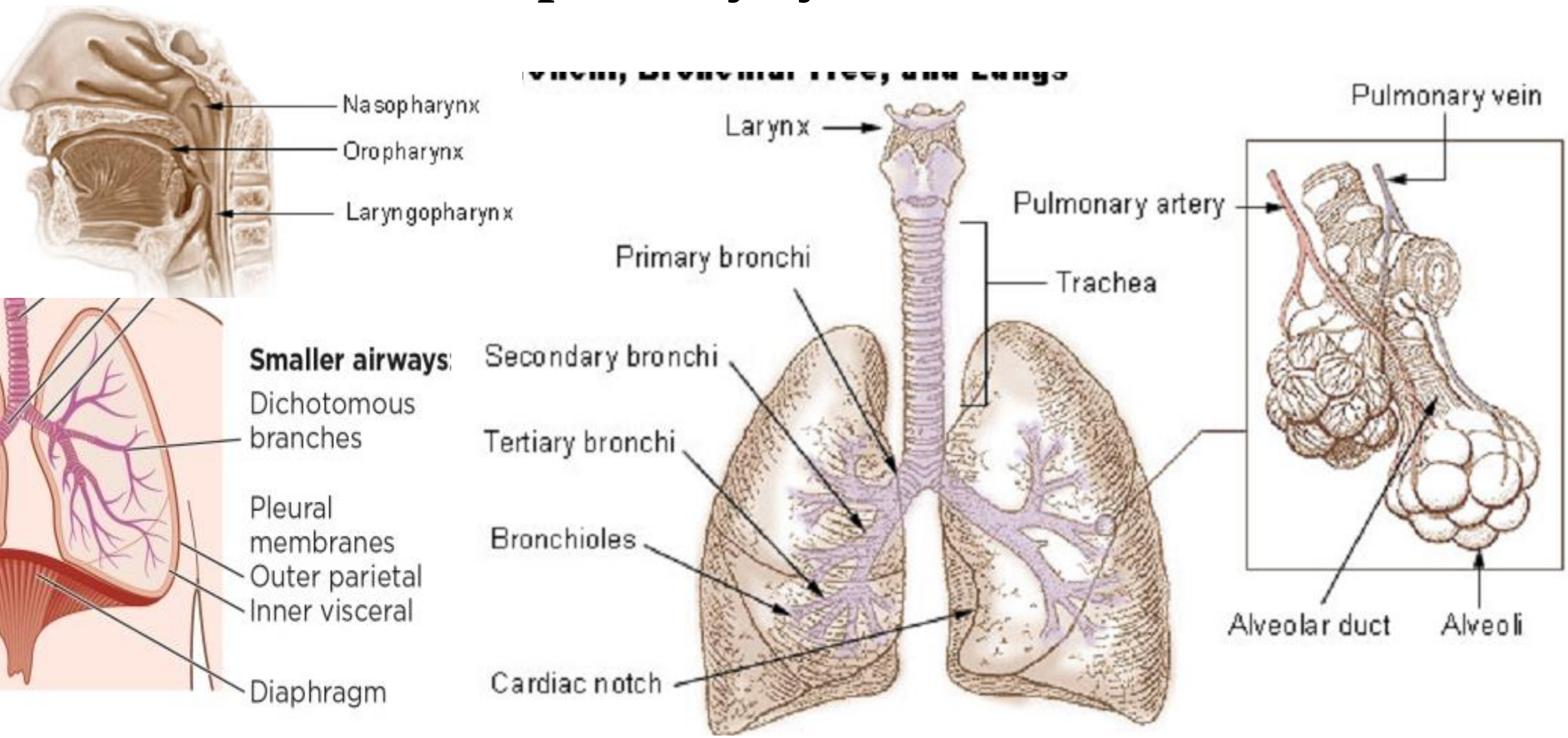
Ruminant digestion




oesophagus
omasum
abomasum
to small intestine
reticulum
rumen

1.4 Respiration

Respiratory system in man



The respiratory tract is divided into two sections:

- Upper Respiratory Tract - Nostrils, Nasal Cavities, Pharynx, Epiglottis and the Larynx.
- Lower respiratory tract - Trachea, Bronchi, Bronchioles and Lungs.

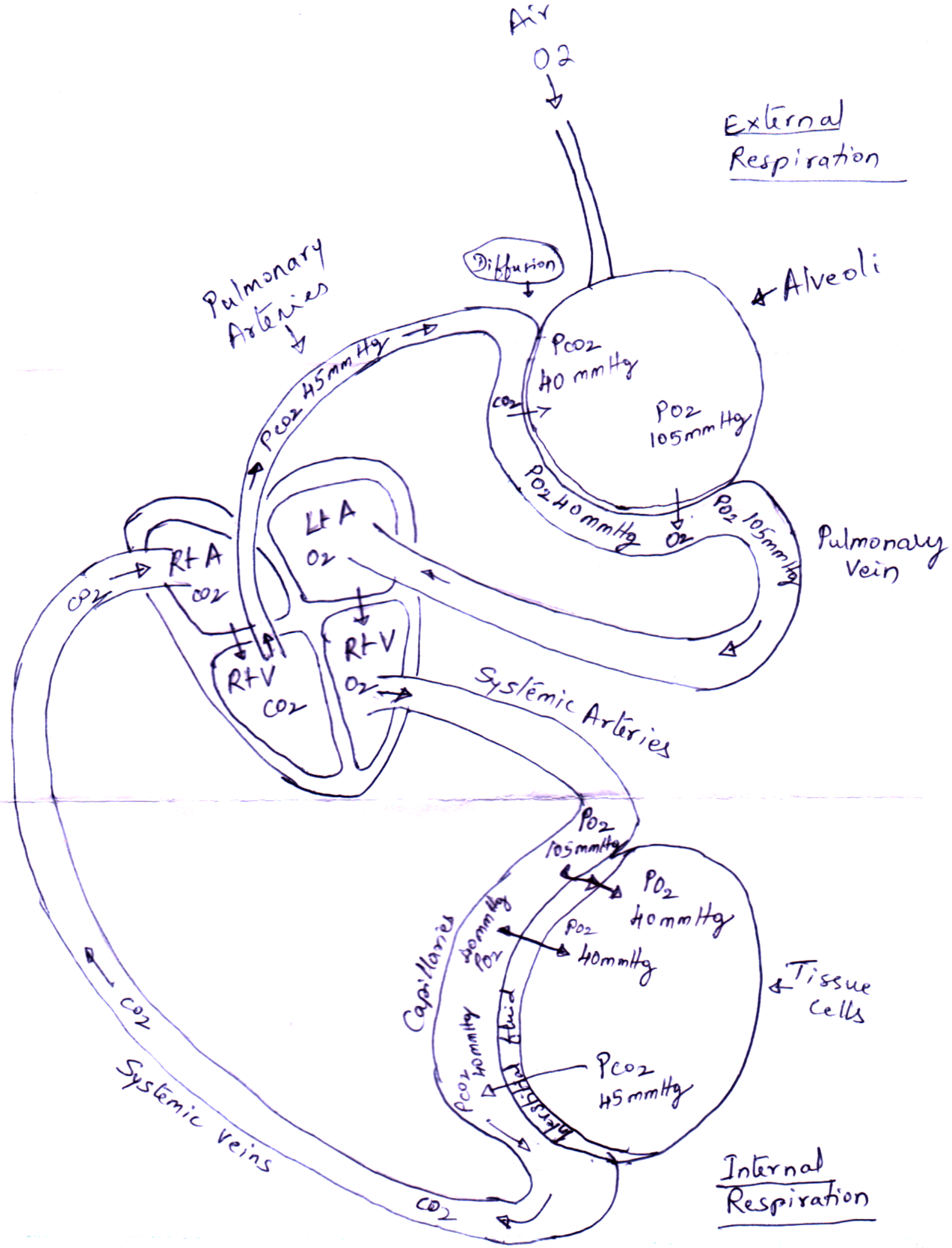
Mechanism of Respiration

- EXTERNAL RESPIRATION

  the exchange of gases (oxygen and carbon dioxide) between **inhaled air and the blood**

- INTERNAL RESPIRATION

  the exchange of gases between the **blood and tissue fluids**



Air
O2
External Respiration
Diffusion
Alveoli
Pulmonary Arteries
Pco2 45mmHg
Pco2 40 mmHg
CO2
PO2 105mmHg
PO2 40mmHg
O2
PO2 105mmHg
Pulmonary Vein
Rt A
CO2
Lt A
O2
Rt V
CO2
Rt V
O2
Systemic Arteries
Po2 105mmHg
Po2 40mmHg
Po2 40mmHg
Capillaries
Tissue Cells
Pco2 45mmHg
Pco2 40mmHg
CO2
Systemic Veins
CO2
Internal Respiration

Respiratory pigments

Haemoglobin

2 parts

- Haeme group (5%) with Metallic iron (color)
- Globin group (95%) (colorless) (17 K – 30 Lakh Da) Mol. wt.

Synthesis - in Mitochondria of liver cells

Precurssor → acetic acid & glycine

Acetic acid ⟶ Succinyl CoA.

Succinyl coA + 2 Glycine ⟶ Pyrrole

4 Pyrrole ⟶ Protoporphyrine (Intermediate product)

Protoporphyrine + Fe^{2+} ⟶ HAEM (iron-porphyrine ring)

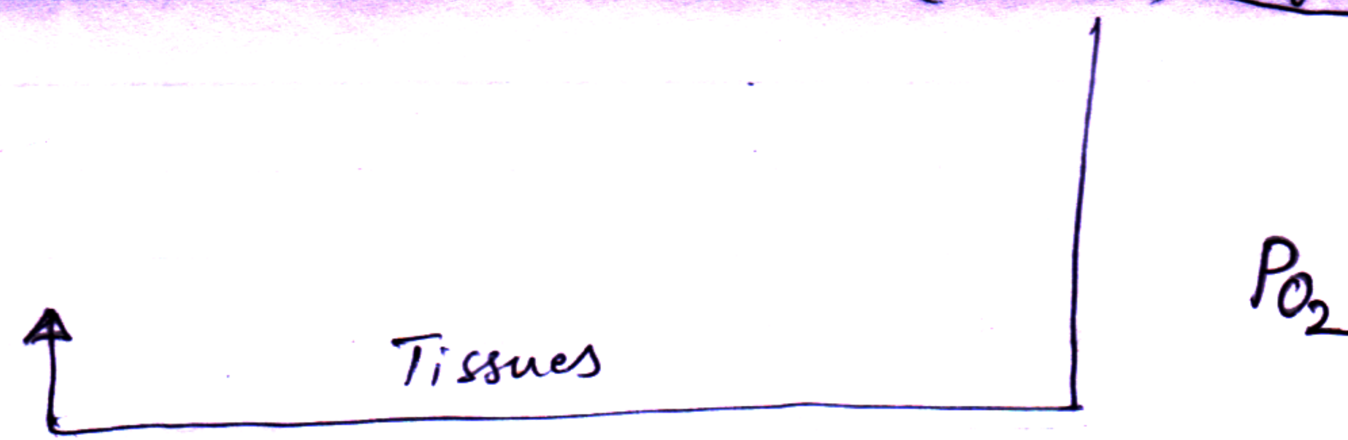
Haem + Globin ⟶ Haemoglobin

Properties.

$$Hb + 4O_2 \xrightarrow[\text{Oxygenation}]{P_{O_2}\ (P_{CO_2},\ P_{O_2},\ pH)} HbO_8$$

Hb (Dark red)

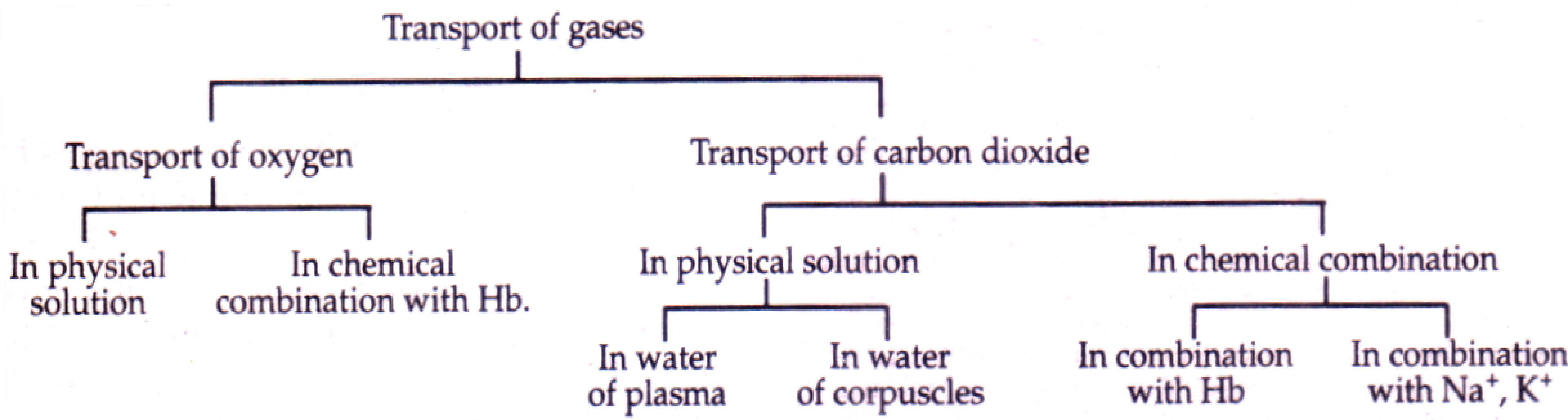
HbO_8 Oxyhaemoglobin (Alveoli) (bright red)



Haemoerythrin

Haemocyanin

TRANSPORT OF GASES



1. Transport of Oxygen.

in two ways-

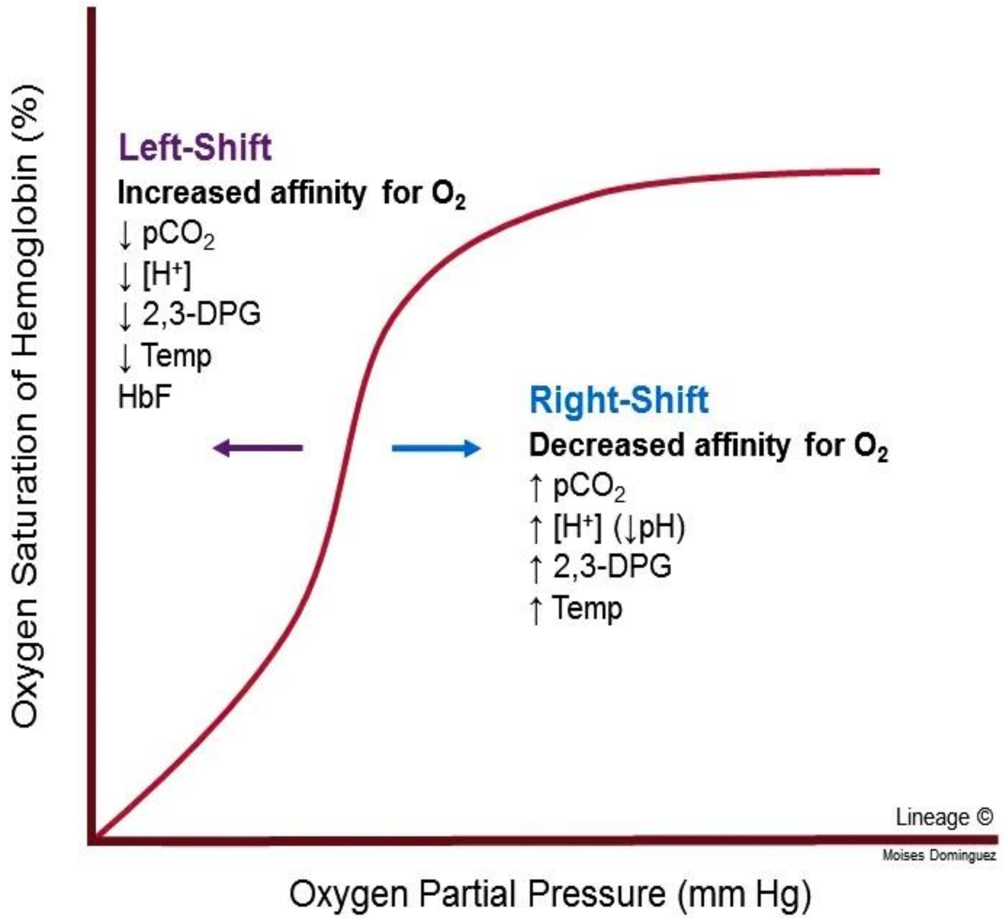
(i) In physical solution, dissolved in the plasma, which is only about 3%.

(ii) In chemical combination with haemoglobin. About 97% of O_2 is carried in this way.

$$\underset{\text{haemoglobin}}{Hb} + \underset{\text{oxygen}}{4O_2} \rightleftharpoons \underset{\text{oxyhaemoglobin}}{HbO_8}$$

Depends on factors:

Haemoglobin and Po_2: **oxygen-dissociation curve**



Oxygen-dissociation curve is affected by

Haemoglobin and temperature:

Temperature ↑ =

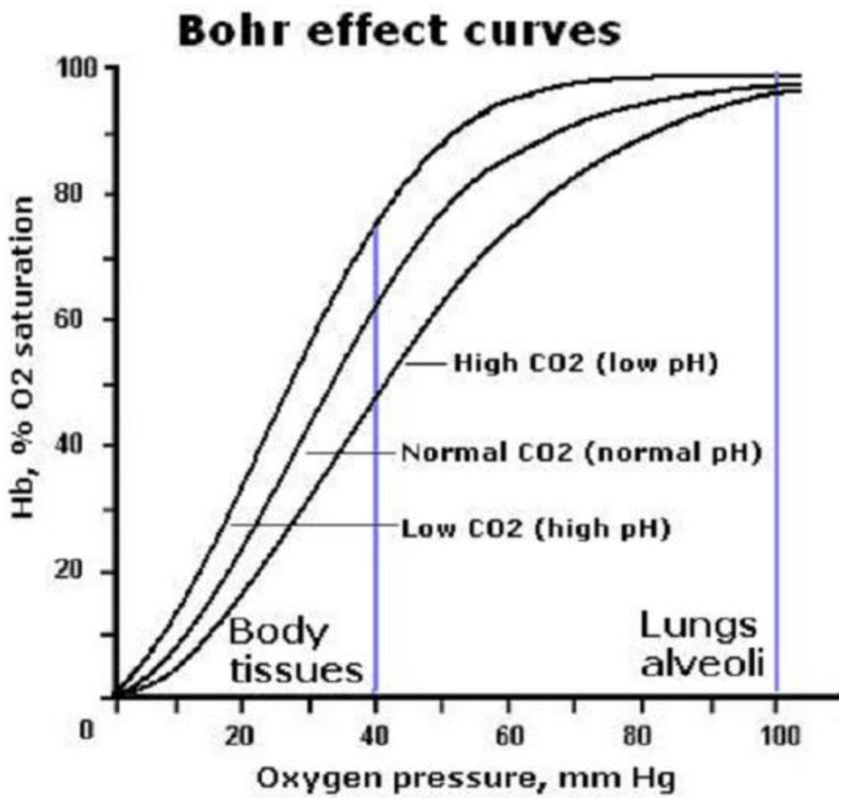
the amount of oxygen released from haemoglobin ↑

- byproduct of the metabolic reactions of the cells = **acid and heat**

- stimulates the oxyhaemoglonbin to release its oxygen.

Haemoglobin and pH:

In an acid environment (low pH) oxygen dissociates readily from haemoglobin, i.e., the oxygen affinity for Hb becomes less - **Bohr Effect**.



$$CO_2 + H_2O \underset{}{\overset{\text{Carbonic anhydrase}}{\rightleftharpoons}} H_2CO_3 \underset{}{\overset{\text{Carbonic anhydrase}}{\rightleftharpoons}} HCO_3^- + H^+$$

- Pco_2 is high → H_2CO_3 → H^+ + Hb → HHb (haemoglobinic acid)
  - alter the structure of the haemoglobin
  - dissociate oxygen.
- low blood pH - lactic acid formation
  anaerobic muscle contraction

Haemoglobin and DPG:

The 2,3 Diphosphoglycerate (DPG) is found in RBC.

- bind reversibly to haemoglobin altering its structure.
- when DPG level is greater in the blood = oxygen is released from hemoglobin

2. Transport of Carbon Dioxide.

solubility in blood is about 20 times higher than that of O_2.

Under normal conditions blood carries about 48 mL of CO_2/dL of blood.

carried from the tissues to the lungs mostly in the **combined form**, as it chemically combines with many substances.

(i) In plasma: About 7% is carried in physical solution in the water of the plasma. The remaining 93% diffuses from the plasma into the RBC. When plasma is carried to alveoli, it diffuses into alveoli from blood.

(ii) Combination with Hb: About 23% of CO_2 combines with the haemoglobin molecules of the RBC, bonding with their amino groups as **Carbaminohaemoglobin**. It is influenced by the Pco_2. Carbaminohaemoglobin is produced more readily when the haemoglobin is reduced (= deoxygenated). Therefore binding of O_2 to Hb reduces its affinity for CO_2. This is called **Haldane effect**.

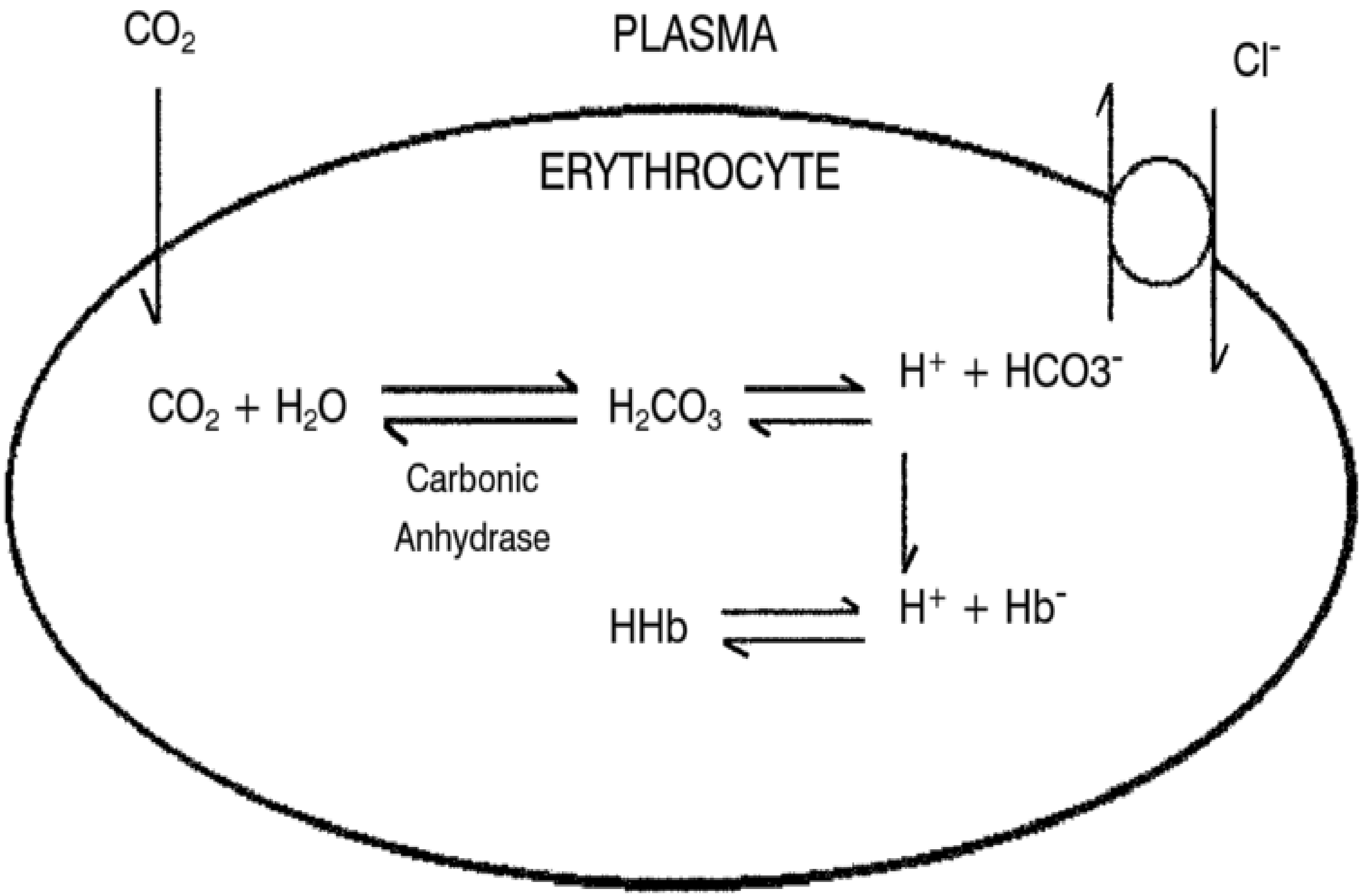
$$Hb + CO_2 \text{------------------------}\rightarrow HbCO_2$$

Carbaminohaemoglobin

(iii) As bicarbonate ions: Around 70% of CO_2 is transported as bicarbonate ions. About 2.6 mL/dL of venous blood carries CO_2 in the form of carbonic acid (H_2CO_3). It ionizes quickly to produce bicarbonate (HCO_3^-) ions and hydrogen (H^+) ions.

$$CO_2 + H_2O \xrightleftharpoons{\text{Carbonic anhydrase}} H_2CO_3 \xrightleftharpoons{\text{Carbonic anhydrase}} HCO_3^- + H^+$$

- **Chloride Shift** or Hamburger's Phenomenon.



Respiratory Quotient

The ratio of the volume of the carbon dioxide liberated to the volume of oxygen consumed is known as the respiratory quotient (RQ).

RQ = Vol. of CO_2 liberated / Vol. of O_2 consumed

(i) If the fuel is a carbohydrate like glucose, its complete oxidation will consume six molecules of oxygen and produces six molecules of carbondioxide. Hence RQ for glucose is 1.0.

$$C_6H_{12}O_6 + 6O_2 \text{ ------------------> } 6CO_2 + 6H_2O$$

$$CO_2 / O_2 = 6/6 = 1. \text{ RQ is unity}$$

(ii) When fats are used as substrate as in germinating oil seeds, the RQ is less than 1.0, i.e., 0.7

For example, for a triglyceride like tripalmitin, with the formula $C_{51}H_{98}O_6$

$$2\ C_{51}H_{98}O_6 + 145\ O_2 \text{---------------->}\ 102\ CO_2 + 98H_2O$$

$$RQ = CO_2/O_2 = 102 / 145 = 0.7\ (RQ < 1.0)$$

(iii) When a protein is aerobically oxidized as in germinating gram, pea, bean seeds,

an RQ of 0.5-0.9 is obtained.

(iv) When organic acids like malic, oxalic are used as substrates the RQ is more than 1.0, as in malic acid

$C_4H_6O_5 + 3O_2$ -----------------> $4CO_2 + 3H_2O$

$RQ = 4/3 = 1.33$ ($RQ > 1.0$)

(v) When a mixture of carbohydrates, proteins and lipids is used, it gives an RQ of 0.8 - 0.9.

(vi) In succulents like Opuntia and Bryophyllum, which do not release CO_2, but fix it in the form of organic acids, RQ is zero.

(vii) During anaerobic respiration RQ is infinity since no oxygen is utilized.