Unit 17 · Digestive System

STUDY NOTES

WHAT NEB'S GRADE 12 EXAM ASKS

- **CDC's grid (2078):** Human Biology (Units 17–24 together): 16 of 75 marks; 4 MCQs (knowledge, understanding, application, higher ability), 1 short question (4 marks: knowledge 1, application 2, higher ability 1) and 1 long question (8 marks: understanding 2, application 2, higher ability 4)
- **The paper:** Botany 37 + Zoology 38; each part: MCQs × 1 (5 Botany, 6 Zoology) · 4 short × 4 · 2 long × 8; one OR in each short and long group; 3 hours; 1 mark per expected point
- **CDC's model paper:** long question (OR): the human alimentary canal
- **Our model papers:** MCQs (chief cells and pepsinogen; no gall bladder → fatty meals upset); Paper 2's short question (salivary amylase; Saugat's three test tubes; why little starch is digested in the stomach)
- **MCQ (1 mark)**
  - gastric glands: branched tubular
  - hardest substance: enamel
  - chief absorption: small intestine
  - trypsinogen → trypsin: enterokinase
  - duct of Santorini: accessory pancreatic
  - Kupffer cells; Wharton's duct
  - HCl activates pepsinogen
  - last water taken back: large intestine
  - bile made in the liver
  - teeth: heterodont, thecodont, diphyodont
- **Short and long (in parts)**
  - the buccal cavity and what is in it
  - salivary glands from a figure: label, secretion, ducts
  - L.S. of a tooth
  - the liver: morphology, anatomy, functions
  - digestion in the small intestine; protein digestion all the way
  - absorption of the end products
  - pancreas section: acini vs islets
  - the alimentary canal (long); carbohydrate, protein, fat digestion with enzymes and their control (long)

Key terms

Nutrients: substances in food the body uses; **organic** (carbohydrates, lipids, proteins, vitamins), **inorganic** (minerals, water).

Digestion: **catabolic** breakdown of complex food into small, soluble, absorbable molecules.

Mechanical digestion: chewing, churning; molecules unchanged; more surface for enzymes.

Chemical digestion: **hydrolysis** by enzymes (hydrolases).

Ingestion → **digestion** → **absorption** → **assimilation** → **egestion** (feces).

Bolus: chewed, slippery ball of food; **chyme**: thick acid semi-liquid leaving the stomach.

Peristalsis: wave of smooth-muscle contraction pushing food along.

Thecodont: teeth in sockets; **diphyodont**: two sets; **heterodont**: different kinds.

Proenzyme: inactive enzyme, switched on where it works (pepsinogen, trypsinogen).

Emulsification: bile salts break fat into tiny droplets.

Absorption: end products pass through the gut lining into blood and lymph.

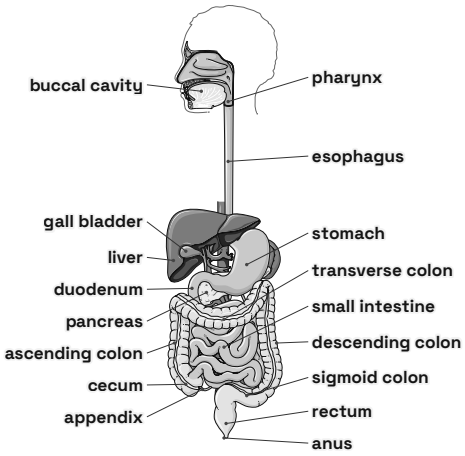
Assimilation: use of absorbed food by the cells.

Chylomicrons: protein-coated fat droplets made in the gut cells; enter **lacteals**.

Chyle: milky lymph in the lacteals after a fatty meal.

The alimentary canal

- complete gut, mouth → anus; ~**9 m** after death (shorter in life)
- mouth · vestibule · buccal cavity · pharynx · esophagus · stomach · small intestine · large intestine · anal canal and anus



The human alimentary canal with the liver, gall bladder and pancreas.

Mouth: slit bounded by upper and lower **lips**; ingestion

Vestibule: between lips and cheeks outside, teeth and gums inside

Buccal (oral) cavity: lined by **stratified squamous epithelium**; palate (roof), tongue (floor), teeth (edge)

- **hard palate** (front): palatine bones + maxillae; ridges, **palatine rugae**, grip food
- **soft palate** (back): muscle; **uvula** (velum palati) hangs from it; rises in swallowing → closes the internal nostrils

Tongue

- **striated** muscle in three directions; tied by the **lingual frenulum**; back fixed to the **hyoid** and mandible
- **terminal sulcus** (Λ): oral part (front ⅔) and pharyngeal part (back ⅓)
- glands: **von Ebner's** (in the circumvallate trenches; **lingual lipase**), **Weber's** (edges; mucus)
- five tastes: **sweet, salty, sour, bitter, umami**; every part with taste buds tastes all five (the "tongue map" is a mistranslation of 1901; write it if asked, and add this)
- jobs: taste; turns food and mixes it with saliva; rolls the **bolus** and pushes it back; speech

Papillae	Where	Shape, number	Taste buds
circumvallate	in a V before the terminal sulcus	largest, in a trench; 7–12	many
fungiform	tip, edges	mushroom; a few hundred	a few each
filiform	front ⅔	smallest, most, threads	**none**: grip

- **foliate**: leaf-like folds at the back of the sides; small in humans

Teeth

- enamel from **ectoderm**; rest from **mesoderm**
- **thecodont**, **diphyodont**, **heterodont**
- milk teeth: 6 months–2½ years; replaced from ~6 to ~12 years
- permanent molars have no milk teeth before them: first ~6, second ~12, **wisdom teeth** ~17–25

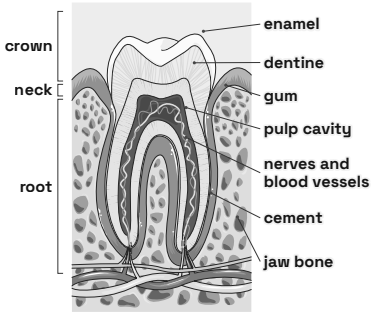
Kind	Shape	Job
incisors	flat, chisel edge	cutting, biting
canines	pointed	tearing, piercing
premolars	2 cusps; 1 or 2 roots	crushing, grinding
molars	4–5 cusps; upper 3 roots, lower 2	grinding

Dental formula (half upper jaw over half lower jaw: I, C, PM, M; × 2)

$\mathrm{I}\,\frac{2}{2}\ \mathrm{C}\,\frac{1}{1}\ \mathrm{PM}\,\frac{2}{2}\ \mathrm{M}\,\frac{3}{3} = \frac{2123}{2123} \times 2 = 32$	adult **Use:** 8 premolars in all
$\mathrm{I}\,\frac{2}{2}\ \mathrm{C}\,\frac{1}{1}\ \mathrm{PM}\,\frac{0}{0}\ \mathrm{M}\,\frac{2}{2} = \frac{2102}{2102} \times 2 = 20$	child (milk teeth) **Use:** no premolars

L.S. of a tooth

- **crown** (above the gum): **enamel**, by **ameloblasts**; ~96% mineral (hydroxyapatite); **hardest substance**; never remade
- **neck**: at the gum line
- **root**: in the jaw bone; covered by **cement**; **periodontal ligament** ties cement to the socket, cushions
- **dentine** (ivory): bulk of the tooth; made by **odontoblasts**
- **pulp cavity**: **pulp** (loose connective tissue, blood vessels, nerves enter at the root tip; odontoblasts at its edge)
- decay hurts only when it reaches the dentine (its tubes reach the pulp's nerves)



L.S. of a molar in its socket.

Pharynx, esophagus, stomach

Pharynx (**~12 cm**): common passage for food and air

- **nasopharynx**: internal nostrils, **Eustachian tubes** open in
- **oropharynx**: food and air
- **laryngopharynx**: **glottis** (to larynx) in front, **gullet** (to esophagus) behind

- **epiglottis** (elastic cartilage) folds over the glottis in swallowing
- tonsils: pharyngeal (adenoids), tubal, palatine, lingual → **Waldeyer's ring**

Esophagus (**~25 cm**)

- behind the windpipe; through the diaphragm at **T10** (**esophageal hiatus**)
- opens at the **cardiac orifice**; **cardiac sphincter** stops acid coming back (leak → heartburn)
- **peristalsis** moves the bolus (works lying down too)
- lining: **non-keratinized stratified squamous**, in long folds; **mucus** glands in the submucosa; **no enzymes**
- outer layer: **tunica adventitia**, not serosa (in the chest)

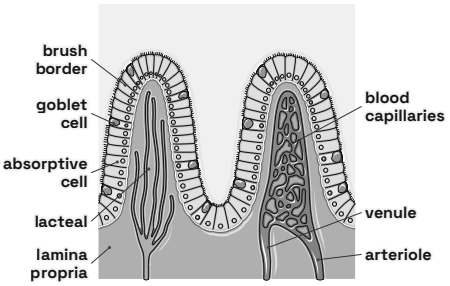
Stomach

- widest part; **J-shaped**; upper left abdomen under the diaphragm; ~25–30 × 15 cm full
- held by **omenta**; embryo's **mesogaster** → greater omentum
- **lesser curvature** (inner), **greater curvature** (outer)
- **greater omentum**: fatty apron over the intestines; "**policeman of the abdomen**"
- regions:
  - **cardia**: round the cardiac orifice
  - **fundus**: dome above it; holds swallowed air
  - **body** (corpus): **gastric rugae**
  - **pylorus**: pyloric antrum → pyloric canal → **pyloric sphincter**
- muscle: **three layers** (extra oblique) → churns
- stores, churns, starts **protein digestion**; absorbs a little water, alcohol, aspirin
- parietal cells' **Castle's intrinsic factor** → B_{12} absorbed in the ileum; lack → **pernicious anemia**

Small and large intestine

Small intestine: longest part; **~6–7 m** after death (~3 m in life); held by **mesenteries**; **plicae circulares** (valves of Kerckring)

- **duodenum**: first, shortest, widest; **C-shaped**, **25–30 cm** round the pancreas's head; bile + pancreatic juice through the **ampulla of Vater**, guarded by the **sphincter of Oddi**; **crypts of Lieberkühn** + **Brunner's glands** (duodenum only); broad villi; **most digestion**
- **jejunum**: **~2.5 m**; thicker, more vessels, large plicae, tall villi; **most absorption**
- **ileum**: **~3.5 m**, longest; thinner villi; absorbs the rest, **B_{12}** and **bile salts**; **Peyer's patches** ("intestinal tonsils", MALT); **ileocecal valve**
- **villi** (~1 mm): blood capillaries + a **lacteal**; cells with **microvilli** (**brush border**); surface **~30 m^2**



Two villi: one cut to show its lacteal, one its capillaries.

Large intestine (**~1.5 m**): no villi; absorbs water and salts; stores waste → feces

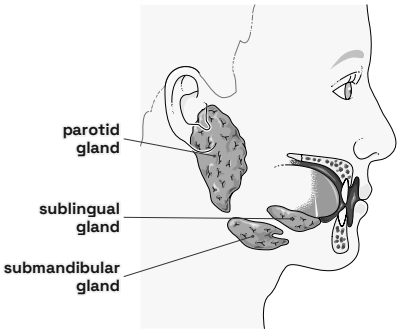
- **cecum**: blind pouch; **vermiform appendix** (~8 cm; lymphoid; store of helpful bacteria)
- **colon**: ascending, transverse, descending, **sigmoid**; **teniae coli** → pouches, **haustra**; bacteria (*E. coli*) make **vitamin K**, some B vitamins (biotin)
- **rectum** (12–15 cm): stores feces

Anal canal (3–4 cm): **anal columns**; **internal sphincter** (smooth, involuntary), **external** (striated, voluntary)

Digestive glands

1. Salivary glands (three pairs)

Gland	Where	Duct	Share	Saliva
parotid (largest)	in front of, below the ear	**Stensen's**, vestibule opposite upper 2nd molar	~25%	watery, amylase
submandibular	under the jaw's angle	**Wharton's**, floor beside frenulum	~70%	amylase + mucus
sublingual (smallest)	under the tongue	**ducts of Rivinus**	~5%	mostly mucus



The salivary glands from the side.

- **mumps**: virus in the parotids (MMR vaccine; Nepal gives MR)
- **saliva**: 1–1.5 L/day; pH **~6.8**; water > 99%, Na^+ K^+ Cl^- HCO_3^-, **salivary amylase** (ptyalin), **lingual lipase**, **lysozyme**, mucus, **IgA**

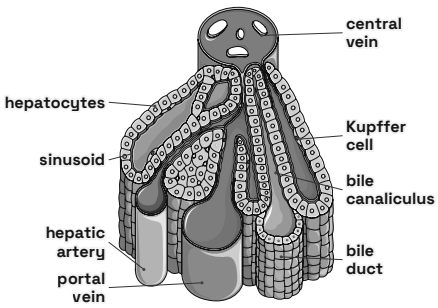
- jobs: moistens, lubricates the bolus; cleans mouth, helps speech; kills germs; starts starch and fat digestion; dissolves food for taste

2. Gastric glands: **branched tubular**, open into gastric pits

- **chief (peptic, zymogen)**: **pepsinogen**, gastric lipase, (prorennin in young mammals)
- **parietal (oxyntic)**: **HCl**, **intrinsic factor**
- **mucous (neck) cells**: mucus + bicarbonate → protects the lining
- **enteroendocrine (argentaffin)**: **G cells** (pyloric antrum) → **gastrin**
- **gastric juice**: 2–3 L/day; pH **1.5–2.5**; no real amylase
- HCl: activates pepsinogen, gives pepsin its pH; kills germs; dissolves bone minerals, loosens meat; pepsin starts proteins; mucus protects
- ulcers: *Helicobacter pylori* (Warren, Marshall; Nobel 2005)

3. Liver: **largest gland**, **~1.5 kg**, upper right under the diaphragm

- **falciform ligament**: right and left lobes; **quadrate** and **caudate** lobes counted with the right
- **gall bladder**: under the right lobe; stores and concentrates bile
- ducts: right + left hepatic → **common hepatic + cystic** → **common bile duct + main pancreatic duct** (Wirsung) → **ampulla of Vater** → duodenum; **sphincter of Boyden** (bile duct), **sphincter of Oddi** (ampulla)
- **Glisson's capsule**; ~100,000 **hepatic lobules** (~1 mm, six-sided):
  - **central vein** in the middle; **hepatic cords** of **hepatocytes** like spokes
  - **sinusoids** between cords: blood flows **in** to the central vein; **Kupffer cells** (phagocytes); **Ito cells** (fat, vitamin A)
  - **bile canaliculi**: bile flows **out** → canals of Hering → bile ducts
  - corners: **portal triad**: hepatic portal vein branch + hepatic artery branch + interlobular bile duct



A wedge of a hepatic lobule.

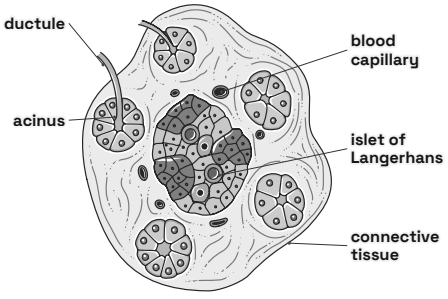
Liver's functions

1. **bile**: yellow-green, alkaline (pH 7.6–8.6), 0.5–1 L/day; **bile salts** (sodium **glycocholate**, **taurocholate**), bile pigments, cholesterol, lecithin, $NaHCO_3$; **no enzymes**
   - bile salts **emulsify** fats; bicarbonate **neutralizes** chyme; helps absorb fats and vitamins A, D, E, K; slows some bacteria, keeps the gut moving
2. blood glucose: **glycogenesis**, **glycogenolysis**, **gluconeogenesis**
3. fats: makes fat from extra glucose, amino acids; cholesterol; fat-carrying proteins
4. **deamination** → ammonia → **urea** (ornithine cycle); **detoxification**
5. Kupffer cells clean blood
6. breaks old RBCs: heme → **biliverdin**, **bilirubin** (color feces); iron kept
7. fetus: **hemopoietic**
8. plasma proteins: albumin, **fibrinogen**, **prothrombin**
9. stores iron, copper, vitamins **A, D, E, K**, $\mathbf{B_{12}}$
10. heat

- **heparin**: made by **mast cells**, basophils, not liver cells; vitamin A from the diet (carotene), **stored** in the liver
- sodium bicarbonate is **not** a bile salt

4. Pancreas: 12–15 cm, ~80 g; behind the stomach; **head** in the C of the duodenum, neck, body, **tail** to the spleen

- **main duct** (Wirsung) → ampulla; **accessory duct** (**Santorini**) opens by itself above
- **mixed (heterocrine)**:
  - **exocrine** (98–99%): **acini**, rings of wedge-shaped cells round a tiny duct → pancreatic juice
  - **endocrine**: ~1 million **islets of Langerhans**: α glucagon, β insulin (most), δ somatostatin; into the blood
- **pancreatic juice**: pH ~**8.4**, 1–1.5 L/day; $NaHCO_3$; **trypsinogen, chymotrypsinogen, procarboxypeptidase, proelastase**; **amylase** (amylopsin); **lipase** (steapsin); **nucleases**
- protein enzymes made inactive → don't digest the pancreas (activated too soon → **acute pancreatitis**)



A section of the pancreas: acini and an islet.

Acini vs islets: exocrine vs endocrine · into a duct vs into the blood · pancreatic juice vs hormones · ~99% vs ~1% · rings round a duct vs clusters with capillaries

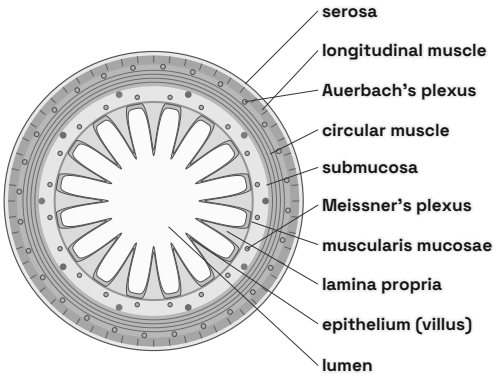
5. Intestinal glands

- **Brunner's**: branched tubular, **duodenum only**, **submucosa**; alkaline mucus
- **crypts of Lieberkühn**: simple tubular, all along the mucosa; intestinal juice; stem cells renew lining every 3–5 days
- **succus entericus**: 1.5–2 L/day, pH ~**7.8**; **enterokinase**, aminopeptidase, dipeptidase, **maltase**, isomaltase, **sucrase**, **lactase**, intestinal lipase, nucleotidases, nucleosidases (most fixed on the brush border)

The wall of the canal (outside → in)

1. **serosa**: mesothelium (visceral peritoneum); esophagus: **tunica adventitia** instead
2. **muscularis**: outer **longitudinal**, inner **circular** smooth muscle; **Auerbach's (myenteric) plexus** between them; stomach + oblique layer
3. **submucosa**: connective tissue, vessels, nerves; **Meissner's (submucous) plexus**; Brunner's glands
4. **mucosa**: **muscularis mucosae** · **lamina propria** · **epithelium** (columnar in stomach, intestines; stratified squamous in mouth, esophagus, end of anal canal)

- the plexuses = **enteric nervous system** (~500 million neurons)



The wall of the small intestine cut across.

Physiology of digestion

- controlled by gut **hormones** and **nerves** (plexuses; **vagus**)

Mouth

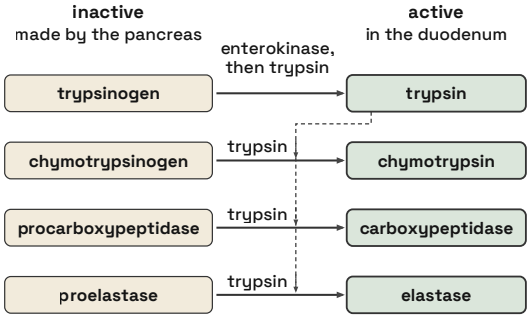
- chewing; mucus binds the bolus
- starch → maltose + isomaltose + dextrins (**salivary amylase**, pH 6.8); up to ~**30%** of starch
- lingual lipase (works mostly in the stomach); lysozyme
- **no digestion** in pharynx and esophagus

Stomach (2–5 hours; longer for fat)

- pepsinogen → **pepsin** (by HCl); pepsin activates more: **autocatalyst**
- proteins → **peptones and proteoses** (pepsin, pH 1.5–2.5)
- young mammals: prorennin → **rennin** (HCl); casein → paracasein; + Ca^{2+} → calcium paracaseinate (curd); human babies: little or none, milk curdled by pepsin and acid
- fats → fatty acids + diglycerides (**gastric lipase**)
- swallowed amylase works until acid reaches it → little starch digested in the stomach
- **chyme** → duodenum in squirts through the pyloric sphincter

Small intestine

- **bile**: neutralizes, **emulsifies**; no enzymes
- trypsinogen → trypsin (**enterokinase**); trypsin activates more trypsinogen, chymotrypsinogen, procarboxypeptidase, proelastase



Enterokinase starts the chain; trypsin activates the rest.

Enzyme	Substrate → product
trypsin, chymotrypsin, elastase	proteins, peptones → polypeptides, peptides
carboxypeptidase	peptides → shorter peptides + amino acids
pancreatic amylase	starch, glycogen → maltose, isomaltose, dextrins
pancreatic lipase	emulsified fats → fatty acids + **monoglycerides**
nucleases	DNA, RNA → nucleotides
aminopeptidase, dipeptidase	peptides → amino acids
maltase	maltose → glucose + glucose
isomaltase	isomaltose, dextrins → glucose
sucrase	sucrose → glucose + fructose
lactase	lactose → glucose + galactose
intestinal lipase	fats → fatty acids + glycerol
nucleotidase	nucleotides → nucleosides + phosphate
nucleosidase	nucleosides → sugar + bases

- **large intestine**: no enzymes; bacteria ferment fiber
- lactose intolerance: adult lactase falls

Protein all the way: stomach (pepsin) → duodenum (trypsin, chymotrypsin, elastase, carboxypeptidase) → brush border (aminopeptidase, dipeptidase) → **amino acids**

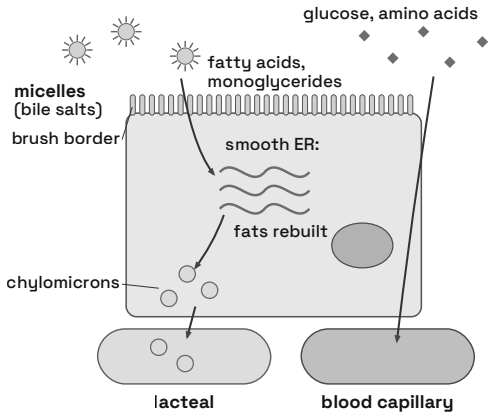
Absorption, assimilation, egestion

- **~90%** in the small intestine, by the villi
- mechanisms: **simple diffusion**, **facilitated diffusion**, **active transport**, **osmosis**
- **glucose, galactose**: active transport with **Na^+** (Na^+ pumped out with ATP); some facilitated
- **fructose**: facilitated diffusion
- **amino acids**: active transport, mostly with Na^+
- **water**: osmosis
- water-soluble vitamins: carriers; **B_{12}** with intrinsic factor in the ileum
- minerals: carriers; iron, calcium actively, duodenum
- sugars, amino acids → blood capillaries → **hepatic portal vein** → liver

Fats

1. fatty acids + monoglycerides + bile salts + lecithin → **micelles**
2. they **diffuse** into the cells; bile salts stay (reabsorbed in the ileum)
3. **smooth ER** rejoins fats → **chylomicrons**
4. too big for capillaries → **lacteal**
5. lymph → **thoracic duct** → **left subclavian vein**

- vitamins A, D, E, K go with fats



How fats are absorbed in one cell of a villus.

- **water**: ~8–9 L/day enter; small intestine takes ~7–7.5 L; large intestine most of the rest (~1.3 L) → solid feces; diarrhea: this fails
- **ORS** (Jeevan Jal): glucose–Na^+ carrier works even in cholera
- **assimilation**: glucose respired or stored (glycogen, fat); amino acids → proteins; fatty acids → membranes, stores
- **egestion**: feces = fiber, water, dead cells, bacteria (⅓–½ of dry mass), fat, salts, mucus; brown **stercobilin**; smell **indole**, **skatole**; rectum stretch → urge; sphincters relax

Hormones of digestion

Hormone	From	Action
gastrin	G cells, pyloric antrum	gastric juice (acid); stomach muscle
GIP (an enterogastrone)	duodenum (fats, sugars)	slows gastric secretion, emptying; insulin
secretin	duodenum (acid chyme)	bicarbonate-rich pancreatic juice; more bile; less gastric juice
CCK	duodenum (fats, proteins)	**gall bladder contracts**; enzyme-rich pancreatic juice
enterocrinin	small intestine	crypts of Lieberkühn (never purified)
duocrinin	duodenum	Brunner's glands (never purified)

- **secretin** (Bayliss and Starling, 1902): first hormone found; Starling coined *hormone*

COMMON MISTAKES

✗ The gall bladder makes bile
✓ the **liver** makes it; the gall bladder stores and concentrates it.

✗ Bile digests fats
✓ bile has **no enzymes**; it emulsifies; lipase digests.

✗ Sodium bicarbonate is a bile salt
✓ bile salts are sodium **glycocholate** and **taurocholate**.

✗ The liver secretes heparin
✓ **mast cells** and basophils do.

✗ Filiform papillae carry taste buds
✓ they have **none**.

✗ Each taste only at its own part of the tongue
✓ every part with taste buds tastes all five.

✗ HCl digests protein
✓ HCl **activates pepsinogen**; pepsin digests.

✗ Trypsinogen is activated by HCl
✓ by **enterokinase**, then by trypsin.

✗ Fats go into the blood capillaries
✓ **chylomicrons** go into the **lacteals**.

✗ Auerbach's plexus is in the submucosa
✓ it lies between the **longitudinal and circular** muscle; Meissner's is in the submucosa.

✗ A child has premolars
✓ the milk set has **no premolars** (2102/2102 = 20).