Feeding & Digestion

Why eat?

- Macronutrients
  - **Energy** for all our metabolic processes
  - **Monomers** to build our polymers
  1. Carbohydrates
  2. Lipids
  3. Protein
- Micronutrients
  - Tiny amounts of vital elements & compounds our body cannot adequately synthesize
  4. Vitamins
  5. Minerals
- Hydration
  6. Water

FEEDING

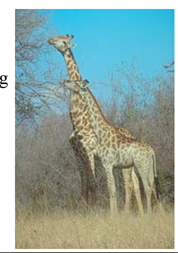
- "Eat": Gr. ***-phagy***; Lt. ***-vore***
- *Your food may not wish to be eaten!*
- DIET & MORPHOLOGY
- FOOD CAPTURE
- MECHANICAL PROCESSING

Never give up!

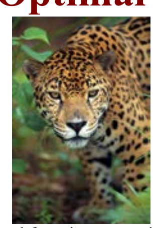
Niche: role played in a community (grazer, predator, scavenger, etc.)

Some organisms have specialized niches so as to:
- increase feeding efficiency
- reduce competition

Optimal foraging model: Need to maximize benefits (energy/nutrients) while minimizing costs (energy expended/risks)



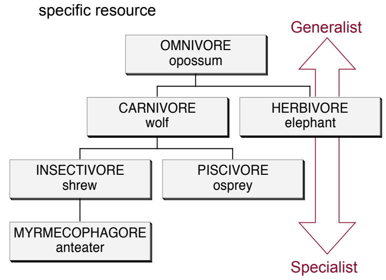
Optimal Foraging Model

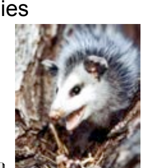


Optimal foraging strategies: Need to maximize benefits (energy/nutrients) while minimizing costs (energy expended / risks)
- Tapirs have 40x more meat, but are much harder to find and catch. So jaguars prefer armadillos.

Optimal Foraging Model

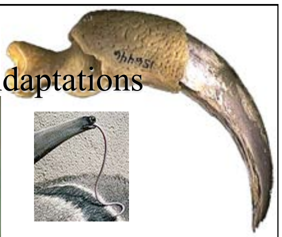
- Morphology reflects foraging strategies
  - **Generalist** is less limited by rarity of resources
  - **Specialist** is more efficient at exploiting a specific resource





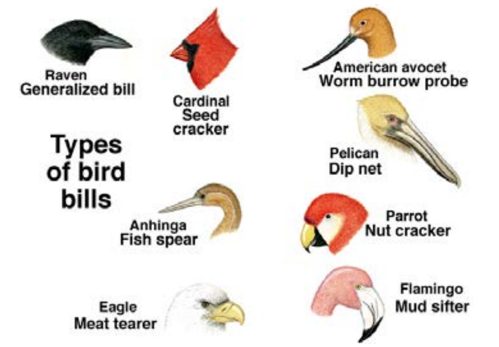
Anteater Adaptations

- Thick fur
- Small eyes
- Long claws in front
- Long snout
- Long barbed tongue
- No teeth



Bird Beaks

- Generalist & specialist bills



FOOD CAPTURE SPECIALIZATIONS

–Fluid Feeding

–Suspension & Deposit Feeding

–Grazers & Browsers

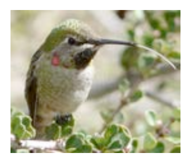
–Predation: Ambush & Attraction

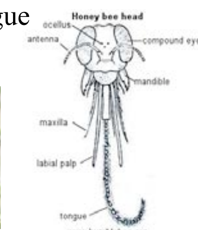
–Venoms

–Tool Use & Team Efforts

Fluid Feeding

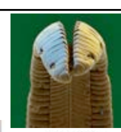
- Sucking with tube
  - mosquitoes & butterflies
- Lapping with brushy tongue
  - hummingbirds, fruit bats
  - bees

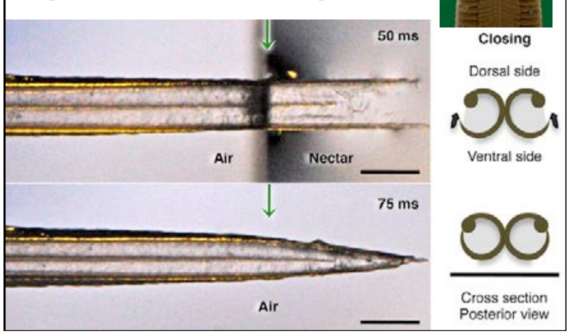




Hummingbird tongue

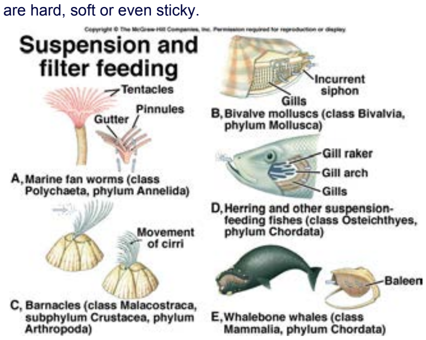
- http://www.youtube.com/watch?v=1wpQ8HQEkvE





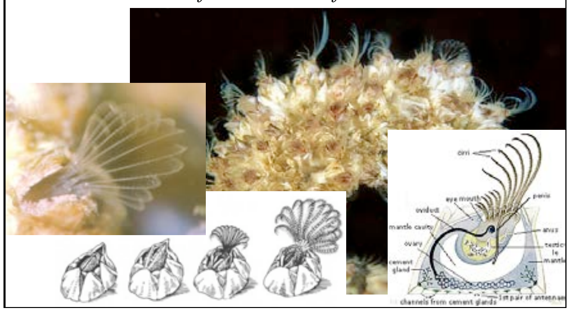
Suspension Feeding (Filter Feeding)

- Filter food (plankton, small animals, organic particles) suspended in water.
- Filters are hard, soft or even sticky.

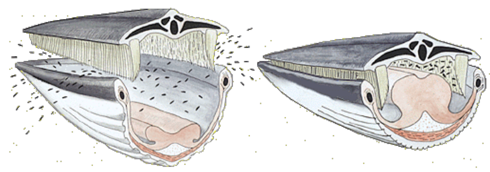


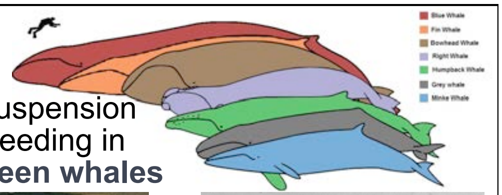
Suspension Feeding (Filter Feeding)

- Barnacles: *"little shrimps that glue their heads to a rock and catch food with their feet"*



suspension feeding in **baleen whales**





suspension feeding in **baleen whales**

- Baleen is tough but flexible filter composed of the protein keratin.
- The length of the baleen depends upon the feeding style of the whale

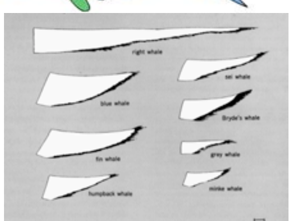


Fig.C—4 : Baleen plates of different species of baleen whales

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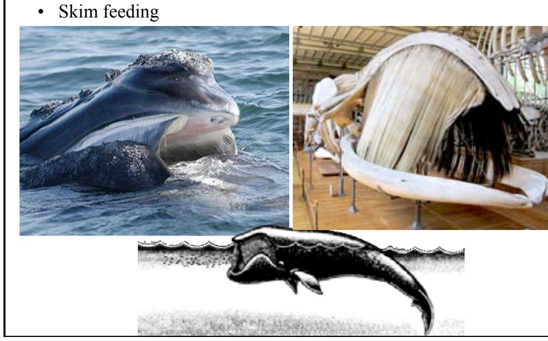
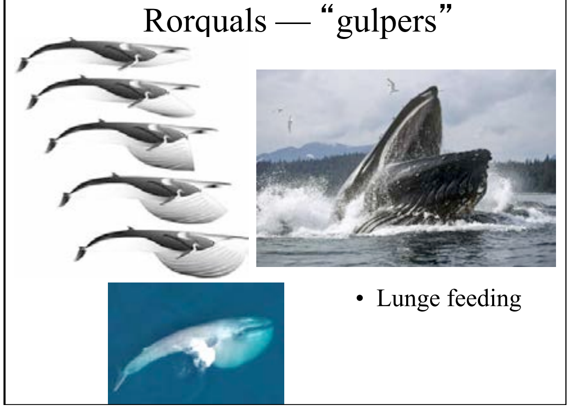
Right Whales — "sippers"

- Skim feeding



Rorquals — "gulpers"

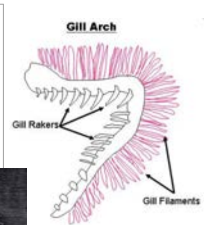


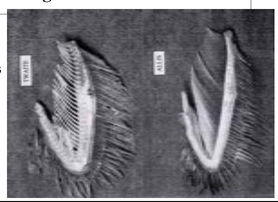
- Lunge feeding

Grey Whales — "mud suckers"

Suspension feeding in fish — **gill rakers**

- Raker spacing determines prey size.
  - If a habitat has two similar species, they diverge in gill raker spacing.
  - Reducing niche overlap is called **resource partitioning** or **niche divergence.**



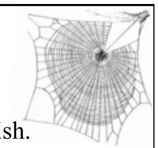


Two species of shad

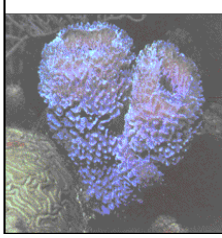
Suspension Feeding in extinct pterosaurs

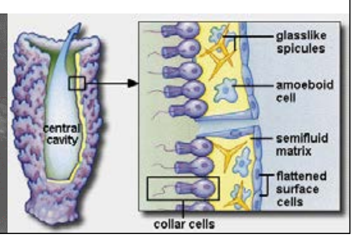
- A pterosaur filters plankton in a lake

Sticky Filters

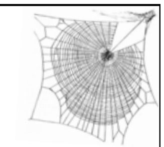


- Glue of spider webs
- Cnidocytes (stinging cells) of jellyfish.
- **Collar cells** of sponges

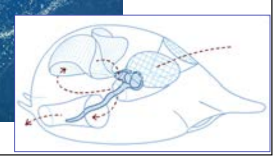




Sticky Filters



- Mucus nets
  - Larvaceans
  - Spoon worms & lug worms

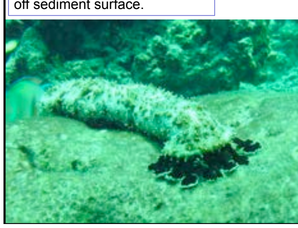


Giant larvacean "house"

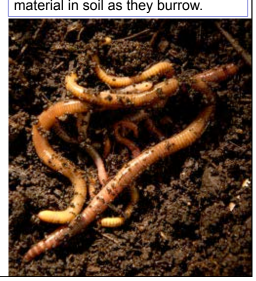
Deposit Feeders

- **Detritivores**: feed on decomposing particles & associated microorganisms deposited on/in sediment/soil

Sea cucumber mops detritus off sediment surface.

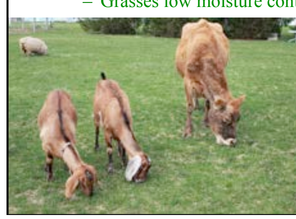


Earthworms swallow & digest organic material in soil as they burrow.

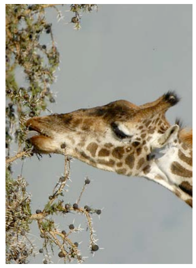


Grazers & Browsers

- **Grazers**: feed on fast growing, abundant, short vegetation (terrestrial grasses; aquatic turf algae) or encrusting animals
  - Slow moving, methodical
  - Mouth-parts for cropping or scraping food close to substrate
  - Grasses low moisture content: need water to drink



Grazers & Browsers



- **Browsers**: feed on taller vegetation (leaves, bark, etc.)
  - More selective; more mobile to locate patches
  - Food moisture may be adequate
  - More anti-herbivore defenses (thorns, toxins, etc.)

Grazers & Browsers

White Rhino (Broad-mouthed Rhino)	Black Rhino (Hooked-lip Rhino)
	
Larger than black rhino. Large bulls reaching weights of 2500 kg.	**Smaller** than the white rhino. A large bull weighs around 1000 kg.
Grazer: have a broad flat mouth which aids in feeding off large quantities of grass	**Browser:** have a small hooked shaped mouth for feeding on trees and shrubs
Head posture faces **downward** so its mouth is always close to the ground while grazing.	**Head posture** is face **upward**, so there is no need for it to lift its head when feeding off trees.

Ambush **Predators**

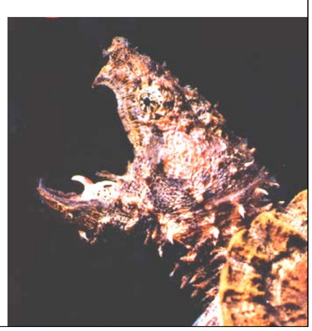
- Crab & trap door spiders, Komodo dragons, lions, etc.
- Works best if animal has **cryptic coloration**.

Ensnare Prey

- Bolas spiders snag 'em, onycophorans slime 'em.

Attraction

- Chemical Lures
  - bolas spider mimics female moth pheromone
- Visual Lures
  - Fireflies
  - Snapping turtles
  - Angler fish

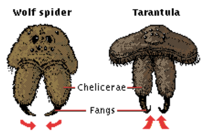


Toxins

- Poison saliva is used by shrews & cephalopods

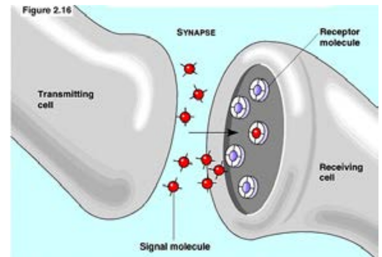
Inject Toxins (Venom)

- Fangs: spiders or snakes
- Stingers: wasps and scorpions



Neurotoxins Immobilize Prey

- Block neurotransmitters that control movement.
- Prevent escape and/or harm to predator.



Tissue-destructive Toxins Digest Prey

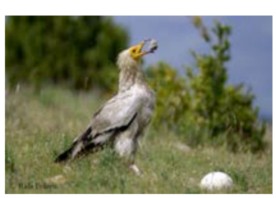
- Scorpions & spiders have external digestion.
- Rattlesnakes consume VERY large prey.

Team Efforts

- Team up to capture larger/faster prey
  - social canids
  - lions
  - orcas

Tool Use

- Galapagos finches, ravens, & Egyptian vultures
- Chimps & sea otters



Digestion

- The hydrolysis (breakdown) of large food molecules (polymers) into small organic subunits (monomers).
- The monomers may then be used for:
  - Metabolic fuel (cellular respiration → ATP & heat)

    or
  - Subunits to build new polymers

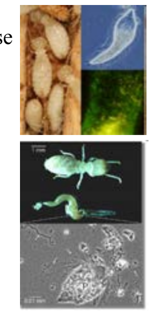
❑ **Hydrolysis is catalyzed by enzymes**
  - May be intracellular or extracellular

Hydrolytic Enzymes

- Hydrolysis reactions catalyzed by enzymes
  - – enzyme names end with *"-ase"*
- **Amylase**: hydrolyze carbohydrates
- **Protease**: hydrolyze proteins
- **Peptidase**: hydrolyze peptides
- **Lipase**: hydrolyze lipids

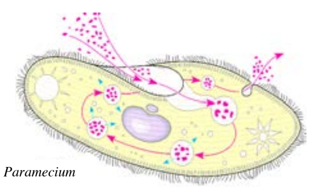
Hydrolytic Enzymes

- Most plant material is largely cellulose
- Yet no animal has enzymes that can digest cellulose
- Most herbivores depend upon symbioses with **cellulytic protists** in their guts
- In turn, the cellulytic protists depend upon symbioses with bacteria to produce the actual enzymes

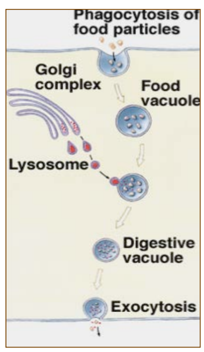


Intracellular Digestion

1. phagocytosis
2. ⇨ food held in vacuole
3. ⇨ vacuole fuses with lysosome filled with digestive enzymes
4. ⇨ food digested
5. ⇨ excytosis of indigestible material

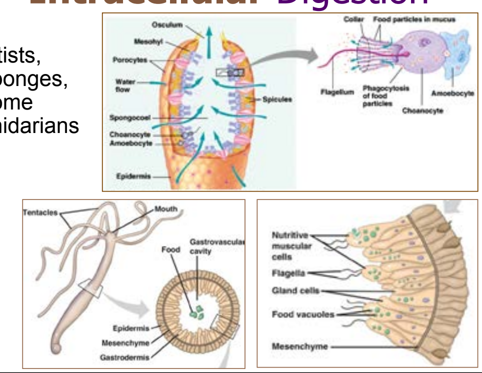


Paramecium



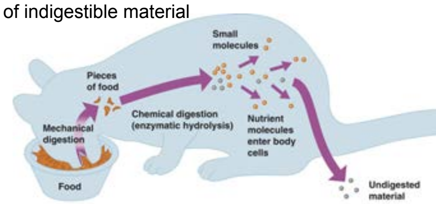
Intracellular Digestion

Protists, sponges, some cnidarians



Extracellular Digestion

1. enzymes secreted into space (lumen of digestive tract)
2. ⇨ food broken into small molecules
3. ⇨ absorption by cells lining the digestive tract
4. expulsion of indigestible material



Internal Digestion & Food Processing

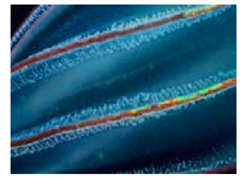
1. Ingestion
   - Consuming food
2. Physical disruption
   - Mastication, dissolution, denaturation, emulsification
3. Motility
   - Swallowing, peristalsis, segmentation, defecation
4. True digestion
   - Hydrolysis of polymers into monomers
5. Absorption
   - Moving nutrients from G.I. Tract into circulatory system
6. Assimilation
   - Incorporate nutrient molecules into tissues

Ingestion for Internal Digestion

1. Ciliary (or flagellar) motility
2. Oral appendages
   a. Ciliary
   b. Grasping / Sweeping
3. Protrusable / prehensile structures
   a. Pharynx
   b. Jaws
4. Swallowing
   a. Ram / Gravity / Lunge / Suction
   b. Pharyngeal / Ratcheting jaws
   c. Lingual

Ingestion for Internal Digestion

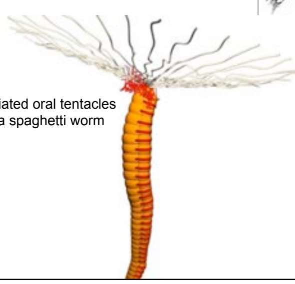
1. Ciliary (or flagellar) motility



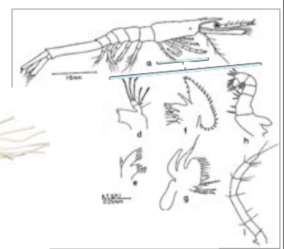
Ctenophore
irridescent comb rows [ctenes] of ciliated plates
for both propulsion & feeding currents
https://www.youtube.com/watch?v=GGFrcWD2jYA

Ingestion for Internal Digestion

2. Oral appendages
   a. Ciliary
   b. Grasping / Sweeping



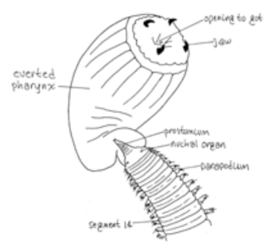
Ciliated oral tentacles of a spaghetti worm



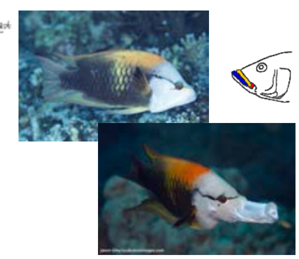
"Mouth field" feeding appendages of a shrimp

Ingestion for Internal Digestion

3. Protrusable / prehensile structures
   a. Pharynx
   b. Jaws



Eversible jawed pharynx of Bloodworm
https://www.youtube.com/watch?v=mktMxLrU8rA



Slingjaw wrasse
https://www.youtube.com/watch?v=pDU4CQWXaNY

Ingestion for Internal Digestion

4. Swallowing
   a. Ram / Gravity / Lunge / Suction

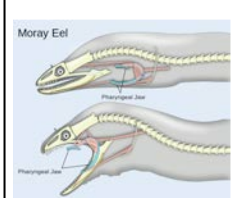
Lunge & gravity swallowing by Blue heron
https://www.youtube.com/watch?v=1-p2AI9uTs0

Suction feeding by Cichlid
https://www.youtube.com/watch?v=TbGILi8p5Y8

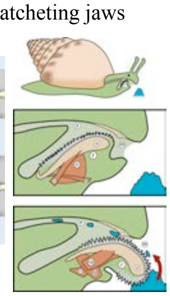
Suction feeding by Tiger fish
https://www.youtube.com/watch?v=m2lcBaqYK1o

Ingestion for Internal Digestion

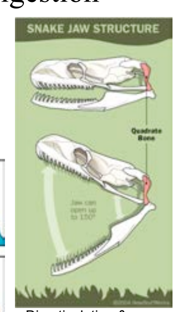
4. Swallowing
   b. Pharyngeal / Ratcheting jaws



Pharyngeal jaws in a moray eel



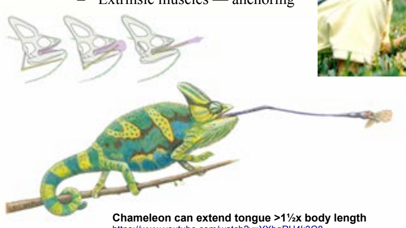
Odontophore in a snail



Disarticulation & independent action of snake jaw bones
https://www.youtube.com/watch?v=HP8Ocr3KJho

Ingestion for Internal Digestion

4. Swallowing
   c. Lingual
      - Tongue of most vertebrates
        - Intrinsic muscles — *hydrostat*
        - Extrinsic muscles — anchoring

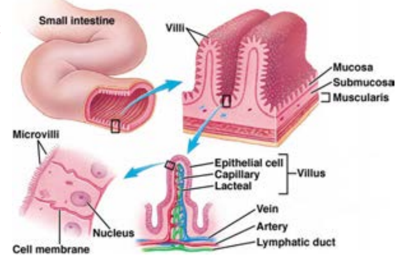


Chameleon can extend tongue >1½x body length
https://www.youtube.com/watch?v=YXbgRU4k3O8

Internal Digestion — Digestive Tracts

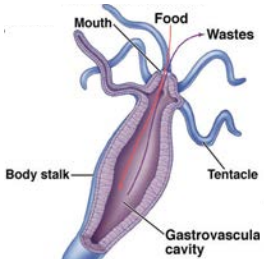
- Epithelial tissue lining a hollow cavity (**lumen**)
- Ridges & wrinkles to increase surface area for absorption
- Usually highly vascularized to transport absorbed materials

Mammalian gut

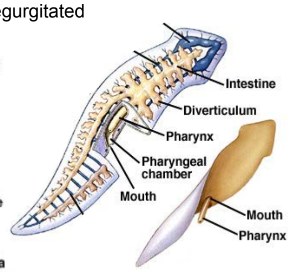


Digestive Tracts

- Gastrovascular systems (blind guts)
  - indigestible material regurgitated



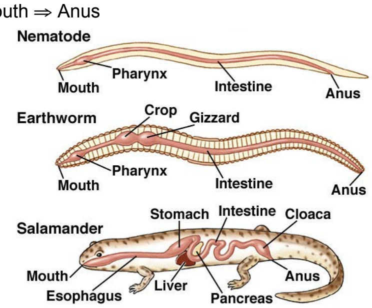
Cnidarian polyp — *Hydra*



Platyhelminth flatworm — *Planaria*

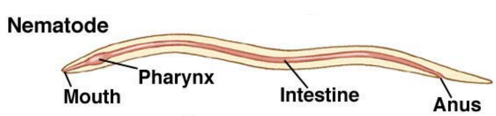
Digestive Tracts

- Complete guts
  - Mouth ⇒ Anus



Digestive Tracts

- Complete guts
  - Mouth ⇒ Anus

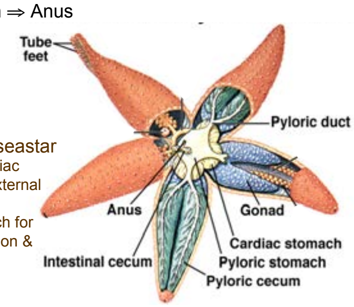


- Muscular pharynx pushes food through non-muscular gut
- Free-living roundworms feed on microbes
- Parasitic roundworms feed on host body fluids
- No need for much specialization of gut

Digestive Tracts

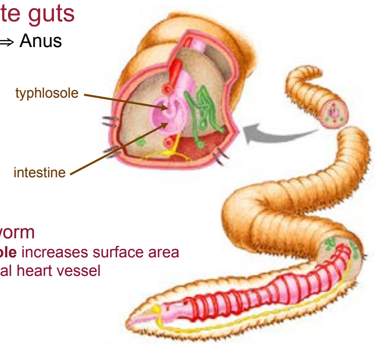
- Complete guts
  - Mouth ⇒ Anus

Echinoderm seastar
- Eversible cardiac stomach for external digestion
- Pyloric stomach for internal digestion & absorption



Digestive Tracts

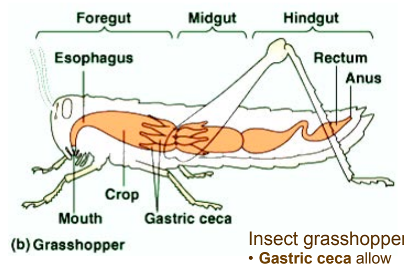
- Complete guts
  - Mouth ⇒ Anus



Annelid earthworm
- Dorsol **typhlosole** increases surface area adjacent to dorsal heart vessel

Digestive Tracts

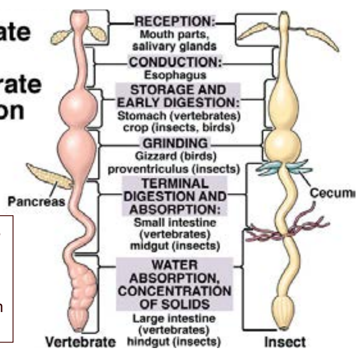
- Complete guts
  - Mouth ⇒ Anus



Insect grasshopper
- **Gastric ceca** allow fermentation of plant material

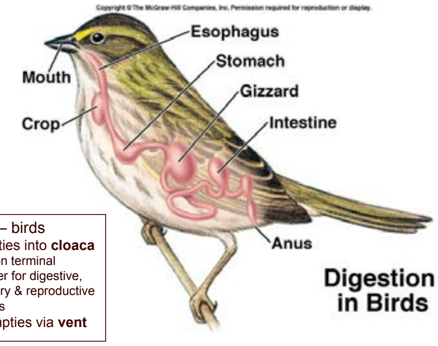
Digestive Tracts

Vertebrate and invertebrate digestion



Insects & Vertebrates
- Gut divisions into specialized regions allows more efficient digestion & exploitation of more food types

Digestive Tracts



Digestion in Birds

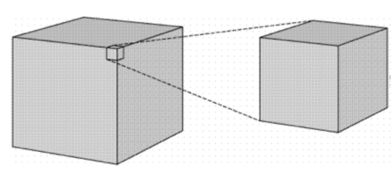
Vertebrate — birds
- Anus empties into **cloaca**
  - common terminal chamber for digestive, excretory & reproductive systems
- Cloaca empties via **vent**

Internal Digestion & Food Processing

1. Ingestion
   - Consuming food
2. Physical disruption
   - Mastication, dissolution, denaturation, emulsification
3. Motility
   - Swallowing, peristalsis, segmentation, defecation
4. True digestion
   - Hydrolysis of polymers into monomers
5. Absorption
   - Moving nutrients from G.I. Tract into circulatory system
6. Assimilation
   - Incorporate nutrient molecules into tissues

Mastication — physical disruption of food particles

- Small particles are more easily broken down by digestive enzymes
  - Chewing ↑ Surface to Volume (S/V) Ratio of particles ∴ ↑ exposure to enzymes

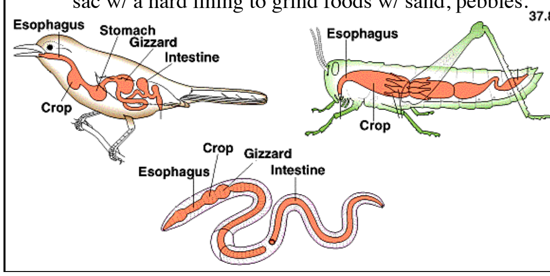


ORAL MASTICATION

- **Beaks** in birds, turtles, & cephalopods
- **Teeth** in vertebrates
- **Mandibles** in insects
- **Radula** in most molluscs

Gastric Mills of Arthropods, Birds and Earthworms

- Storage **crop** leads to grinding **gizzard** - a muscled sac w/ a hard lining to grind foods w/ sand, pebbles.

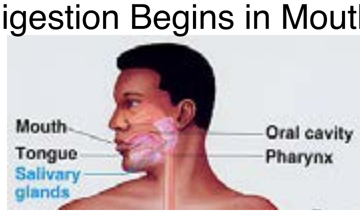


Vertebrate Digestive System

- Alimentary Canal (humans: 26-foot long tube)
  - Mouth
  - Pharynx
  - Esophagus
  - gastrointestinal [G.I.] tract ("gut")
    - Stomach
    - Small Intestine
    - Large Intestine
- Accessory Organs
  - Salivary Glands
  - Liver & Gall Bladder
  - Pancreas

Human Digestive System

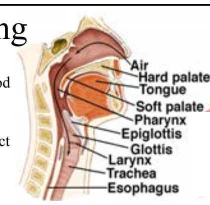
Digestion Begins in Mouth

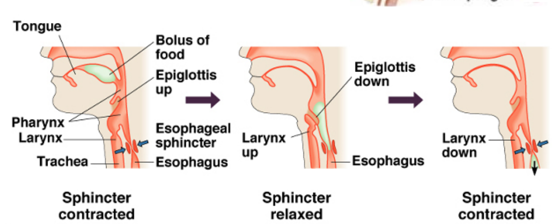


- Salivary glands produce **Amylase**
  - Enzyme hydrolyzes starch
  - Cleans teeth
- Saliva also contains mucous, buffers, antibacterials
- Slug of mashed food and saliva is a **Bolus**

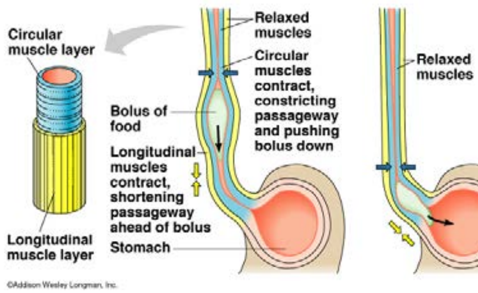
Swallowing

- Salivary glands
  - Water & mucus: moisten/lubricate food
- Pharynx
  - Initiate swallowing reflex
  - Divert food bolus from respiratory tract
- Esophagus
  - uses peristaltic action



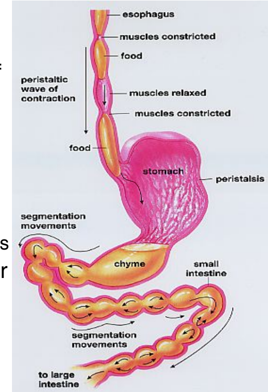


Peristalsis



Gut Motility

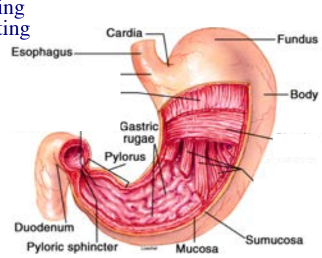
- **Peristalsis** — waves of involuntary muscle contraction
  - Esophagus, stomach, small intestines
- **Segmentation** — churning action
  - Stomach, small intestines
- **Sphincters** — muscular rings that control entry/ exit
  - Esophageal sphincter
  - Pyloric sphincter
  - Anal sphincter



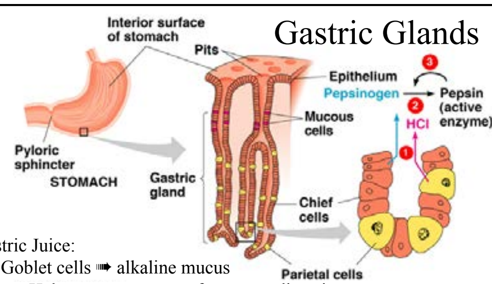
Muscular action in the human gut

Stomach

- Distensible: stores swallowed food pending further processing. Sealed by sphincters at either end.
- Mucosa wrinkled to form rugae that increase surface area
- Highly motile. Regulates rate of passage to intestines.
- Many gastric pits leading to gastric glands secreting gastric juice
- Masticated food + digestive juices = **chyme**
- Acid in gastric juice disinfects the chyme



Gastric Glands



Gastric Juice:

A. Goblet cells ➠ alkaline mucus
   - Helps protect mucosa from auto-digestion.

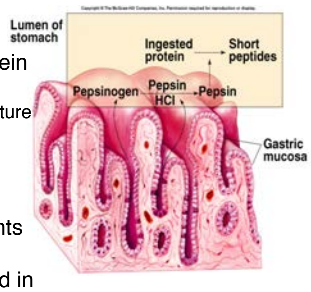
B. Parietal cells ➠ hydrochloric acid [HCl] ➠ pH < 2
   - Disinfects chyme; denatures protein

C. Chief cells ➠ pepsinogen (a weak protease)
   - Auto-hydrolyzes to form pepsin (stronger protease)

D. Other cells produce hormones

Protein Digestion Begins in the Stomach

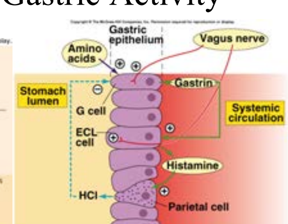
1. Acid **denatures** protein in the chyme
   - Unfolded protein structure more vulnerable to hydrolysis
2. Pepsin **hydrolyzes** polypeptides into oligopeptide fragments
3. Digestion and absorption completed in small intestines



Regulation of Gastric Activity

Table 18.6 The Three Phases of Gastric Secretion

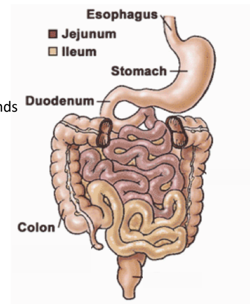
Phase of Regulation	Description
Cephalic Phase	1. Sight, smell, and taste of food cause stimulation of vagus nuclei in brain 2. Vagus stimulates acid secretion a. Direct stimulation of parietal cells (major effect) b. Stimulation of gastrin secretion (lesser effect)
Gastric Phase	1. Distension of stomach stimulates vagus nerve; vagus stimulates acid secretion 2. Amino acids and peptides in stomach lumen stimulate acid secretion a. Direct stimulation of parietal cells (lesser effect) b. Stimulation of gastrin secretion; gastrin stimulates acid secretion (major effect) 3. Gastrin secretion inhibited when pH of gastric juice falls below 2.5
Intestinal Phase	1. Neural inhibition of gastric emptying and acid secretion a. Arrival of chyme in duodenum causes distension, increase in osmotic pressure b. These stimuli activate a neural reflex that inhibits gastric activity 2. In response to fat in chyme, duodenum secretes a hormone that inhibits gastric acid secretion



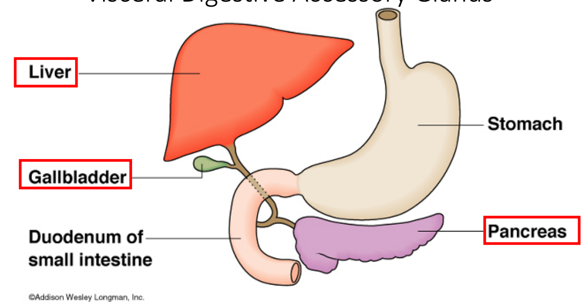
- Gastric secretion and motility stimulated by parasympathetic neurons, intrinsic stretch reflex, gastrin hormone, and amino acids in chyme (positive feedback amplification).
- Inhibited by stretch reflex and hormones from intestines, or chyme pH <1.5.

Digestion Completed in **Small Intestine**

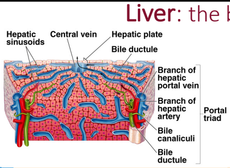
- Longest region of gut
- Chyme enters via the **pyloric sphincter**.
- First segment = **duodenum**: secretions from accessory glands enter via common bile duct.
- Next 40% = **jejunum**: most digestion and absorption of macro- & micronutrients.
  - Highly vascularized
- Final 60% = **ileum**: most absorption/reabsorption of water and salts.
  - ~2L from diet + 7L from secretions per day



Visceral Digestive Accessory Glands



Liver: the biochemistry lab



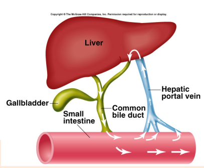
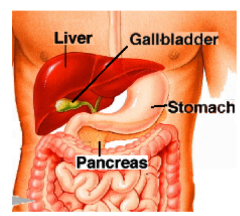


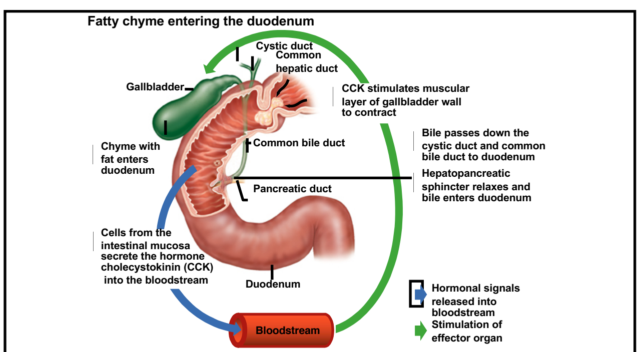
Table 18.3 Major Categories of Liver Function

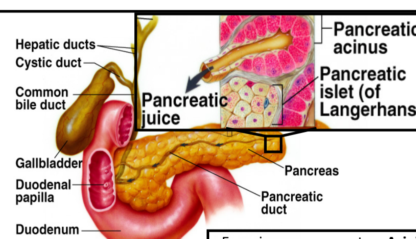
Functional Category	Actions
Detoxication of Blood	Phagocytosis by Kupffer cells Chemical alteration of biologically active molecules (hormones and drugs) Production of urea, uric acid, and other molecules that are less toxic than parent compounds Excretion of molecules in bile
Carbohydrate Metabolism	Conversion of blood glucose to glycogen and fat Production of glucose from liver glycogen and from other molecules (amino acids, lactic acid) by gluconeogenesis Secretion of glucose into the blood
Lipid Metabolism	Synthesis of triglycerides and cholesterol Excretion of cholesterol in bile Production of ketone bodies from fatty acids
Protein Synthesis	Production of albumin Production of plasma transport proteins Production of clotting factors (fibrinogen, prothrombin, and others)
Secretion of Bile	Synthesis of bile salts Conjugation and excretion of bile pigment (bilirubin)

Liver to Gall Bladder:
Bile Salts: Fat Emulsifier

- Liver produces **bile salts** & pigments.
- Bile is stored & released by **Gall Bladder** into Small Intestine.
- Emulsify: Bile salts break large fat globs into small droplets (detergent action).



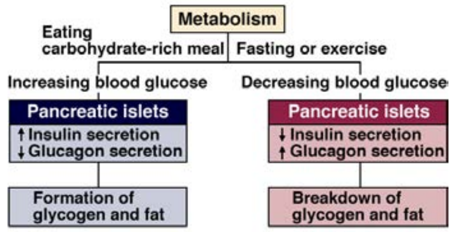




Pancreas

- <u>Exocrine</u> component — **Acini**:
  - Secrete pancreatic juice.
    - Bicarbonate to neutralize acid chyme
    - Suite of hydrolytic enzymes
- <u>Endocrine</u> component — **Islets**:
  - Secrete insulin and glucagon.

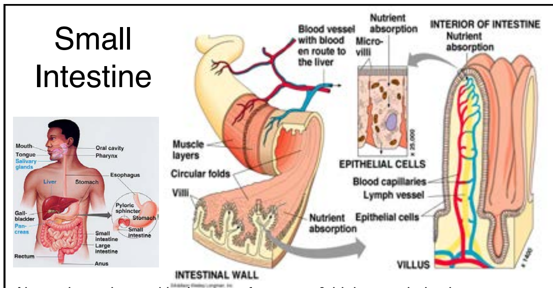
Actions of Insulin and Glucagon



Pancreas

- Endocrine component — Islets:
  - Secrete insulin and glucagon.

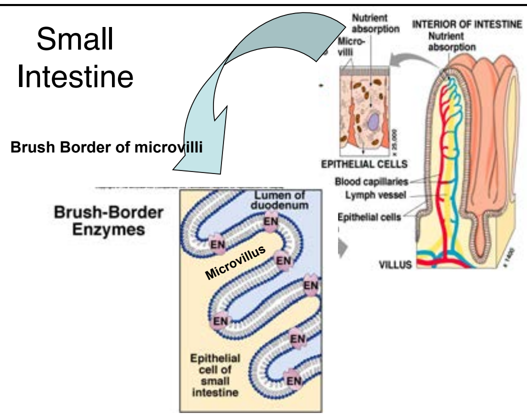
Small Intestine



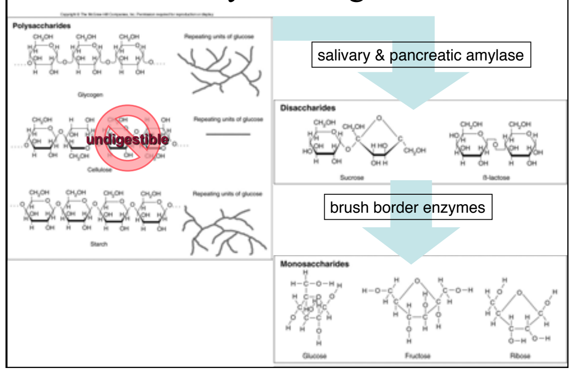
Absorption enhanced by large surface area & high vascularization:

- Lining wrinkled into ridges (plicae) and finger-like protrusions (villi).
- Surface of mucosal epithelia cells wrinkled into microvilii (brush border).
- Core of each villus bears dense capillary beds surrounding a central lacteal (lymphatic vessel).
- Capillaries carry absorbed substances to the hepatic portal vein and then to the liver. Lacteal transports to central veins and general circulation.

Small Intestine



Carbohydrate digestion



Carbohydrate Digestion — Summary

1. Hydrolysis of polysaccharides (poly-glucose) starts with **salivary amylase**.
   - Minor significance — amylase denatured by gastric acid.
2. **Pancreatic amylase** in duodenum & jejunum hydrolyzes polysaccharides into maltose & maltriose.
3. **Brush border enzymes** hydrolyze tri-/disaccharides into monosaccharides.
4. **Brush border transporters** absorb monosaccharides by active cotransport into hepatic portal vein.
5. Insulin dependent: monosaccharides taken up by liver for glycogenesis, or circulate as energy substrate for glycolysis or lipogenesis.

Protein Digestion — Summary

1. Proteins are denatured by gastric **acid** in stomach.
2. Hydrolysis of exposed polypeptides starts with **pepsin** in gastric juice under acidic pH.
3. **Pancreatic proteases & peptidases**, plus **brush border peptidases** in duodenum & jejunum hydrolyze poly-/oligopeptides into tri-/dipeptides & amino acids.
4. **Brush border transporters** absorb tri-/dipeptides & amino acids into mucosal epithelia. **Intracellular peptidases** hydrolyze tri-/dipeptides into amino acids. Amino acids absorbed into hepatic portal vein.
5. Insulin dependent: amino acids taken up by liver for gluconeogenesis, or circulate as substrate for protein synthesis

Lipid Digestion — Summary

1. Fats & oils are *emulsified* by **bile salts** (detergent) in duodenum & jejunum .
2. **Pancreatic lipases** in duodenum & jejunum hydrolyze triglycerides into monoglycerides & fatty acids.
3. Monoglycerides & fatty acids, plus cholesterol, coalesce with **bile salts** to form micelles.
4. **Brush border transporters** absorb micelles into mucosal epithelia. **Intracellular liposynthases** condense monoglycerides & fatty acids into new triglycerides. Triglycerides & cholesterol are bound to carrier proteins to form **chylomicron** lipoprotein.
5. Chylomicrons are absorbed into the lacteal and systemic circulation. **Lipoprotein-lipase** of vessel endothelia releases fatty acids & glycerol for tissue lipogenesis.

Absorption/Assimilation of Lipids

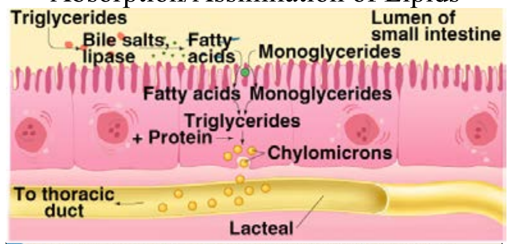


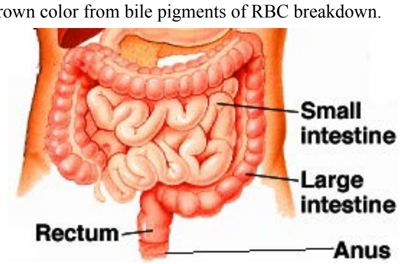
Table 18.8 Characteristics of the Lipid Carrier Proteins (Lipoproteins) Found in Plasma

Lipoprotein Class	Origin	Destination	Major Lipids	Functions
Chylomicrons	Intestine	Many organs	Triglycerides, other lipids	Deliver lipids of dietary origin to body cells
Very-low-density lipoproteins (VLDLs)	Liver	Many organs	Triglycerides, cholesterol	Deliver endogenously produced triglycerides to body cells
Low-density lipoproteins (LDLs)	Intravascular removal of triglycerides from VLDLs	Blood vessels, liver	Cholesterol	Deliver endogenously produced cholesterol to various organs
High-density lipoproteins (HDLs)	Liver and intestine	Liver and steroid-hormone-producing glands	Cholesterol	Remove and degrade cholesterol

LDLs are *Lousy*; HDLs are *Healthy*

Large Intestine

- Final water absorption
- Compaction, storage, & excretion of **feces**
  - 1/3 bacteria by weight (some make K & B vitamins).
  - Brown color from bile pigments of RBC breakdown.

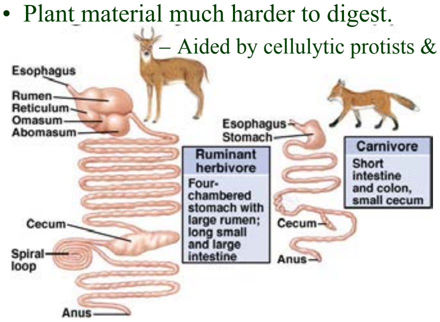


Digestion Overview

	(a) Carbohydrate digestion	(b) Protein digestion	(c) Nucleic acid digestion	(d) Fat digestion
Oral cavity, pharynx, esophagus	Polysaccharides (starch, glycogen) ↓ Salivary amylase ↓ Smaller polysaccharides, maltose			
Stomach		Proteins ↓ Pepsin ↓ Small polypeptides		
Lumen of small intestine	Polysaccharides ↓ Pancreatic amylases ↓ Maltose and other disaccharides	Polypeptides ↓ Trypsin, Chymotrypsin ↓ Smaller polypeptides; Aminopeptidase, Carboxypeptidase ↓ Amino acids	DNA, RNA ↓ Nucleases ↓ Nucleotides	Fat globules ↓ Bile salts ↓ Fat droplets (emulsified) ↓ Lipase ↓ Glycerol, fatty acids, glycerides
Epithelium of small intestine (brush border)	Disaccharidases ↓ Monosaccharides	Small peptides ↓ Dipeptidases ↓ Amino acids	Nucleotidases ↓ Nucleosides ↓ Nucleosidases ↓ Nitrogenous bases, sugars, phosphates	

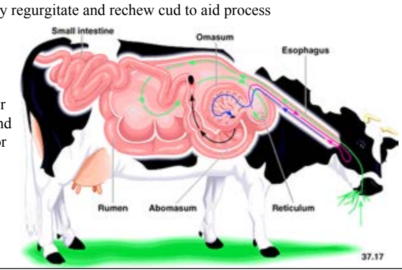
Carnivores Have Short Tracts
Herbivores Have Long Tracts

- Plant material much harder to digest.
  - Aided by cellulytic protists & bacteria



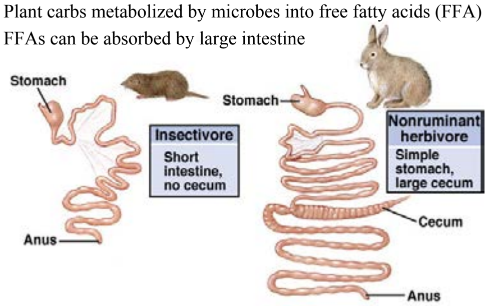
Ruminant herbivores

- Masticated vegetation swallowed into **rumen**
  - First of four stomach chambers
- Cultures of microbes digest the cellulose and other complex carbohydrates
  - Occasionally regurgitate and rechew cud to aid process
- Microbial populations actual food
  - Pass to other chambers and intestines for digestion & absorption

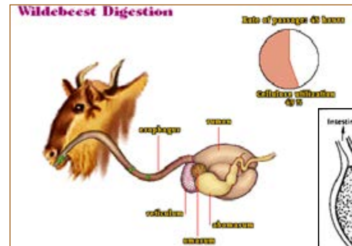


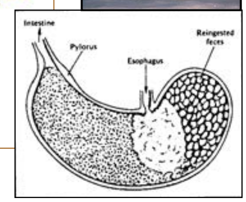
Non-ruminant herbivores

- Cellulytic protists & bacteria in **cecum**
  - Enlarged region of large intestine right after junction with small intestine
- Plant carbs metabolized by microbes into free fatty acids (FFA)
- FFAs can be absorbed by large intestine



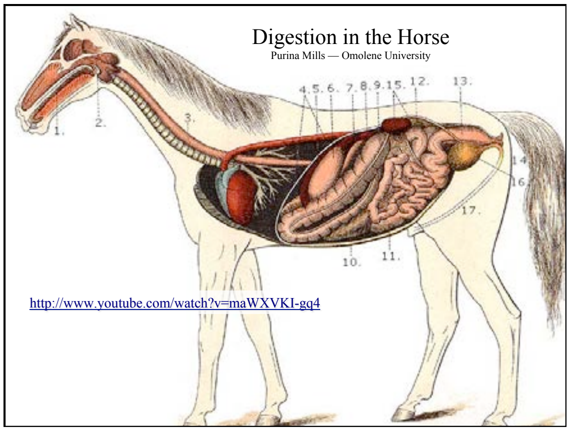
Ruminants re-chew a cud. Rabbits and other juvenile non-ruminants re-chew by **coprophagy**





Digestion in the Horse

Purina Mills — Omolene University



http://www.youtube.com/watch?v=maWXVKI-gq4

Non-ruminant herbivores

- Similar solution in **herbivorous reptiles**
- Cellulytic protists & bacteria in **enlarged colon**
  - Stomach=30% of total gut; colon=60%
- Plant carbs metabolized by microbes into volatile free fatty acids (FFA)
  - FFAs can be absorbed by large intestine
- **BUT**, cellulytic microbes require warm temperatures!
  - ∴ *ectothermic* herbivorous reptiles are limited to tropics & deserts

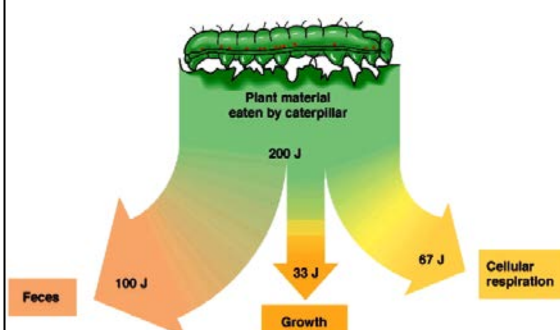
Green iguana

Green sea turtle

Lengthening Intestine to Meet Metabolic Demands

- House wrens lengthen 22% in winter
- Mammals lactating
- All eat more too

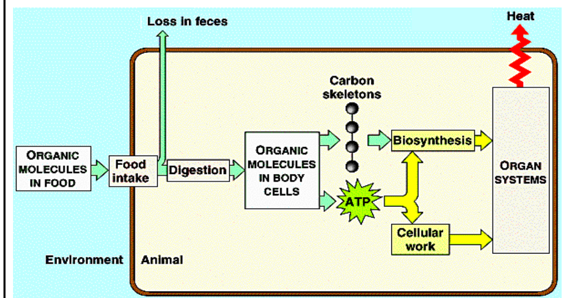
WHAT HAPPENS TO IT ALL?



Fate of Chemical Energy

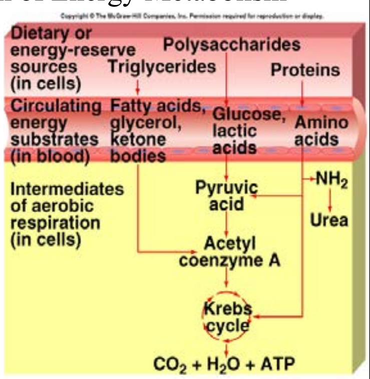
- Stored as
  - blood sugars
  - liver & muscle glycogen
  - body fat
- Stored energy used for
  - 1) metabolism
  - 2) growth
    - many insects don't feed as adults
  - 3) reproduction

WHAT HAPPENS TO IT ALL?



Regulation of Energy Metabolism

- Energy reserves:
  - Molecules that can be oxidized for energy are derived from storage molecules (glycogen, protein, and fat).
- Circulating substrates:
  - Molecules absorbed through small intestine and carried to the cell for use in cell respiration.



Malnutrition:

"the cellular imbalance between supply of nutrients and energy and the body's demand for them to ensure growth, maintenance, and specific functions."
— World Health Organization

Stages of malnutrition caused by excessive or inadequate intake of nutrients.
Modified from Olson RE: "Pharmacology of nutrients and nutritional disease," in *Principles of Pharmacology,* edited by PL Munson. New York, Munson, Chapman, and Hall, 1995; in *Merck Manual of Diagnosis and Therapy*, 2004.