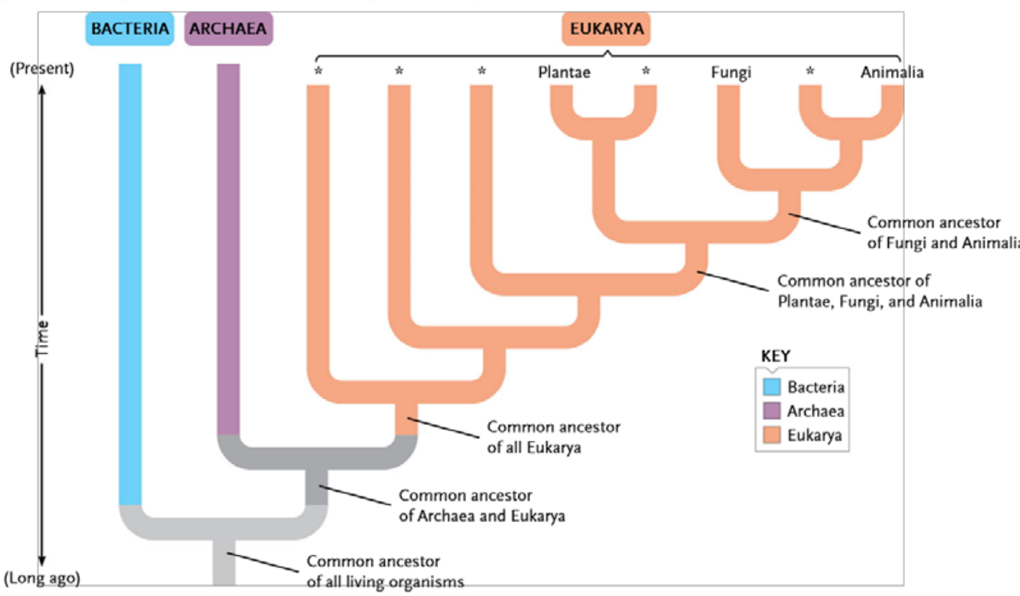
I. Organizing Biodiversity: the Three Domains of Life *(009-014)*

II. Characteristics of Animals *(706-708)*
  A. Cellular Characteristics
  B. Organismal Characteristics

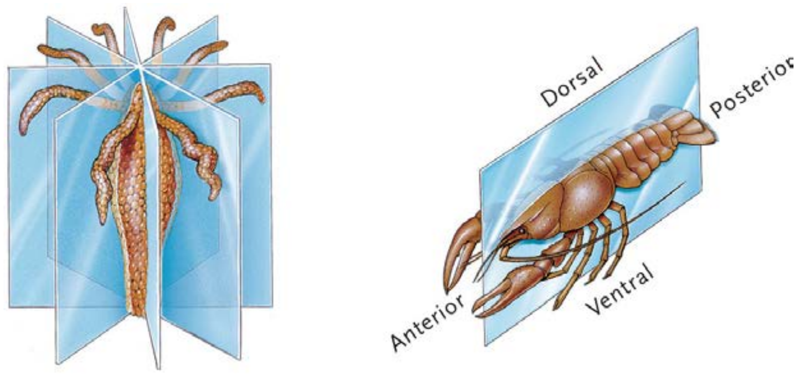
III. Animal Diversity: Body Plans and Complexity *(708-713)*
  A. Phylogenetic Trees
    1. Definition
    2. Understanding animal diversity
  B. Subkingdoms of Animals
    1. Parazoa
    2. Eumetazoa
  C. Branches of the Subkingdom Eumetazoa
    1. Radiata
    2. Bilateria
  D. Body Plans and Body Cavities

01-1

An overview of the Tree of Life illustrates the relationships between the three domains. Branches and twigs are not included for Bacteria and Archaea. The branches of the Eukarya include three well-defined kingdoms (Plantae, Fungi, and Animalia), as well as five groups of organisms that were once collectively described as protists (marked with *); biologists have not yet clarified their evolutionary relationships.

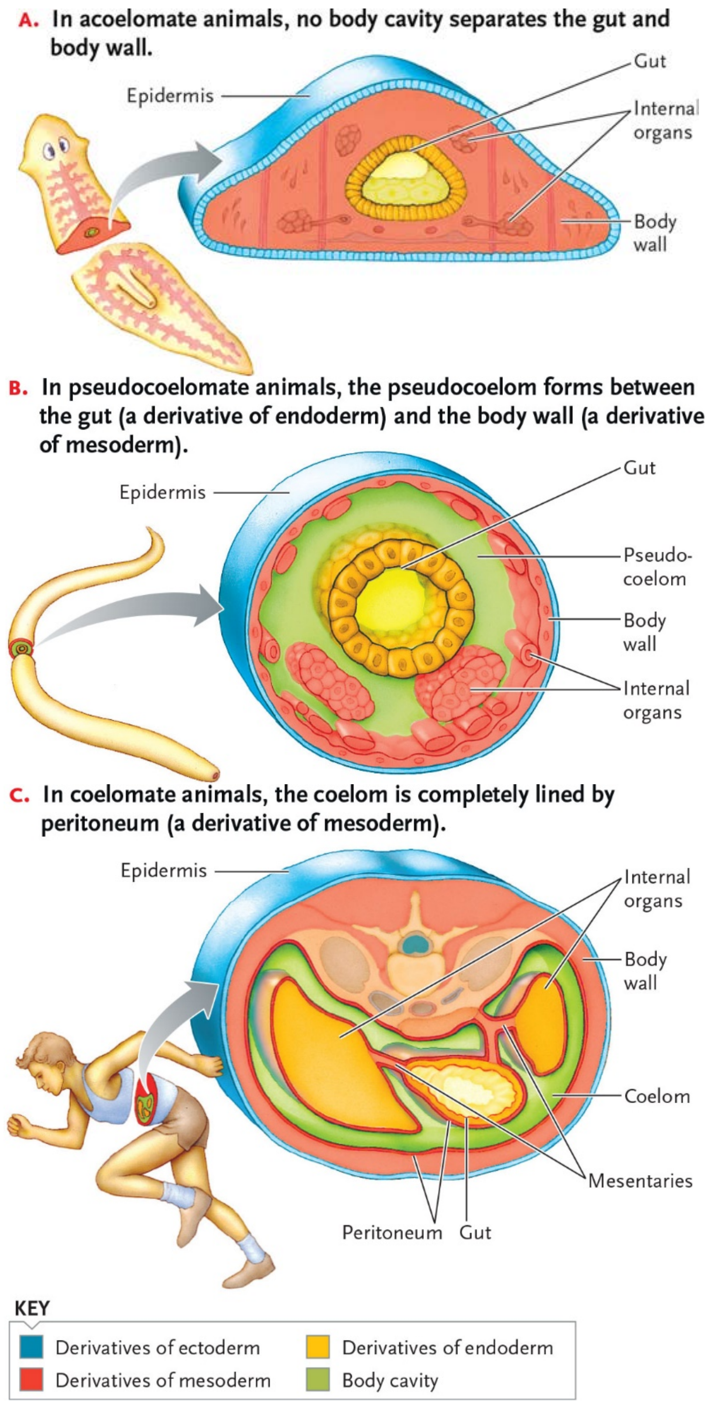


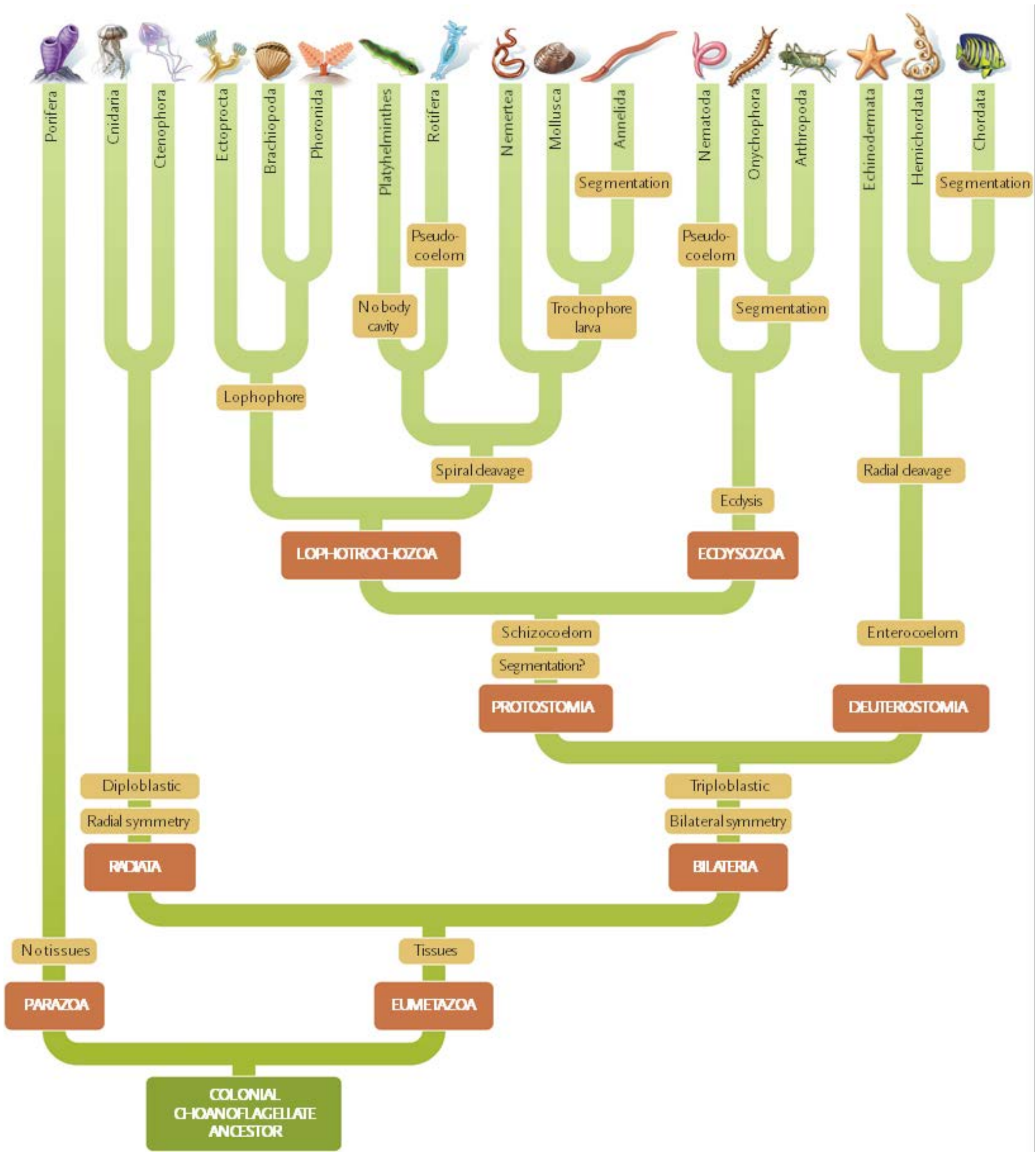
SUMMARY Phylogenetic trees contain more information than simple hierarchical classifications do because the trees illustrate which ancestors gave rise to which descendants, as well as when those evolutionary events occurred. Each fork between trunks, branches, and twigs on the phylogenetic tree represents an evolutionary event in which one ancestral species gave rise to two descendant species. Detailed phylogenetic trees illustrate how, over time, descendant species gave rise to their own descendants, producing the great diversity of life.



Radial symmetry

Bilateral symmetry





Porifera
Cnidaria
Ctenophora
Ectoprocta
Brachiopoda
Phoronida
Platyhelminthes
Rotifera
Nemertea
Mollusca
Annelida
Nematoda
Onychophora
Arthropoda
Echinodermata
Hemichordata
Chordata
Segmentation
Pseudo-coelom
Segmentation
Pseudo-coelom
No body cavity
Trochophore larva
Segmentation
Lophophore
Spiral cleavage
Radial cleavage
Ecdysis
LOPHOTROCHOZOA
ECDYSOZOA
Schizocoelom
Segmentation?
Enterocoelom
PROTOSTOMIA
DEUTEROSTOMIA
Diploblastic
Radial symmetry
Triploblastic
Bilateral symmetry
RADIATA
BILATERIA
No tissues
Tissues
PARAZOA
EUMETAZOA
COLONIAL CHOANOFLAGELLATE ANCESTOR

2. Nutrients and Energy Acquisition *Chapter 47*

I. Heterotrophy: A Functional View *(1093-1095)*

- A. Nutrient and Energy Needs
  1. The metabolism equation
  2. Energy for metabolism
  3. Bulk nutrients *versus* trace nutrients
- B. Steps in Energy and Nutrient Acquisition
  1. Food acquisition
  2. Mechanical processing
  3. Chemical processing
  4. Absorption
  5. Elimination of Wastes

II. Digestive Systems: A Structural View *(1096-1109)*

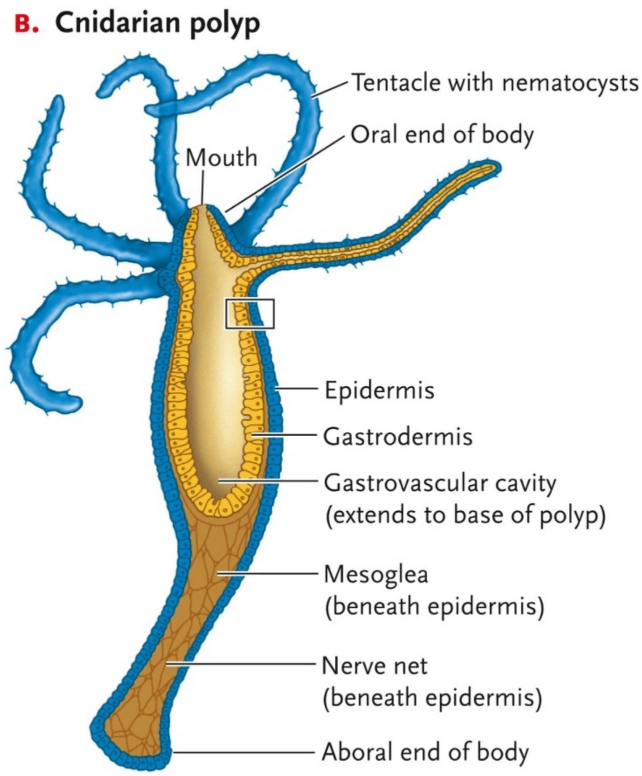
- A. Digestive Cavities
- B. Digestive Tracts

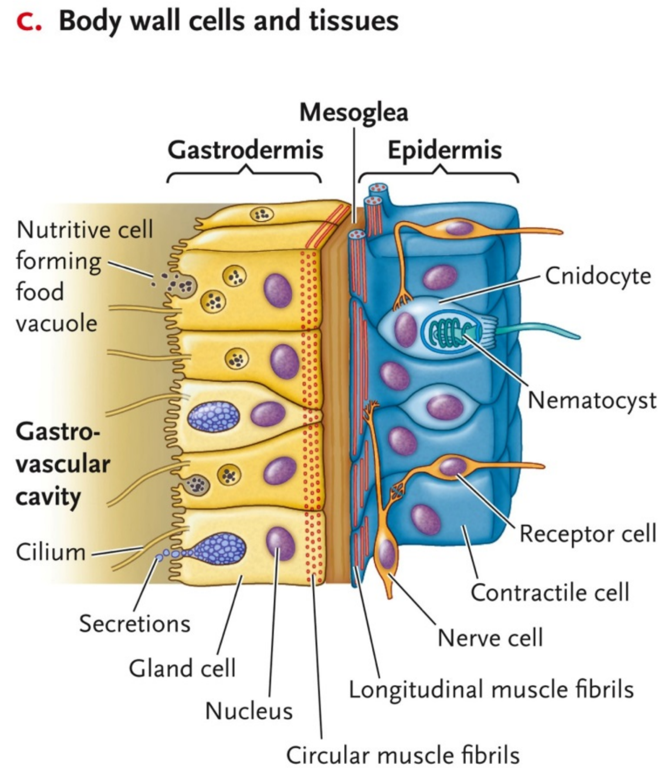
III. Herbivores *(1110-1114)*

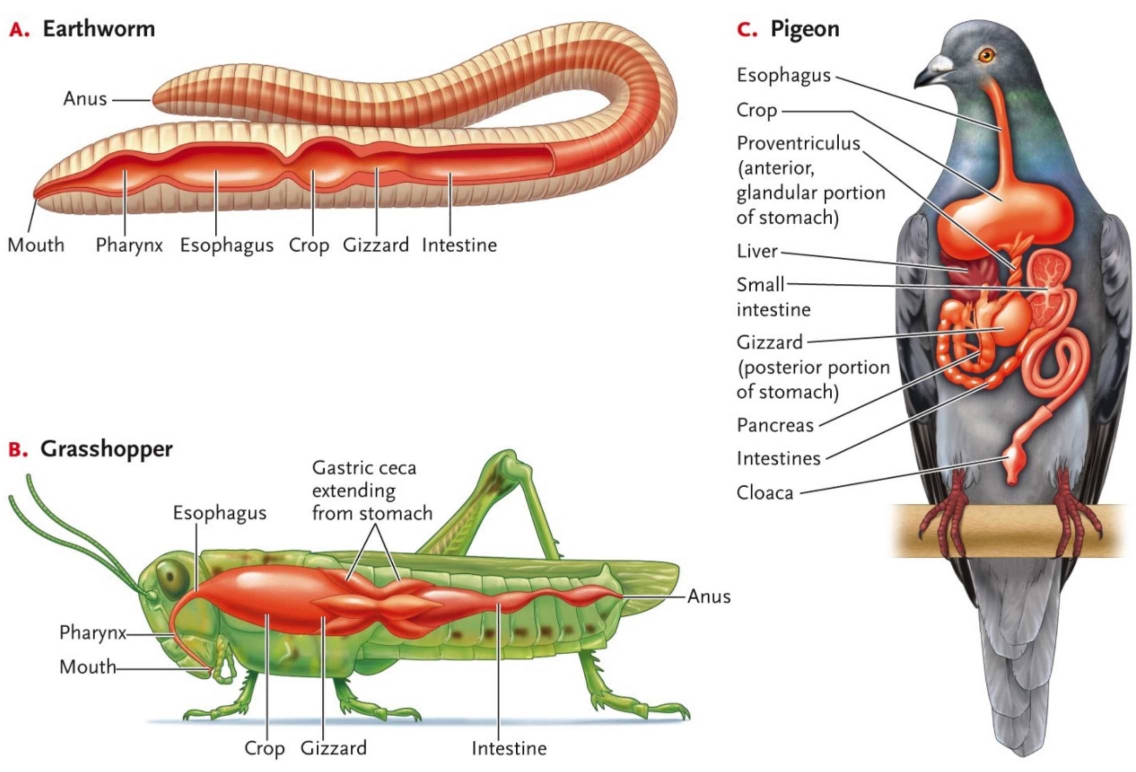
- A. Plants as Food
  1. Indigestibility of cellulose
  2. Low energy and nutrient yield
  3. Self-defense by plants
- B. Structures for Mechanical Processing
- C. Chemical Processing and Digestive Endosymbionts in Mammals
  1. Types of symbionts
  2. Ruminants and their cud
  3. Small non-ruminant mammals

V. Carnivores *(1110-1114)*

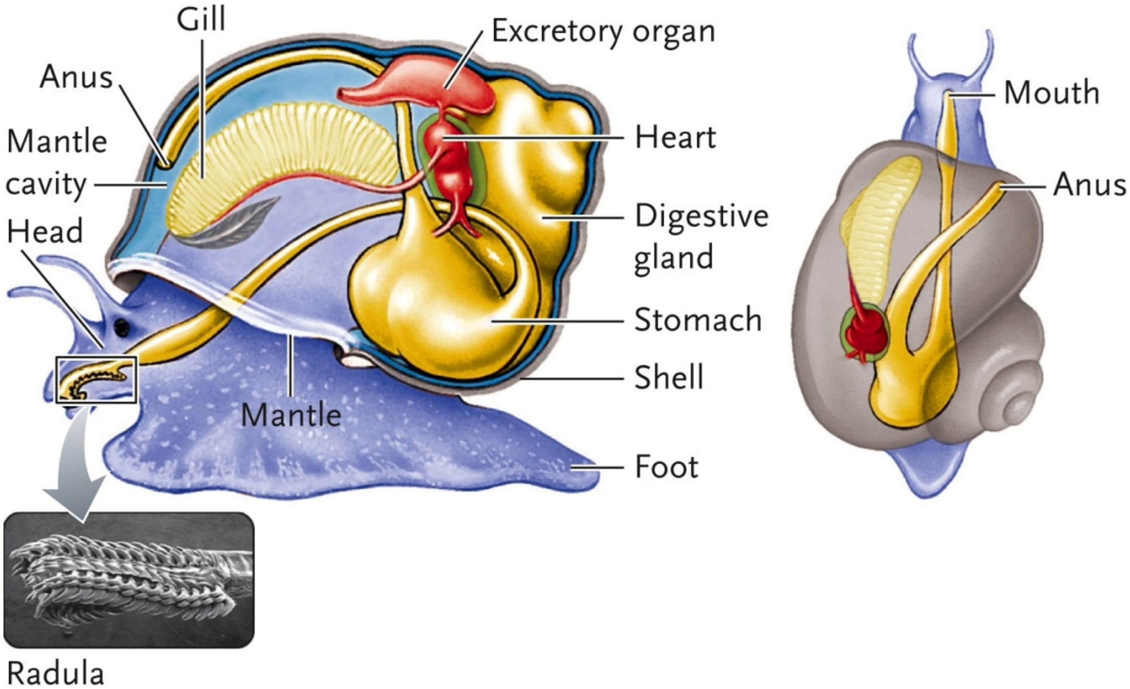
- A. Meat as Food
  1. High quality
  2. Digestibility
- B. Structures of Teeth


B. Cnidarian polyp
Tentacle with nematocysts
Oral end of body
Mouth
Epidermis
Gastrodermis
Gastrovascular cavity
(extends to base of polyp)
Mesoglea
(beneath epidermis)
Nerve net
(beneath epidermis)
Aboral end of body

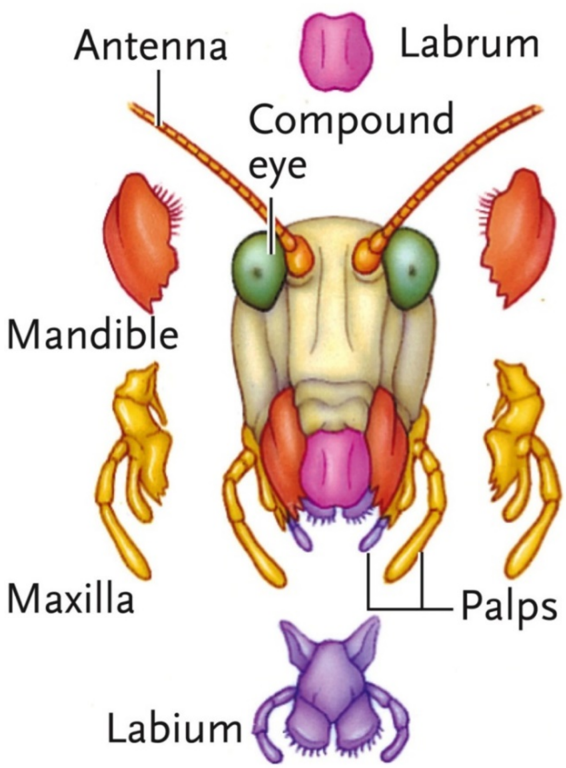

C. Body wall cells and tissues
Mesoglea
Gastrodermis
Epidermis
Nutritive cell forming food vacuole
Gastro-vascular cavity
Cilium
Secretions
Gland cell
Nucleus
Circular muscle fibrils
Longitudinal muscle fibrils
Nerve cell
Contractile cell
Receptor cell
Nematocyst
Cnidocyte

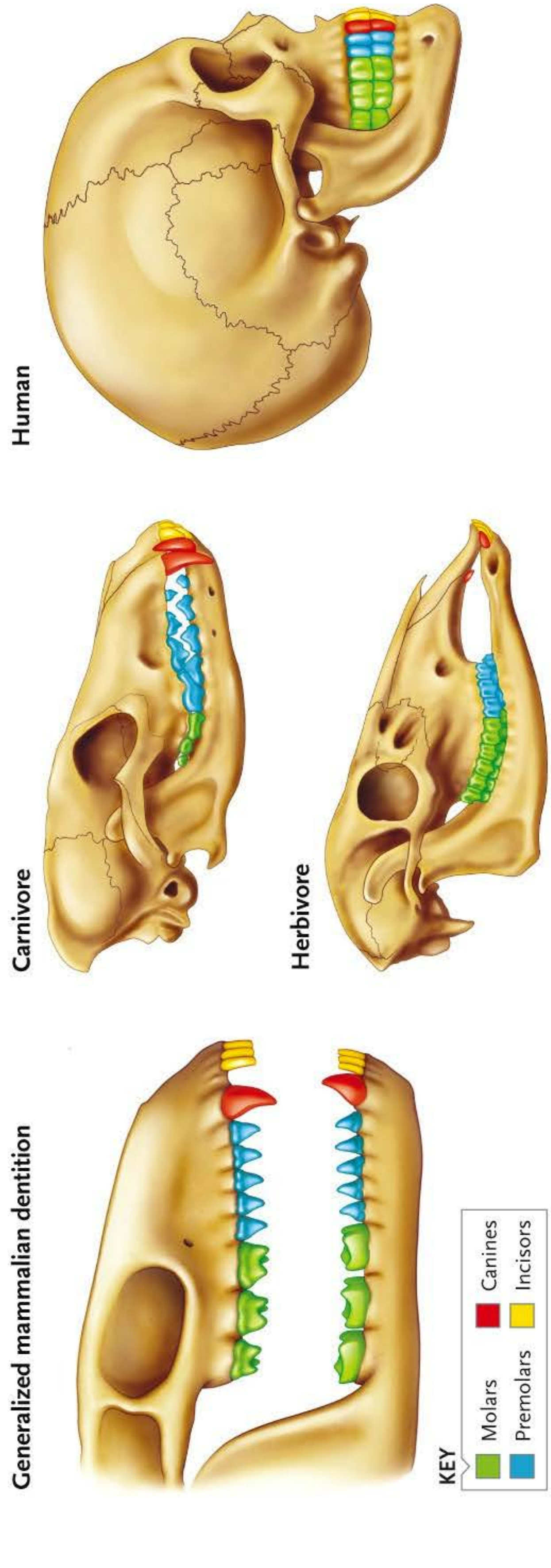

A. Earthworm
Anus
Mouth
Pharynx
Esophagus
Crop
Gizzard
Intestine
B. Grasshopper
Esophagus
Gastric ceca extending from stomach
Anus
Pharynx
Mouth
Crop
Gizzard
Intestine
C. Pigeon
Esophagus
Crop
Proventriculus (anterior, glandular portion of stomach)
Liver
Small intestine
Gizzard (posterior portion of stomach)
Pancreas
Intestines
Cloaca

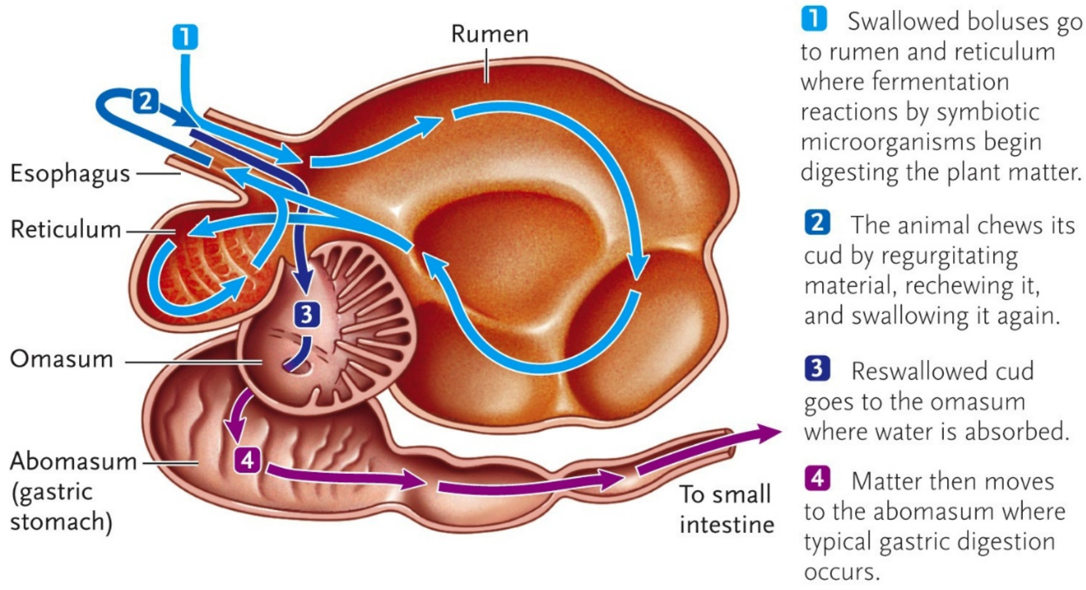
A. Gastropod body plan

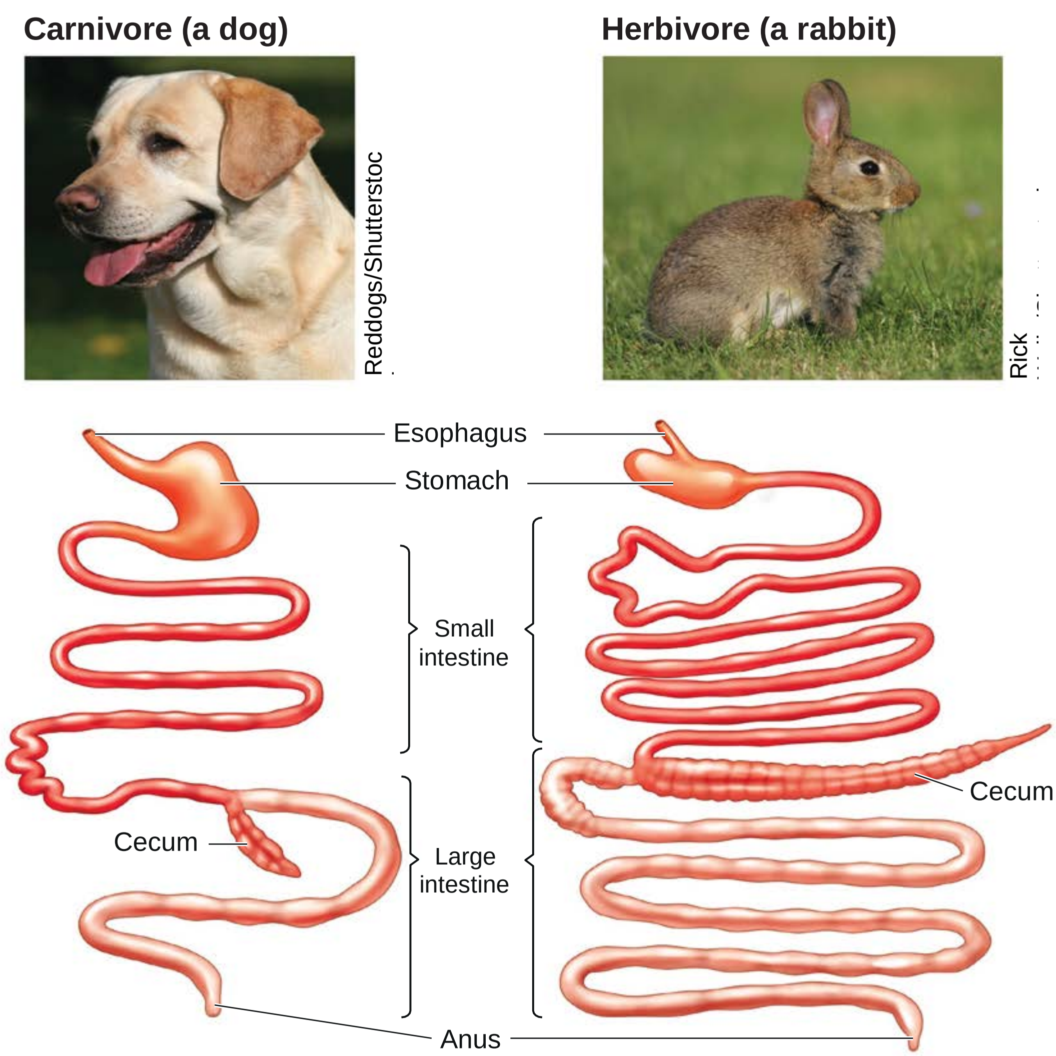


A. Grasshopper




Generalized mammalian dentition
KEY
Molars
Premolars
Canines
Incisors
Carnivore
Herbivore
Human


Rumen
Esophagus
Reticulum
Omasum
Abomasum (gastric stomach)
To small intestine
1 Swallowed boluses go to rumen and reticulum where fermentation reactions by symbiotic microorganisms begin digesting the plant matter.
2 The animal chews its cud by regurgitating material, rechewing it, and swallowing it again.
3 Reswallowed cud goes to the omasum where water is absorbed.
4 Matter then moves to the abomasum where typical gastric digestion occurs.


Carnivore (a dog)
Herbivore (a rabbit)
Reddogs/Shutterstoc
Rick
Esophagus
Stomach
Small intestine
Large intestine
Cecum
Cecum
Anus

3. Gas Exchange and Respiratory Systems of Animals *Ch 46*

I. Introduction *(1074-1077)*

- A. Evolution of the Atmosphere and Oxygen Consumption
- B. Anaerobic versus Aerobic Metabolism
- C. Structures Necessary for Respiration

II. Diffusion: The Physical Mechanism of Oxygen Acquisition *(1074-1077)*

- A. Diffusion
  1. Definition
  2. Importance
- B. Factors Affecting Diffusion Rates
  1. Concentration differences
  2. Area across which diffusion occurs
  3. Density of medium
- C. Oxygen Availability in Different Habitats

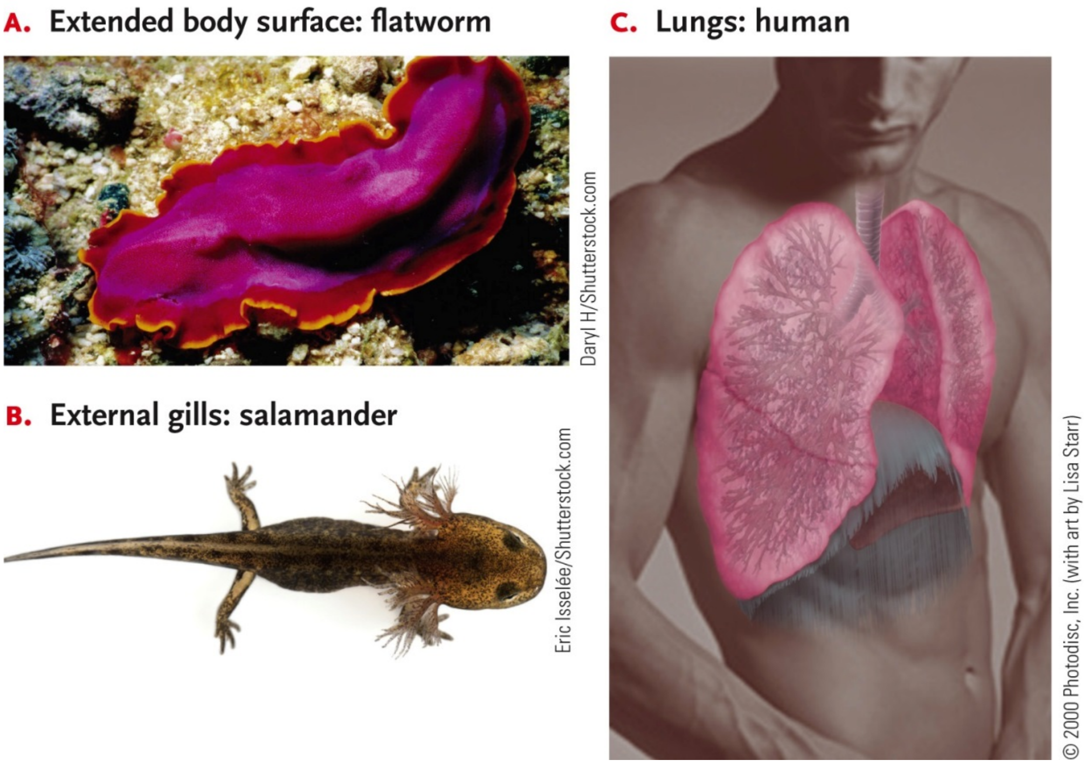
III. Respiratory Surfaces *(1077-1079)*

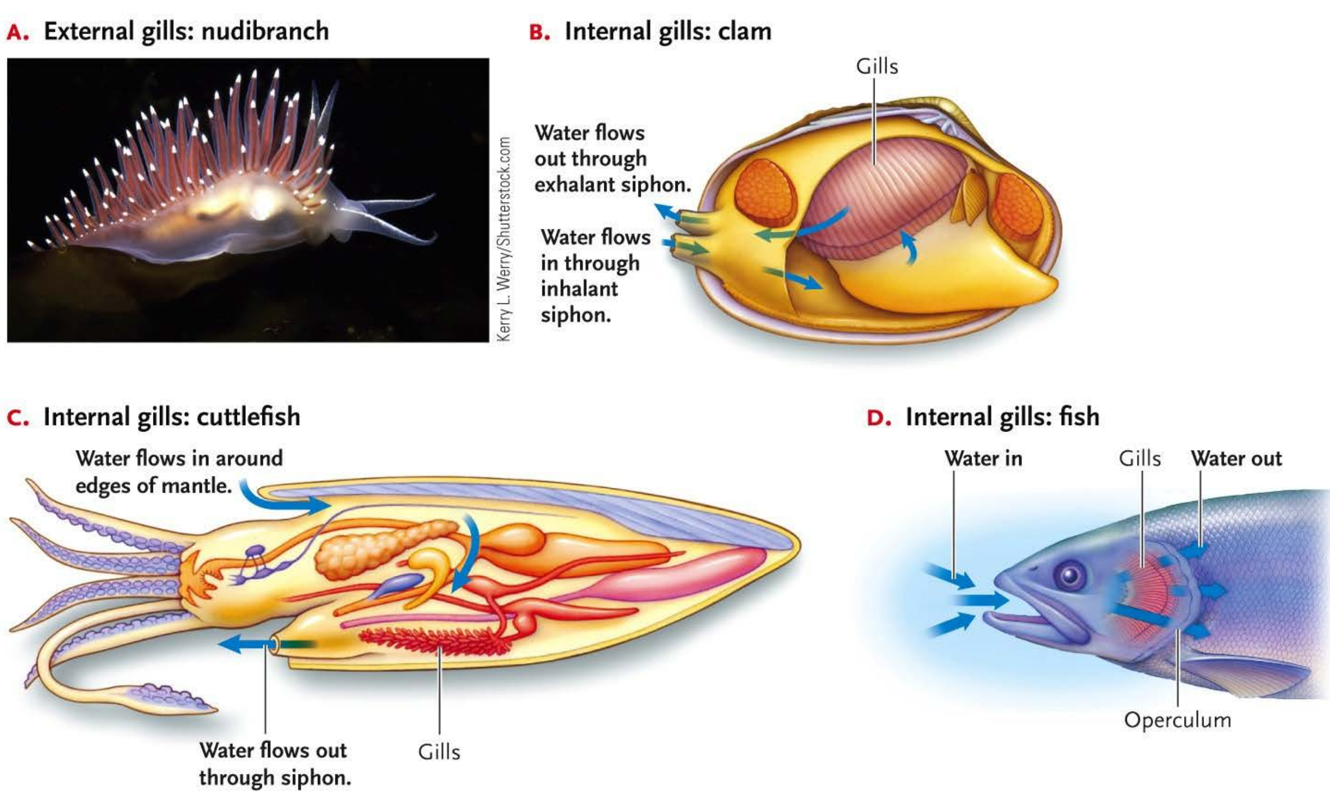
- A. Respiration Across Unspecialized Surfaces
  1. Diffusion across body surfaces
  2. Ventilation
- B. Body Size and Specialized Respiratory Surfaces
- C. Countercurrent Exchangers
  1. How they do not work
  2. How they do work
  3. General importance in biology
  4. Example from fish gill
  5. Carbon dioxide elimination

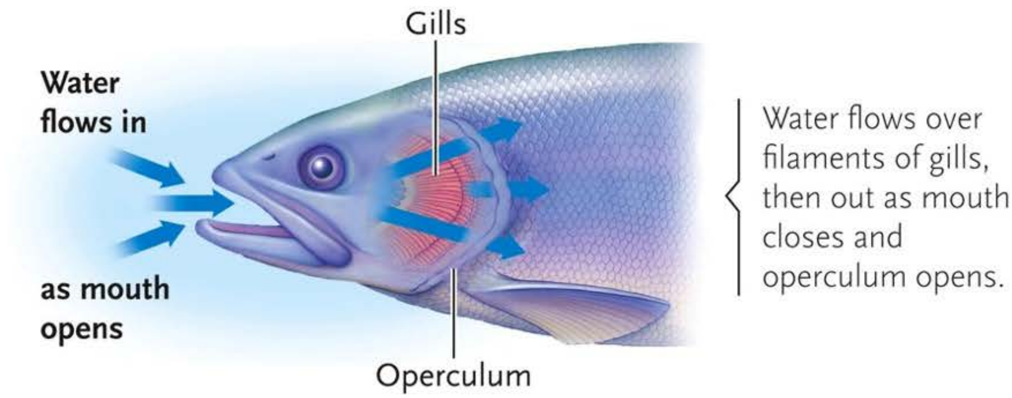
IV. Tracheal Systems in Insects *(1078-1079)*

V. Respiratory Structures in Vertebrates *(1079-1083)*

- A. Fishes
- B. Amphibians
- C. Mammals

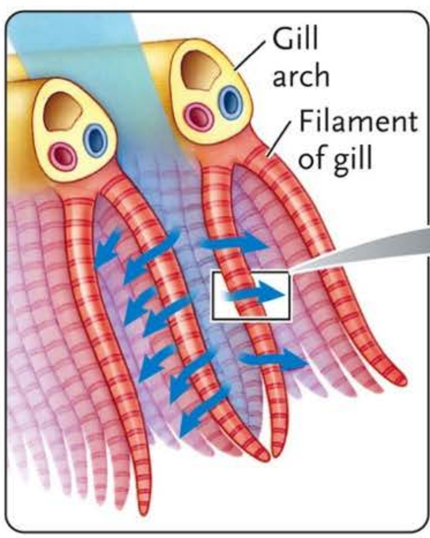

A. Extended body surface: flatworm
Daryl H/Shutterstock.com
B. External gills: salamander
Eric Isselée/Shutterstock.com
C. Lungs: human
© 2000 Photodisc, Inc. (with art by Lisa Starr)

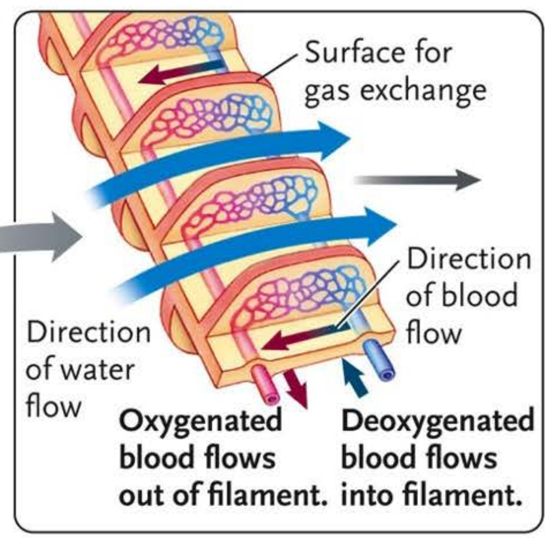

A. External gills: nudibranch
Kerry L. Werry/Shutterstock.com
B. Internal gills: clam
Gills
Water flows out through exhalant siphon.
Water flows in through inhalant siphon.
C. Internal gills: cuttlefish
Water flows in around edges of mantle.
Water flows out through siphon.
Gills
D. Internal gills: fish
Water in
Gills
Water out
Operculum



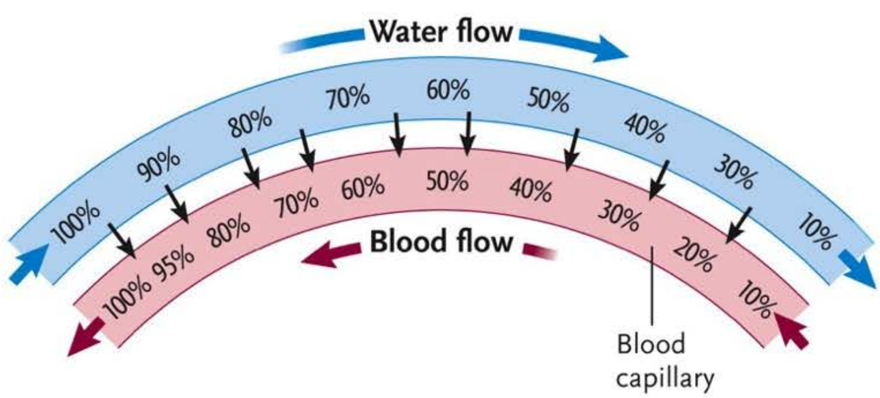
A. The flow of water around the gill filaments

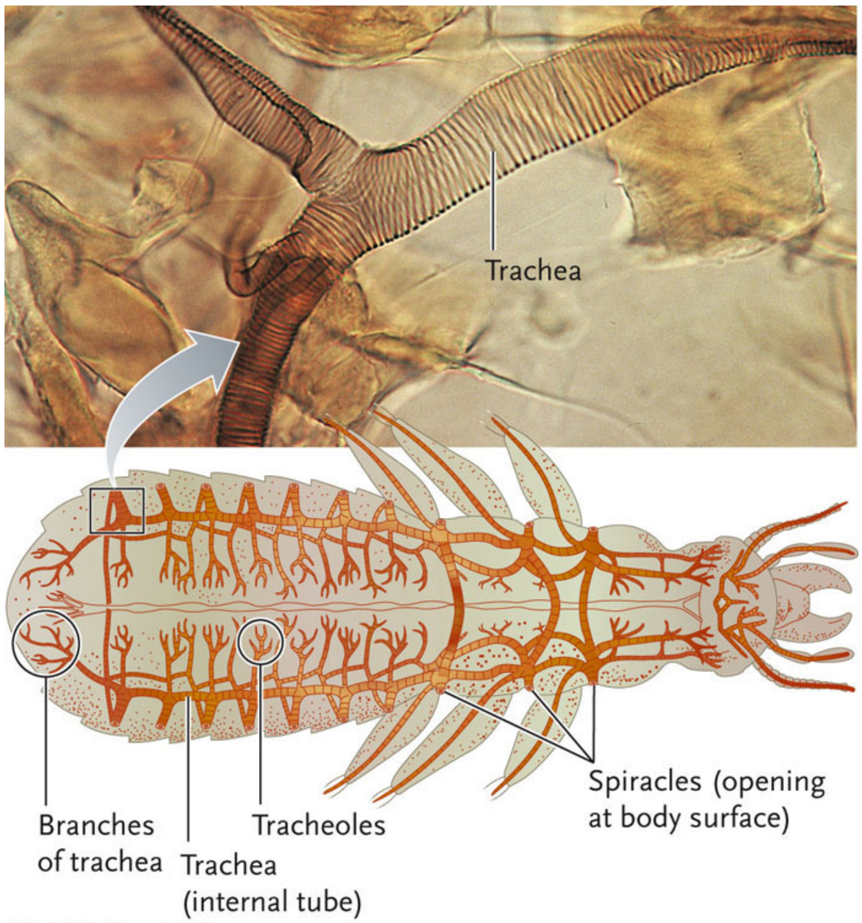
B. Countercurrent flow in fish gills, in which the blood and water move in opposite directions

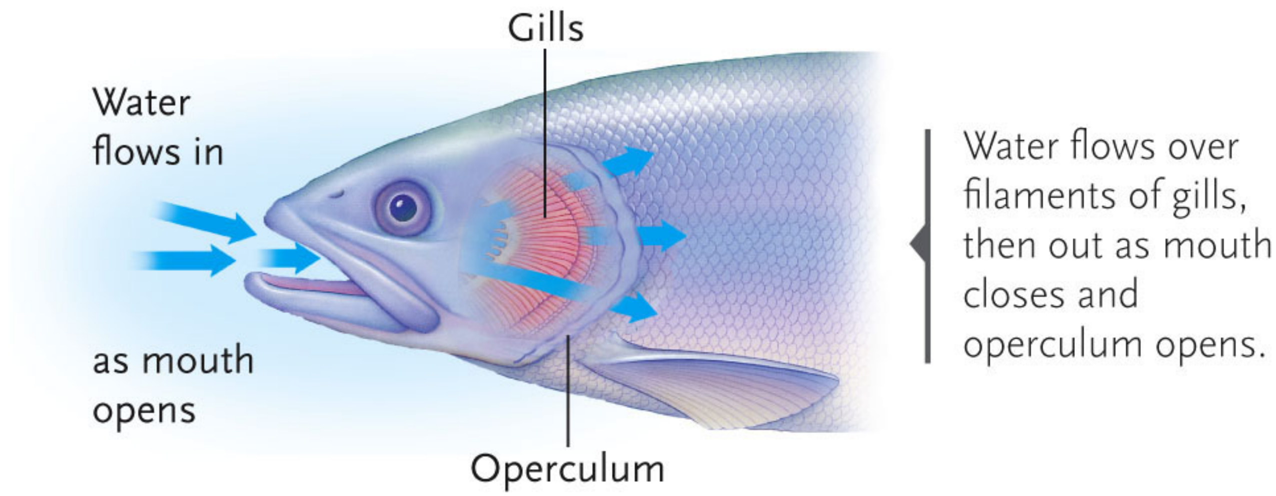


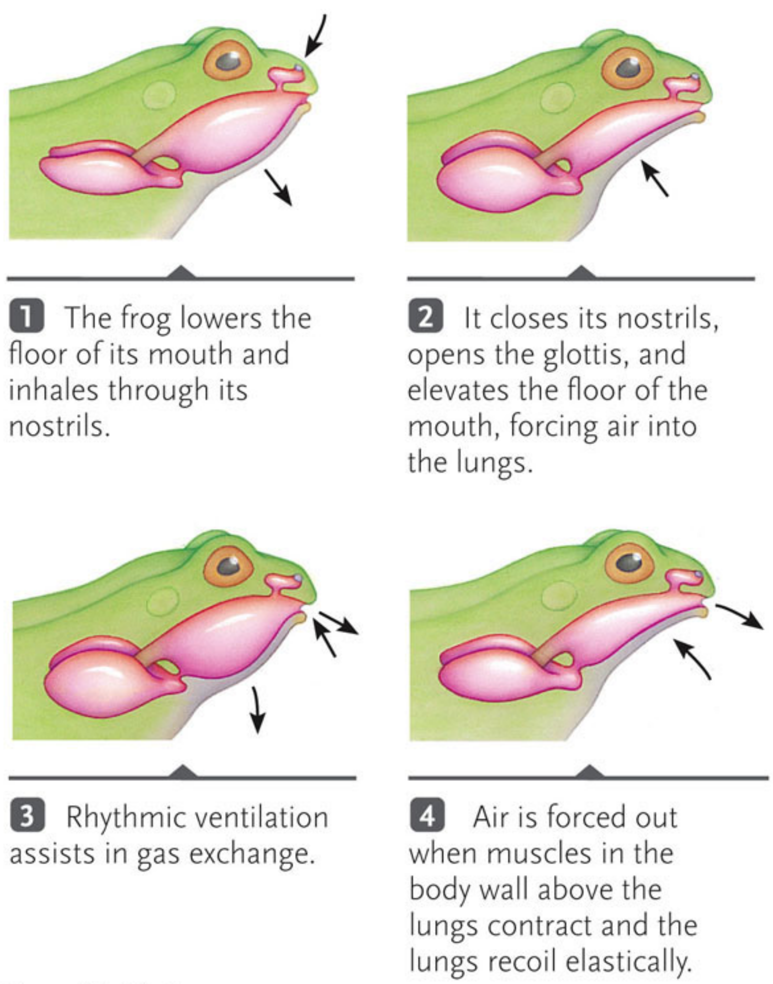


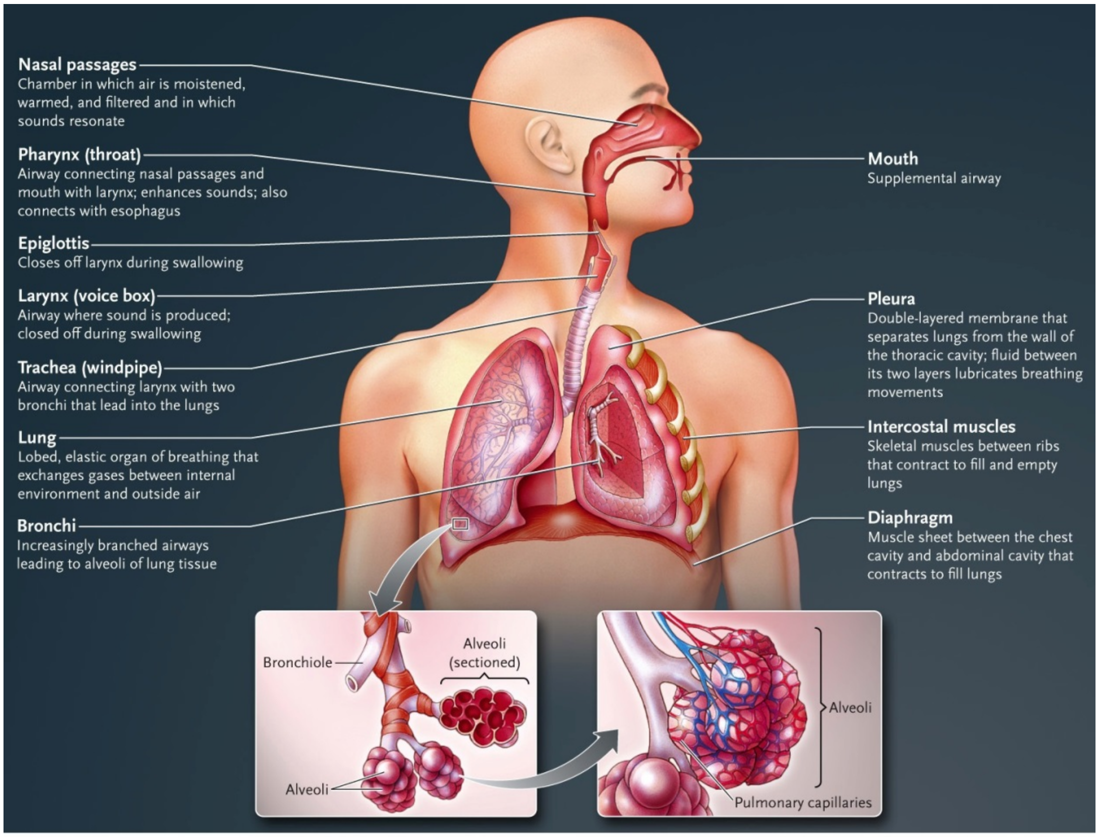
C. In countercurrent exchange, blood leaving the capillaries has the same O_2 content as fully oxygenated water entering the gills

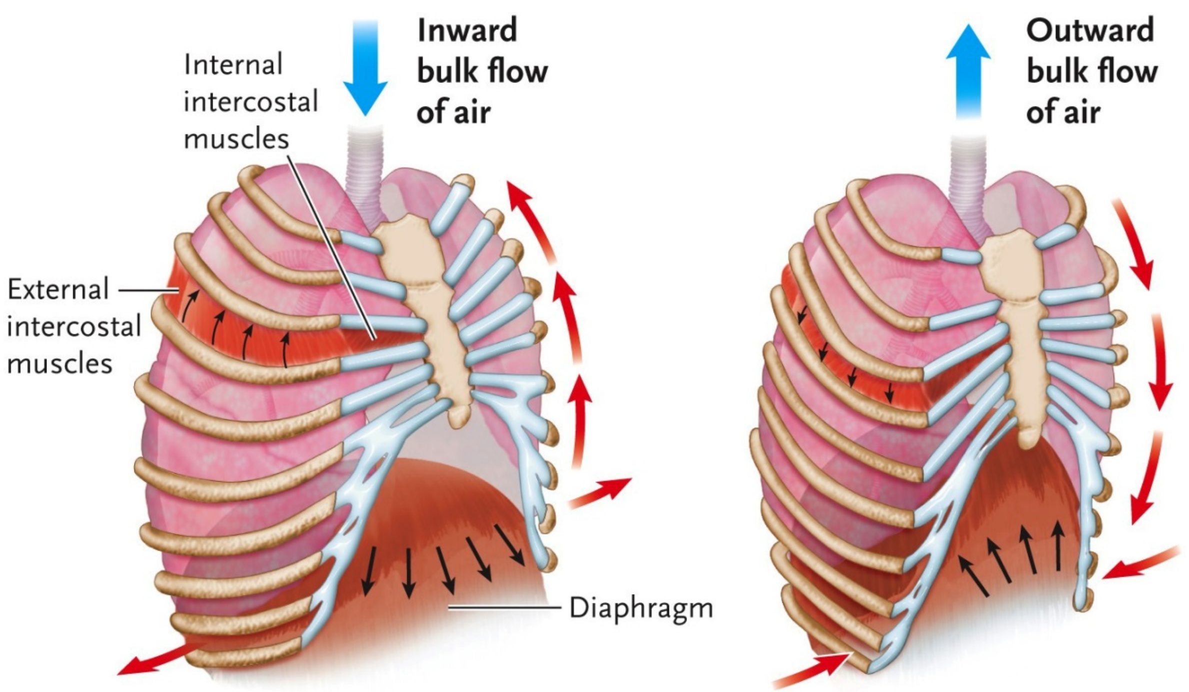



Trachea
Branches
of trachea
Trachea
(internal tube)
Tracheoles
Spiracles (opening
at body surface)


Gills
Water flows in
as mouth opens
Operculum
Water flows over filaments of gills, then out as mouth closes and operculum opens.


1 The frog lowers the floor of its mouth and inhales through its nostrils.
2 It closes its nostrils, opens the glottis, and elevates the floor of the mouth, forcing air into the lungs.
3 Rhythmic ventilation assists in gas exchange.
4 Air is forced out when muscles in the body wall above the lungs contract and the lungs recoil elastically.





Inhalation.
Diaphragm contracts and moves down. The external intercostal muscles contract and lift rib cage upward and outward. The lung volume expands.

Exhalation during breathing or rest.
Diaphragm and external intercostal muscles return to the resting positions. Rib cage moves down. Lungs recoil passively.

4. Evolution of Circulatory Systems: Structure and Function *Ch 44*

I. Introduction *(1031)*

- A. Evolution of Complexity: Body Size and Body Cavities
- B. Transport Functions of Circulatory Systems

II. Structure and Function of Circulatory Systems *(1032-1034, 1042-1045)*

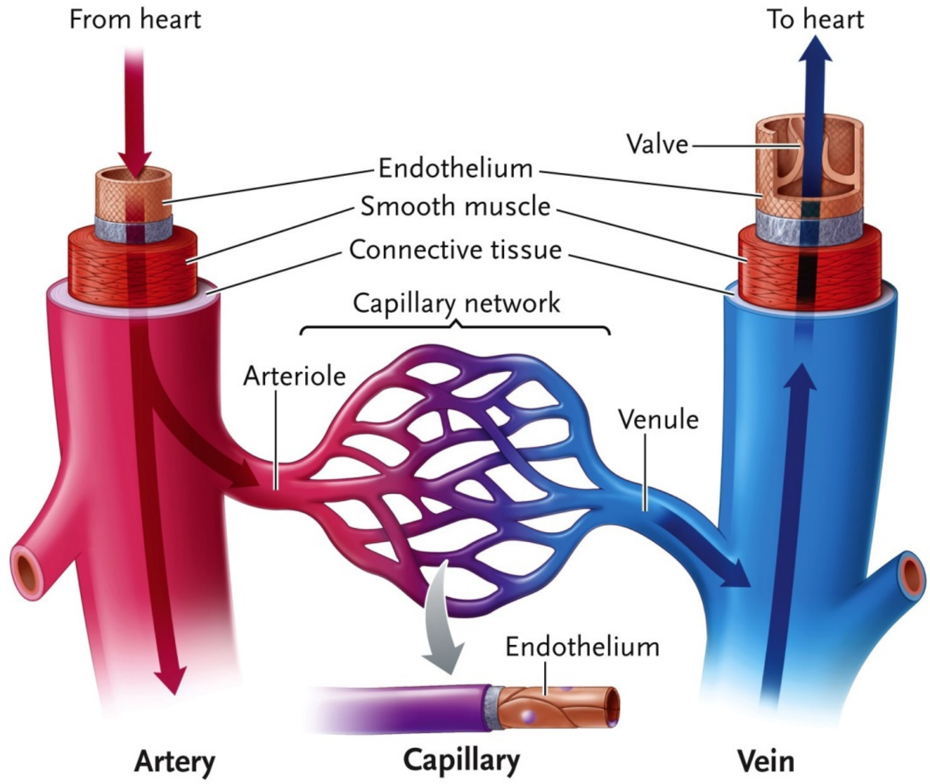
- A. Basic Structural Units
  1. Hearts
  2. Arteries and arterioles
  3. Venules and veins
  4. Valves
  5. Capillary beds
- B. Capillary Function
  1. hydrostatic pressure
  2. osmotic pressure
- C. Open *versus* Closed Circulatory Systems
- D. Circulatory Circuits
  1. Pulmonary
  2. Systemic

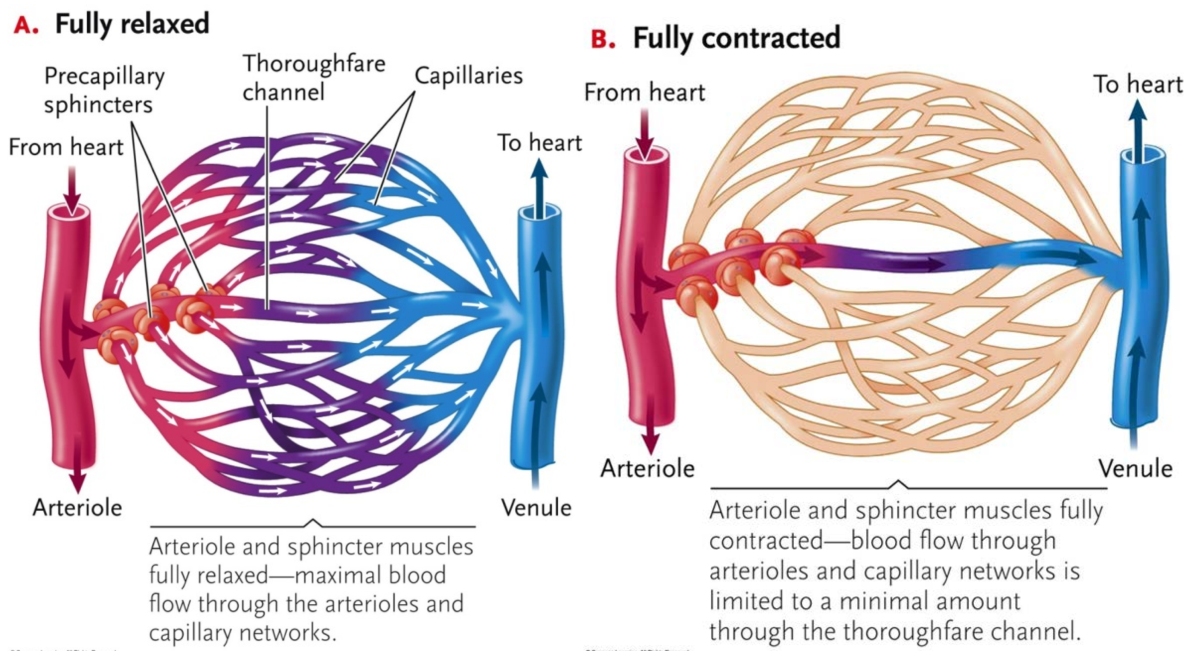
III. Circulatory Systems in Invertebrates *(1032-1033)*

- A. Mollusks
  1. General pattern of circulation
  2. Closed systems in Cephalopoda
- B. Insects
  1. Relation to respiratory structures
  2. Vessels and blood tracing
  3. Functioning of the tube heart

IV. Circulatory Systems in Vertebrates *(1033-1034)*

- A. General Characteristics
- B. Fishes
  1. Gills and oxygen acquisition
  2. Circuitry and heart structure
- C. Amphibians and Reptiles
  1. Lungs and oxygen acquisition
  2. Circuitry and heart structure
- D. Birds and Mammals
  1. Circuitry
  2. Heart structure
  3. Functional significance
  4. Analogy of systems


From heart
To heart
Valve
Endothelium
Smooth muscle
Connective tissue
Capillary network
Arteriole
Venule
Endothelium
Artery
Capillary
Vein


A. Fully relaxed
Precapillary sphincters
Thoroughfare channel
Capillaries
From heart
To heart
Arteriole
Venule
Arteriole and sphincter muscles fully relaxed—maximal blood flow through the arterioles and capillary networks.
B. Fully contracted
From heart
To heart
Arteriole
Venule
Arteriole and sphincter muscles fully contracted—blood flow through arterioles and capillary networks is limited to a minimal amount through the thoroughfare channel.

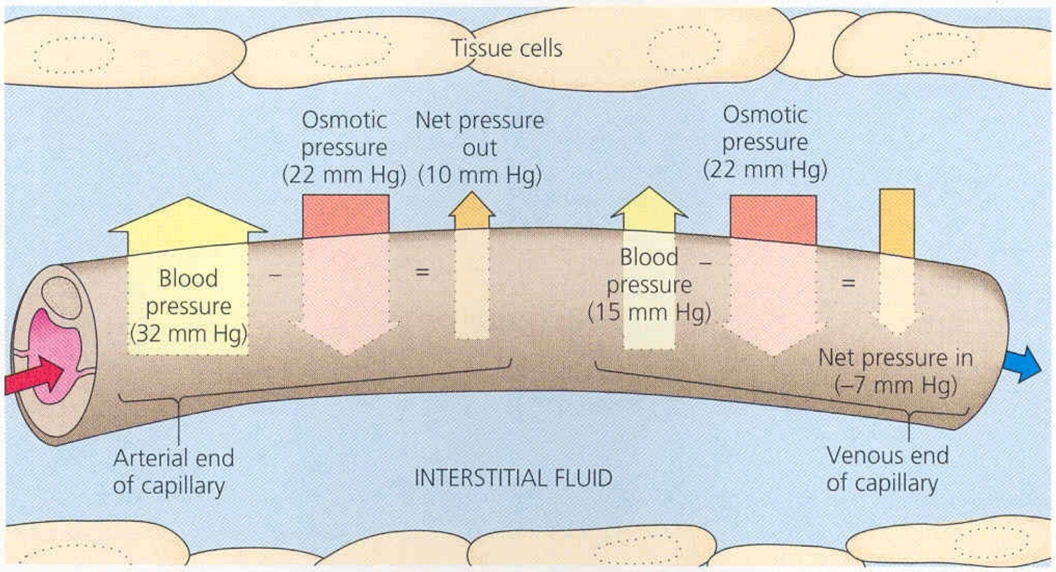
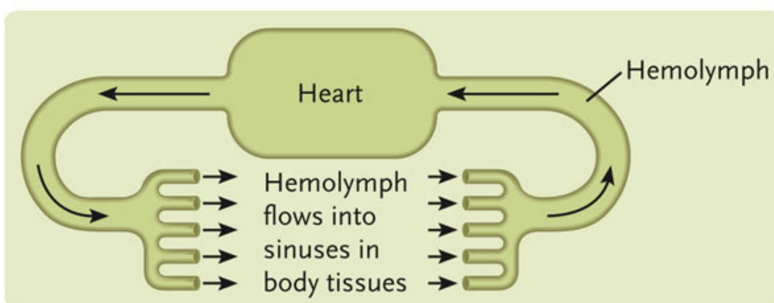


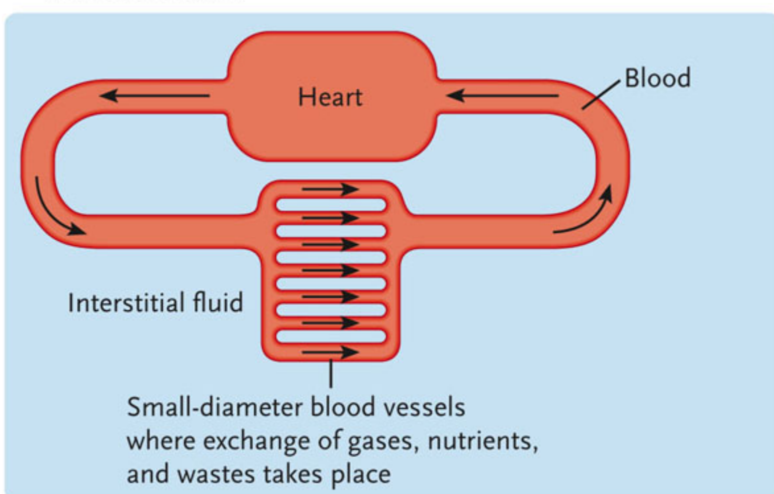
FIGURE 42.13 The movement of fluid between capillaries and the interstitial fluid. Fluid flows out of a capillary at the upstream end near an arteriole and reenters a capillary downstream near a venule. The direction of fluid movement across the capillary wall at any point depends on the difference between two opposing forces: blood pressure and osmotic pressure.

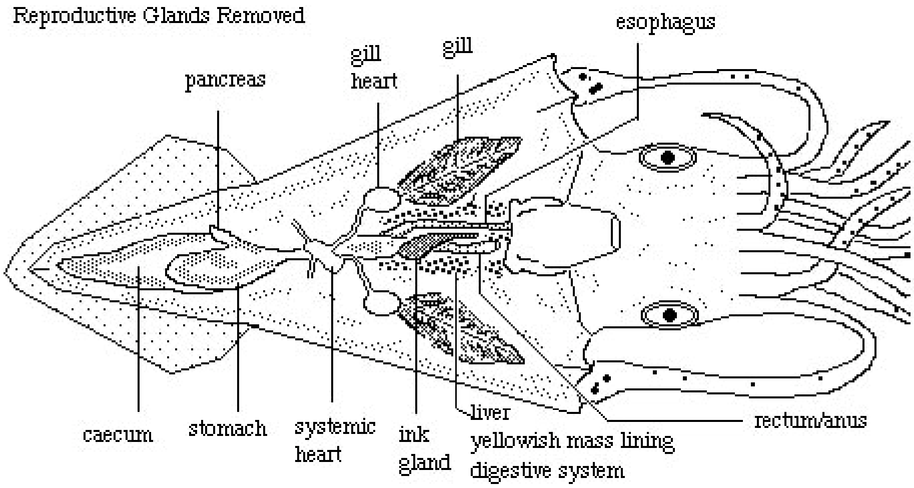
---

a. Open circulatory system: no distinction between hemolymph and interstitial fluid

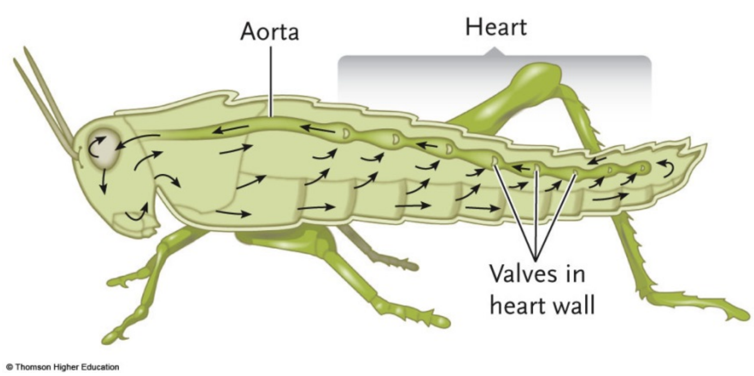


b. Closed circulatory system: blood separated from interstitial fluid



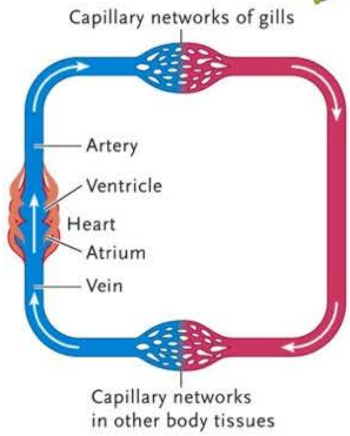


SQUID



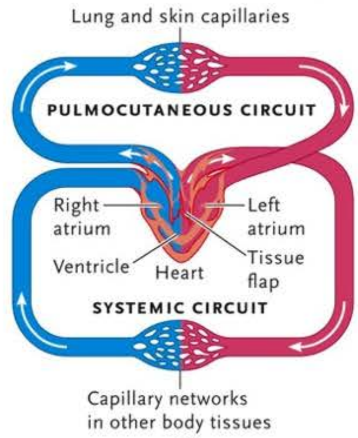
INSECT

A. Circulatory system of fishes



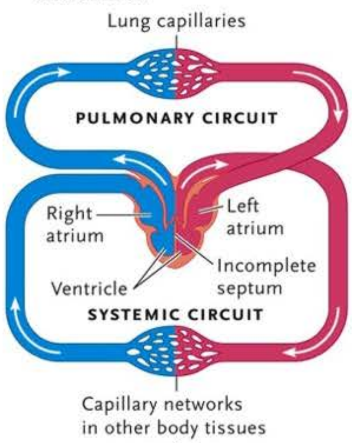
In fishes, the heart consists of a series of two chambers and pumps blood into one circuit. The ventricle pumps blood into arteries that lead to the capillary networks of the gills, where the blood releases CO_2 and picks up O_2. The oxygenated blood flows through other arteries to capillary networks in other body tissues where it releases O_2 and picks up CO_2. The deoxygenated blood enters veins that carry it to the atrium of the heart.

B. Circulatory system of amphibians



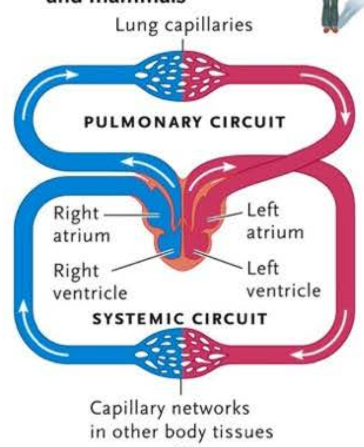
In amphibians, the three-chambered heart pumps blood through two circuits. Oxygenated blood from the lungs and skin enters veins that lead to the left atrium, while deoxygenated blood from the rest of the body enters the right atrium. The atria contract simultaneously, pumping oxygenated and deoxygenated blood in the single ventricle. The two types of blood remain largely (90%) separate because of a smooth pattern of flow and a small tissue flap. Contraction of the ventricle moves most of the oxygenated blood into the systemic circuit, which delivers blood to most tissues and cells of the body. Deoxygenated blood moves into the pulmocutaneous circuit, which leads to the lungs and skin where CO_2 is released and O_2 is picked up.

C. Circulatory system of turtles, lizards, and snakes



In turtles, lizards, and snakes, an incomplete septum improves the separation of oxygenated blood from the lungs and deoxygenated blood from the rest of the body in the partially divided ventricle.

D. Circulatory system of crocodilians, birds, and mammals



In the four-chambered heart of crocodilians, birds, and mammals, a complete septum forms two ventricles and keeps the flow of oxygenated blood from the lungs and deoxygenated blood entirely separate from the rest of the body.

KEY

- Deoxygenated blood (blue)
- Oxygenated blood (red)

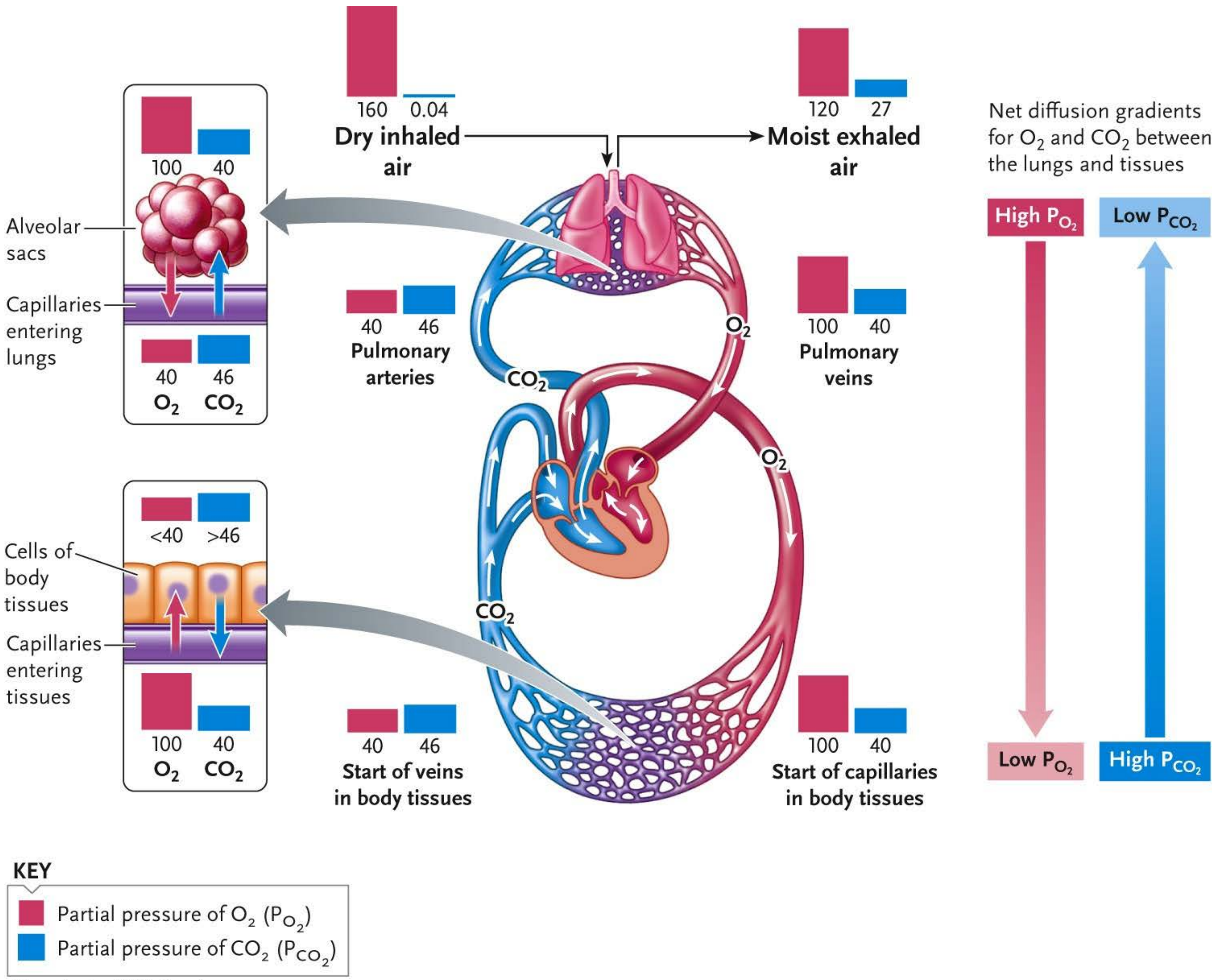
5. Vascular Fluids: Composition and Function *Ch 44, 46*

I. Introduction
- A. Functions of Circulatory Systems
- B. Body Fluids

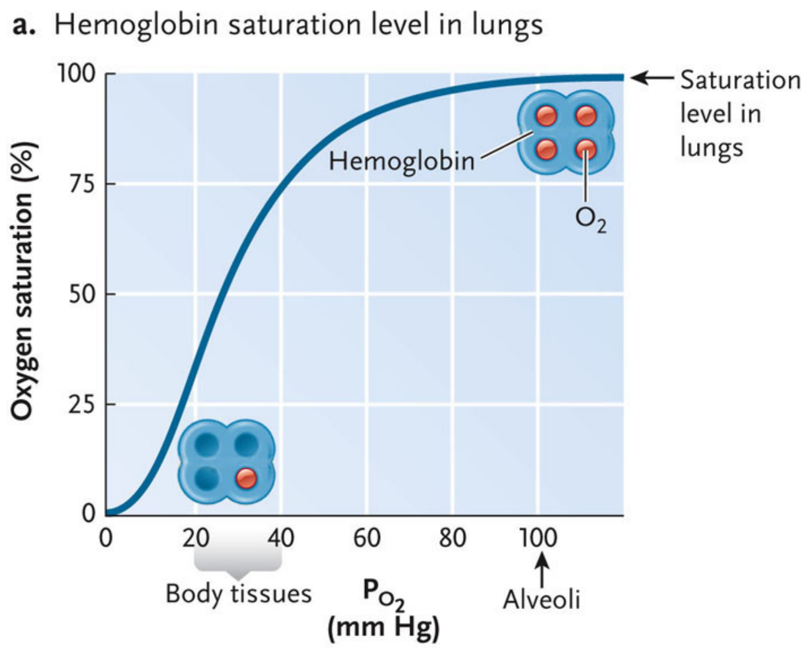
II. Composition of Blood *(1035-1038)*
- A. Plasma
  1. Water content
  2. Solutes
- B. Cell Types
  1. Erythrocytes
  2. Leukocytes
  3. Platelets

III. Oxygen Transport by Blood *(1083-1089)*
- A. Efficiency of Oxygen Delivery
- B. Respiratory Pigments
  1. Diversity of pigments
  2. General function
  3. Packaging of pigments
  4. Oxygen loading and unloading
- C. Functioning of Respiratory Pigments
  1. Partial pressure of a gas
  2. Oxygen dissociation curves
  3. Factors affecting dissociation curves
  4. Storage pigments
- D. Special Adaptations for Low Oxygen Availability
  1. Diving
  2. High altitudes

IV. Carbon Dioxide Elimination *(1085-1086)*
- A. The Problem of Acidosis
  1. Carbonic acid and bicarbonate ions
  2. Buffering of blood
- B. Elimination of Waste at Respiratory Surface

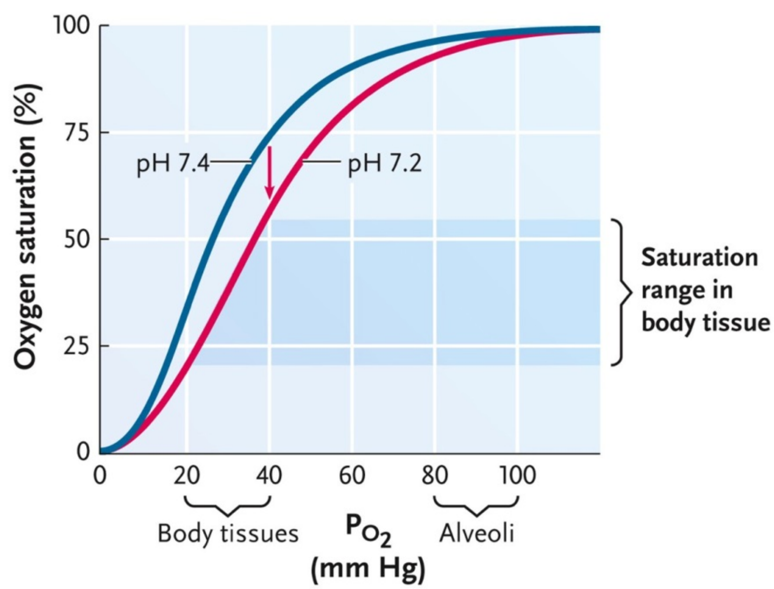


100 40
Alveolar sacs
Capillaries entering lungs
40 46
O2 CO2
<40 >46
Cells of body tissues
Capillaries entering tissues
100 40
O2 CO2
160 0.04
Dry inhaled air
120 27
Moist exhaled air
40 46
Pulmonary arteries
100 40
Pulmonary veins
CO2
O2
CO2
O2
CO2
40 46
Start of veins in body tissues
100 40
Start of capillaries in body tissues
Net diffusion gradients for O2 and CO2 between the lungs and tissues
High PO2
Low PCO2
Low PO2
High PCO2
KEY
Partial pressure of O2 (PO2)
Partial pressure of CO2 (PCO2)



In the alveoli, in which the P_{O_2} is about 100 mm Hg and the pH is 7.4, most hemoglobin molecules are 100% saturated, meaning that almost all have bound four O_2 molecules.

B. Body tissues



In the capillaries of body tissues, where the P_{O_2} varies between about 20 and 40 mm Hg depending on the level of metabolic activity and the pH is about 7.2, hemoglobin can hold less O_2. As a result, most hemoglobin molecules release two or three of their O_2 molecules to become between 25% and 50% saturated. The drop in pH to 7.2 (red line) in active body tissues reduces the amount of O_2 hemoglobin can hold as compared with pH 7.4. The reduction in binding affinity at lower pH increases the amount of O_2 released in active tissues.

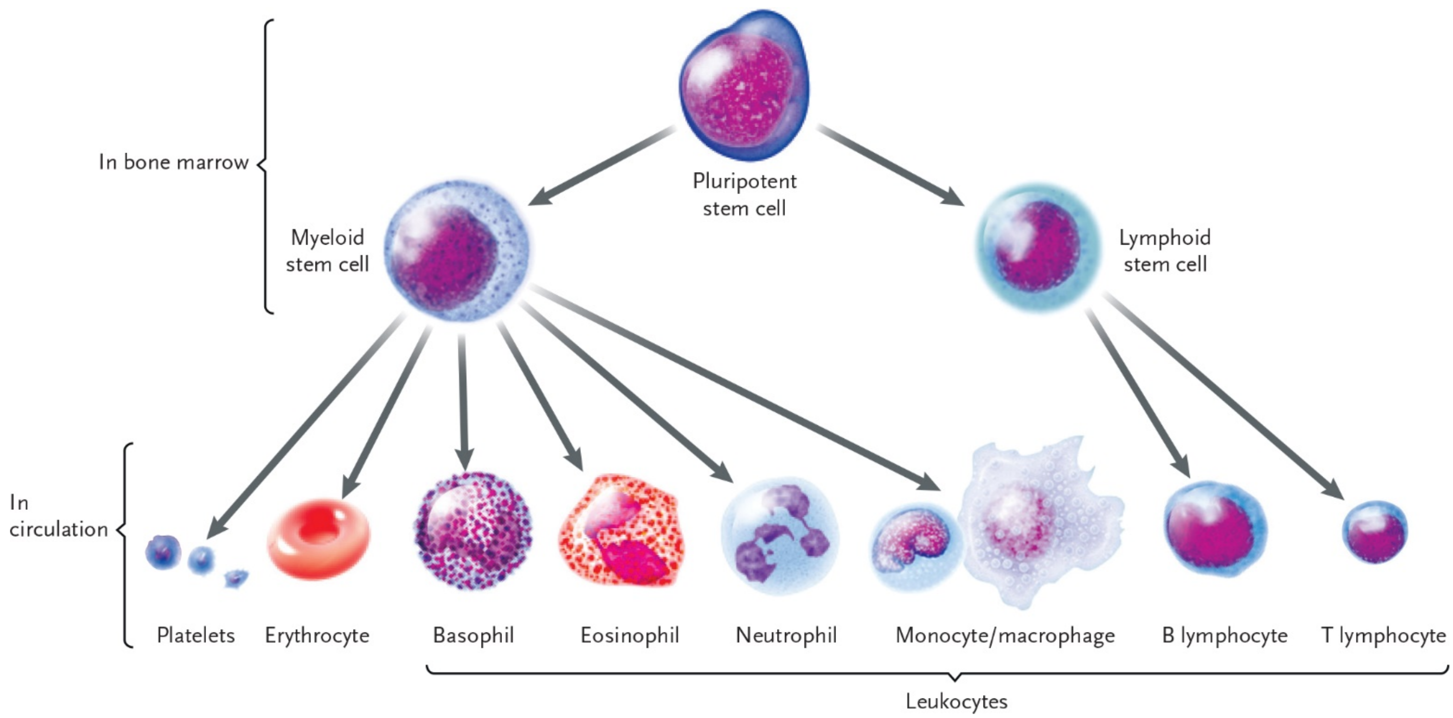
6. Immune System and Other Defenses *Ch 45*

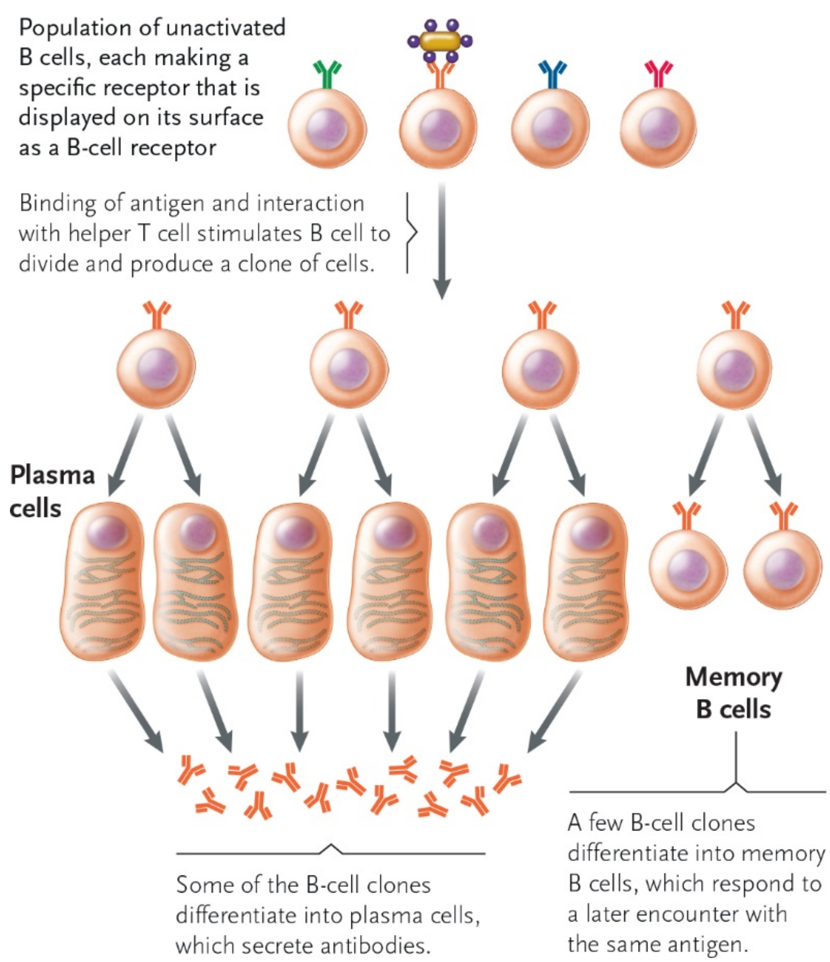
I. Defense Against Pathogens *(1052-1057)*
- A. Innate Immunity
- B. Adaptive Immunity

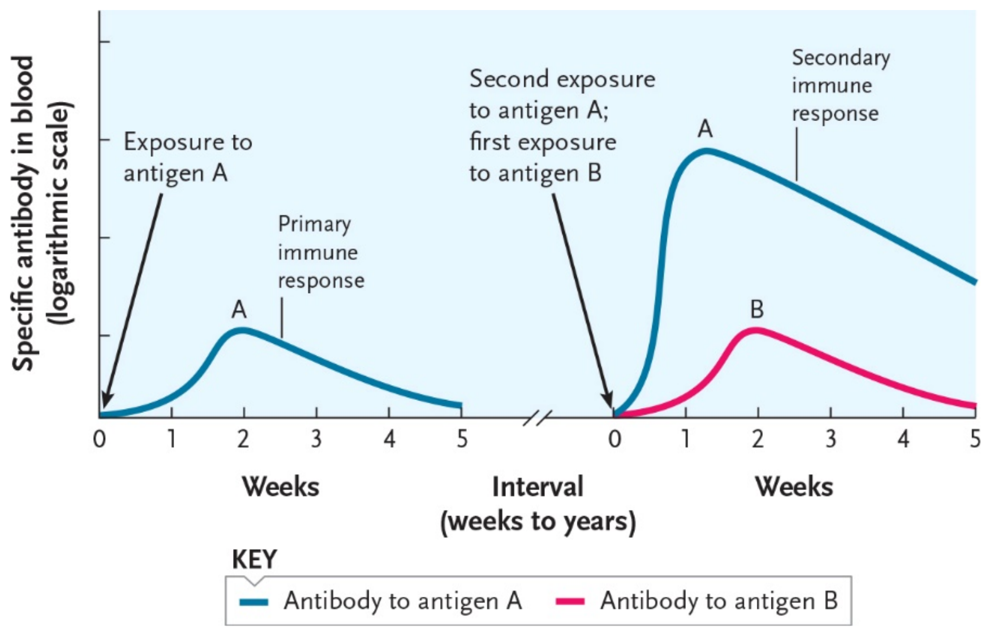
II. The Adaptive Immune Response *(1057-1067)*
- A. Definitions and Functions
  1. Antigens
  2. Antibodies
- B. Cells of Circulatory, Lymphatic, and Immune Systems
  1. Hemopoiesis
  2. Differentiation of cell types
  3. Lymphoid types
- C. Lymphocyte Activation
  1. Binding of antigen
  2. Clonal selection
  3. Effector cells and memory cells

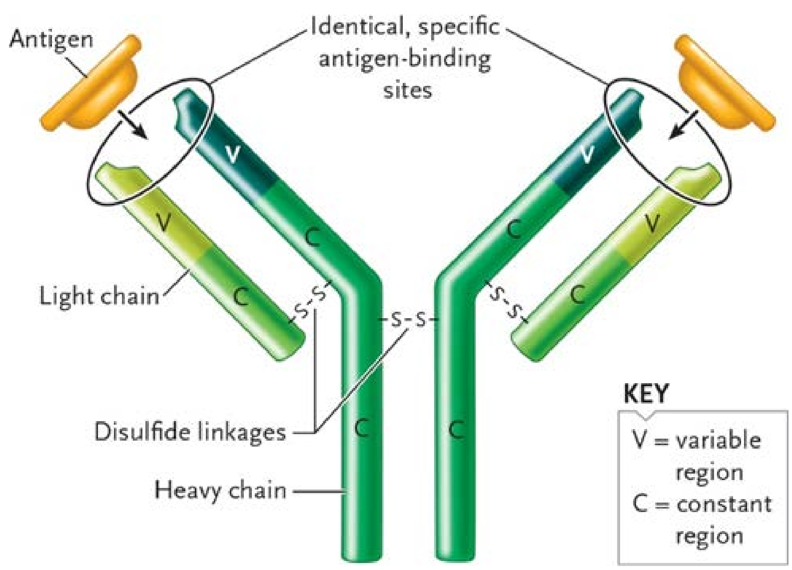
III. Essentials of the Antibody-Mediated Immune Response *(1058-1065)*
- A. B Cell Activation and Antibody Production
- B. Antibody Structure and Function
- C. Antibody-Mediated Response
  1. Neutralization
  2. Agglutination
  3. Precipitation
  4. The complement system
- D. T Cells and the Antibody-Mediated Immune Response
  1. Activation and proliferation of helper T cells
  2. Helper T cell stimulation of B cells

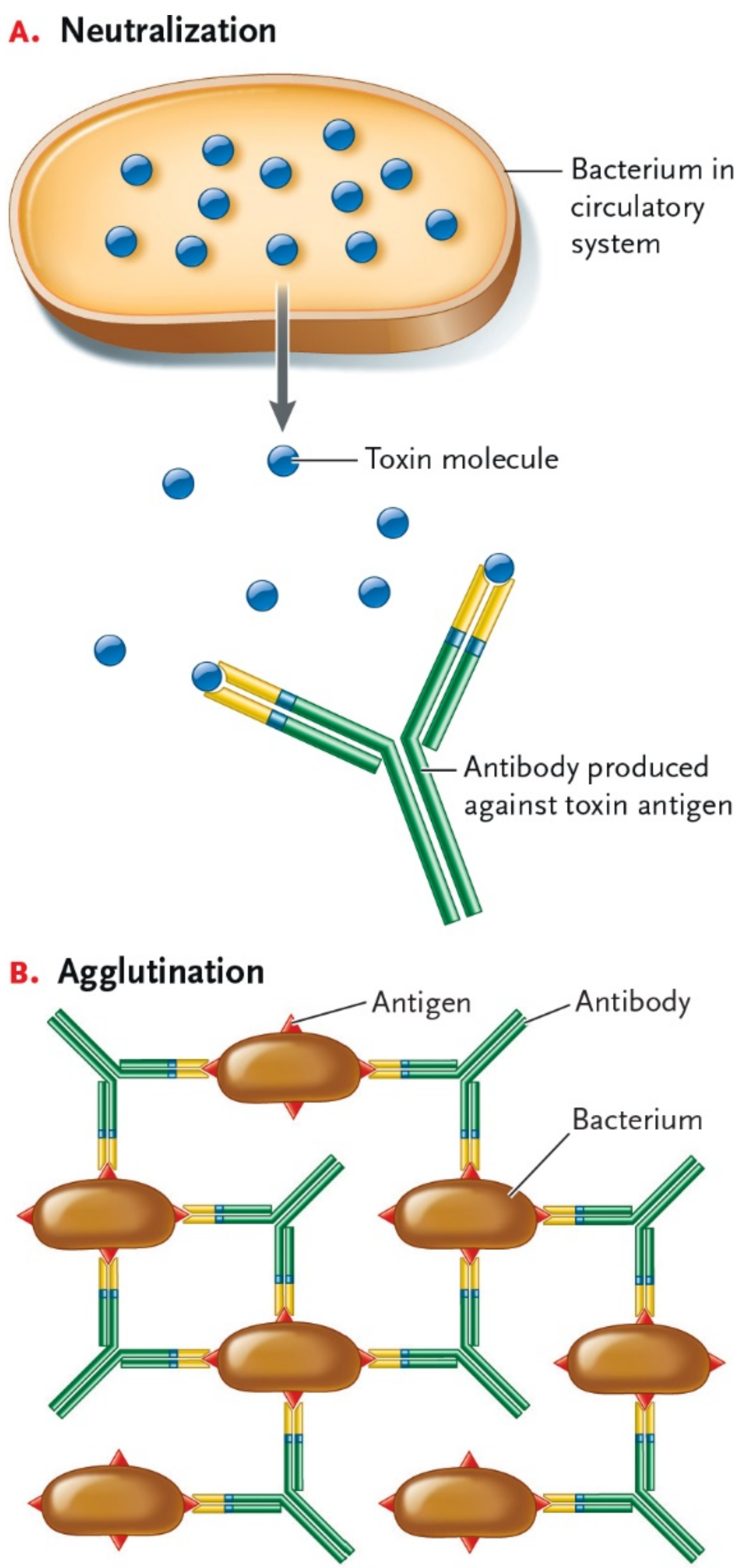
IV. Cell-Mediated Immune Response *(1065-1067)*
- A. Introduction
- B. T Cell Activation
  1. Antigen presenting cells
  2. Clonal selection
- C. Action of cytotoxic T cells


In bone marrow
Pluripotent stem cell
Myeloid stem cell
Lymphoid stem cell
In circulation
Platelets
Erythrocyte
Basophil
Eosinophil
Neutrophil
Monocyte/macrophage
B lymphocyte
T lymphocyte
Leukocytes


Population of unactivated B cells, each making a specific receptor that is displayed on its surface as a B-cell receptor
Binding of antigen and interaction with helper T cell stimulates B cell to divide and produce a clone of cells.
Plasma cells
Memory B cells
Some of the B-cell clones differentiate into plasma cells, which secrete antibodies.
A few B-cell clones differentiate into memory B cells, which respond to a later encounter with the same antigen.


Specific antibody in blood (logarithmic scale)
Exposure to antigen A
Primary immune response
A
Second exposure to antigen A; first exposure to antigen B
A
Secondary immune response
B
0 1 2 3 4 5
0 1 2 3 4 5
Weeks
Interval (weeks to years)
Weeks
KEY
Antibody to antigen A
Antibody to antigen B


Antigen
Identical, specific antigen-binding sites
V
C
V
C
Light chain
S-S
S-S
Disulfide linkages
C
Heavy chain
KEY
V = variable region
C = constant region

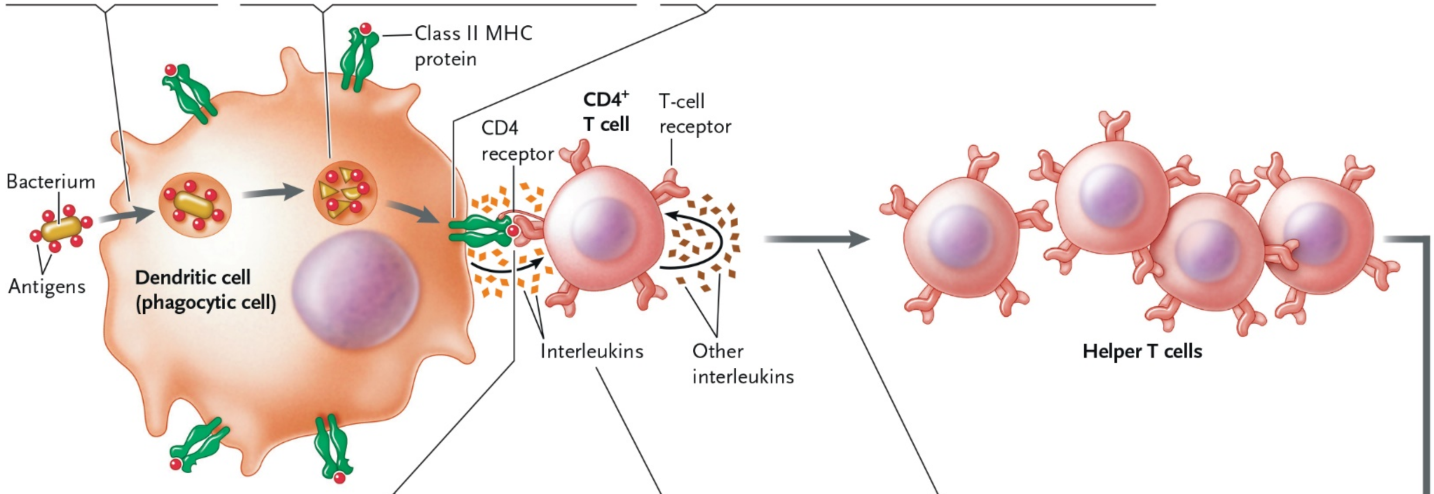

A. Neutralization
Bacterium in circulatory system
Toxin molecule
Antibody produced against toxin antigen
B. Agglutination
Antigen
Antibody
Bacterium

Antigen recognition and T-cell activation and differentiation

1 Engulfment of bacterium. A bacterium is taken up by a dendritic cell by phagocytosis.

2 Degradation of bacterium and release of antigens. The bacterium is degraded within a lysosome. The released bacterial proteins are broken into pieces, which act as antigens.

3 Presentation of antigens on dendritic cell surface. Antigens bind to class II MHC proteins within the cell and the interacting molecules then are displayed on the cell surface. The cell is now an antigen-presenting cell (APC).

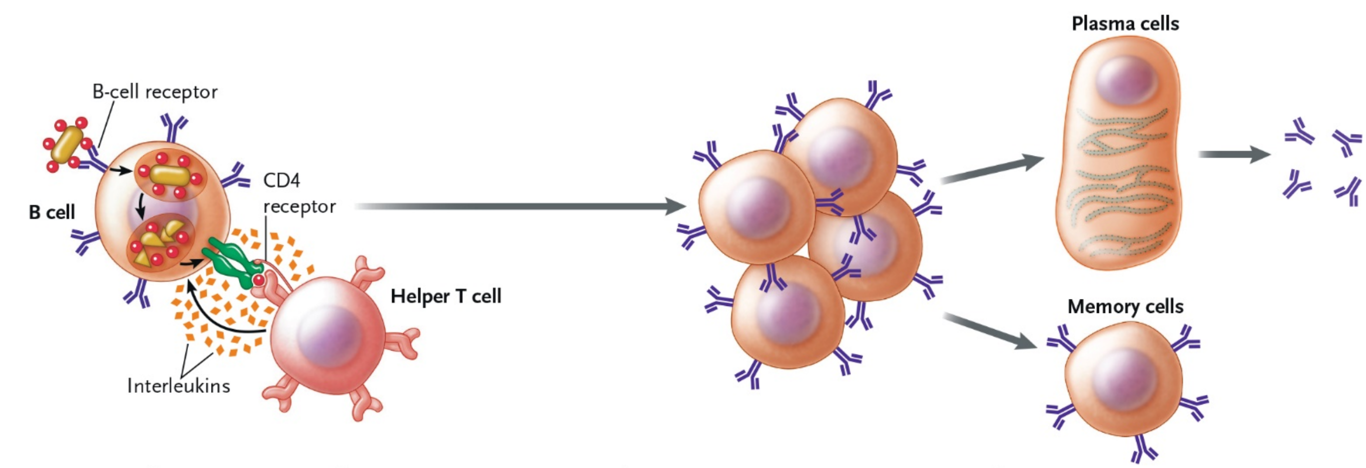


4 Interaction of APC with lymphocyte. The APC presents the antigen to a CD4⁺ T cell with a T-cell receptor that recognizes the antigen. The CD4 receptor binds directly to the class II MHC protein. The APC and the T cell become linked together.

5 Activation of T cell. The APC secretes interleukins, which activate the T cell.

6 Production of helper T cells. Activated T cell secretes other interleukins, which stimulate the T cell to proliferate to produce a clone of cells. The cloned cells differentiate into helper T cells and memory helper T cells.

B-cell activation by helper T cells and differentiation of B cells into antibody-producing cells



7 Presentation of antigens on B cell surface. The B-cell receptor binds to antigen on the bacterium. Bacterium is engulfed and its macromolecules degraded. The antigens produced are displayed on cell surface bound to class II MHC proteins.

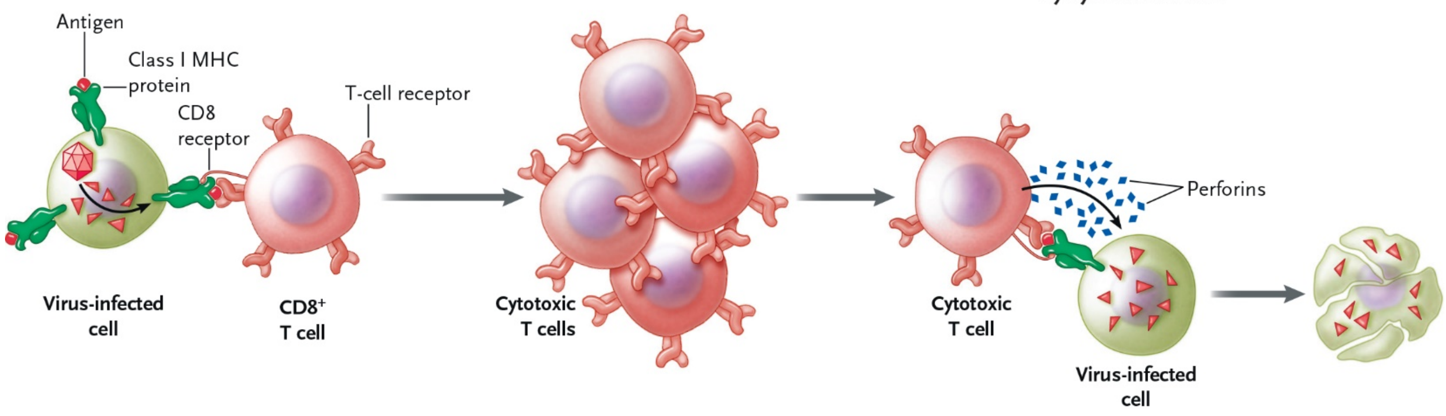
8 Interaction of B cell with helper T cell. The T-cell receptor of a helper T cell recognizes the antigen on the B cell and links the two cells together.

9 Activation of B cell. Interleukins secreted by the helper T cell activate the B cell and then stimulate B-cell proliferation to produce a clone of cells.

10 Production of plasma cells and memory B cells. Some cloned B cells differentiate into plasma cells, which secrete antibodies, while a few differentiate into memory B cells.

Antigen recognition and T-cell activation and differentiation

Destruction of infected cells by cytotoxic T cells



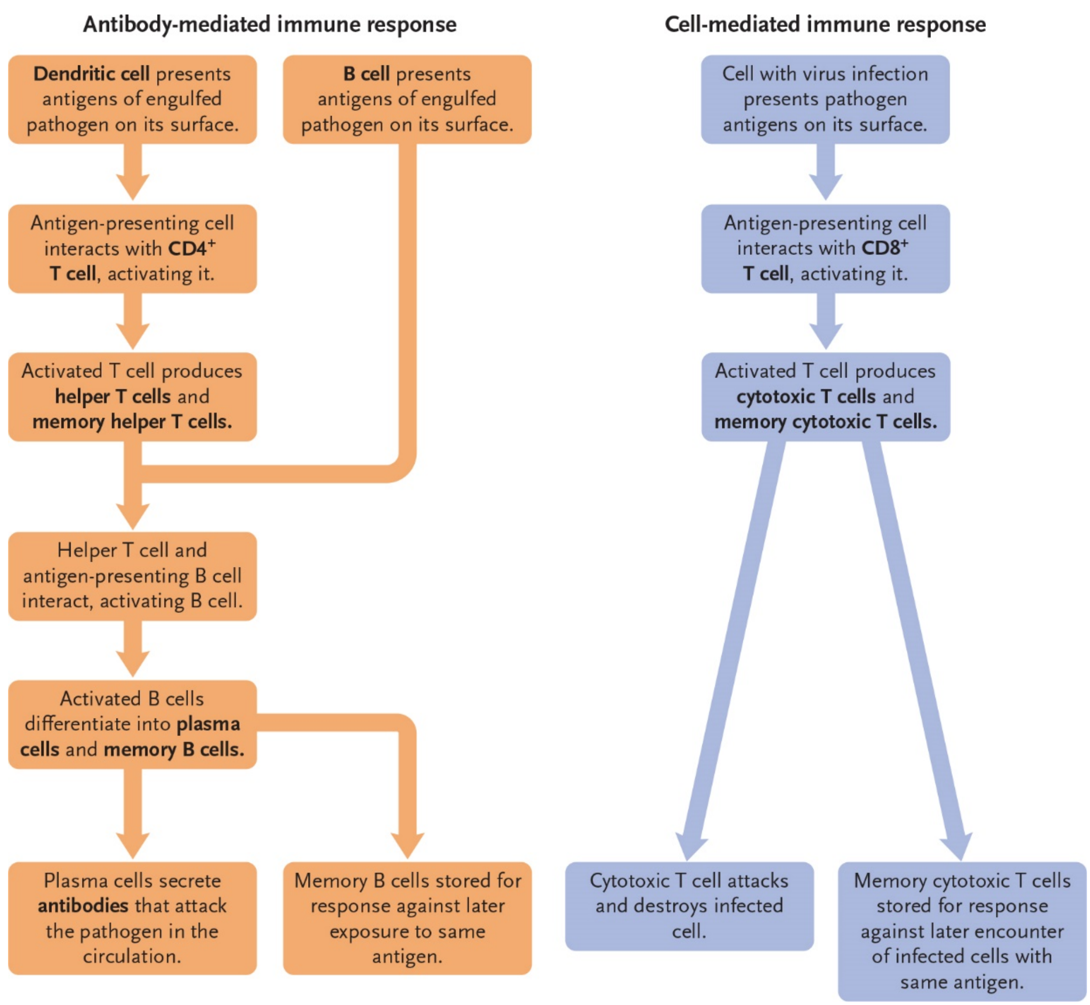
1 Presentation of antigens on cell surface. Viral proteins are degraded into fragments that act as antigens. The antigens are displayed on the cell surface bound to class I MHC proteins.

2 Activation of T cell. A T-cell receptor on a CD8$^+$ T cell recognizes an antigen bound to a class I MHC protein on an infected cell, the CD8 receptor binds directly to the class I MHC protein, and the two cells link together. The interaction along with cytokines from helper T cells activates the T cell.

3 Production of cytotoxic T cells. The activated CD8$^+$ T cell proliferates and forms a clone. The cloned cells differentiate into cytotoxic T cells and memory cytotoxic T cells.

4 Attack of infected cell by cytotoxic T cell. A T-cell receptor on a cytotoxic T cell recognizes the antigen bound to a class I MHC protein on the infected cell. The T cell releases perforins.

5 Destruction of infected cell. The perforins insert themselves into the membrane of the infected cell, forming pores. Leakage of ions and other molecules (along with other events) causes the cell to lyse.



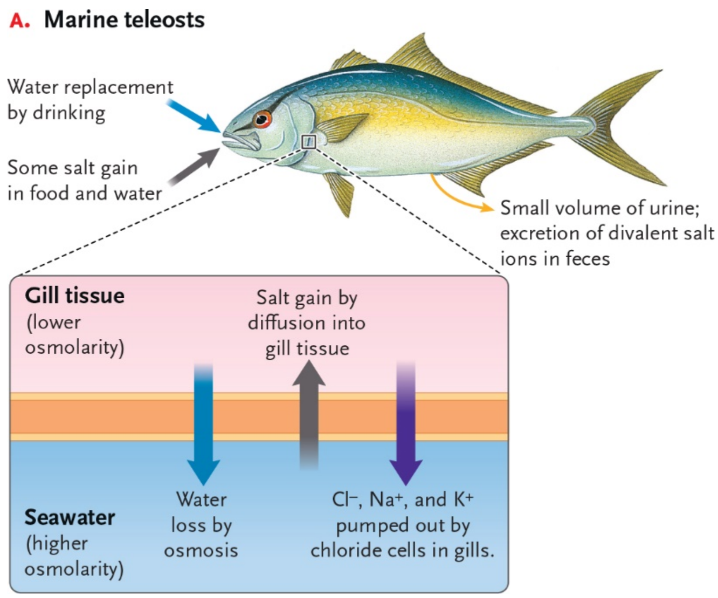
7. Water Balance and Excretion of Nitrogenous Wastes *Ch 38, 47, 48*

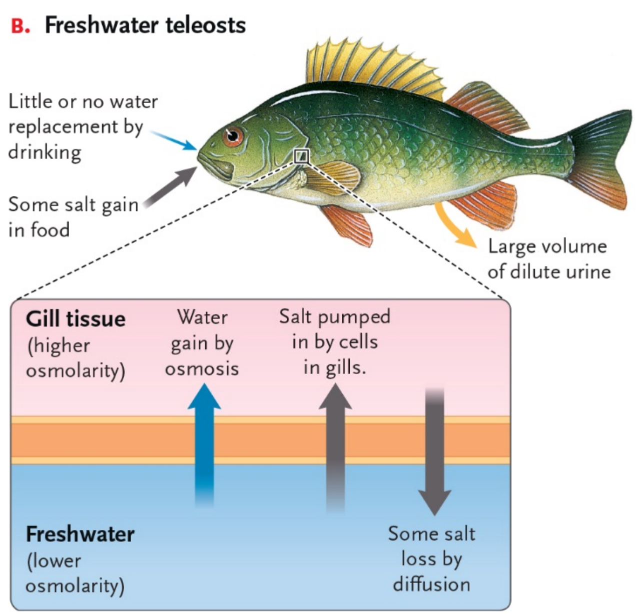
I. Introduction *(921-926, 1118)*
   A. Homeostasis
   B. Body Fluids
      1. Fluid compartments
      2. Osmosis

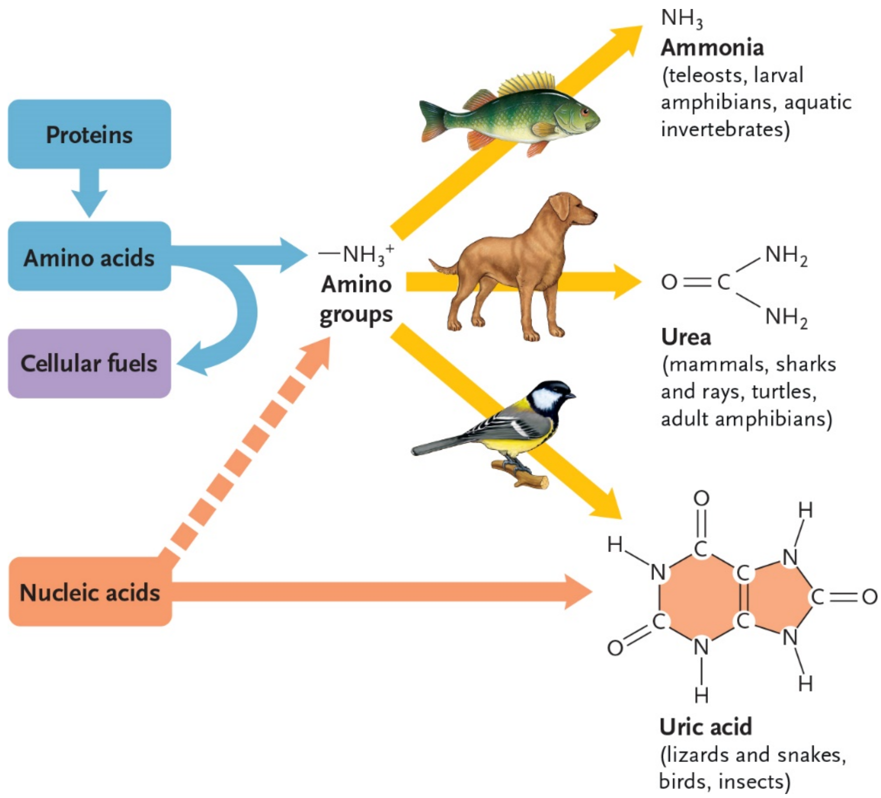
II. Solute and Water Balance *(1119-1132)*
   A. Paths of Water Flux
      1. Water gain
      2. Water loss
   B. Physiologically Wet and Physiologically Dry Habitats
      1. General definitions
      2. Marine environments
      3. Freshwater environments
      4. Terrestrial environments
   C. Osmoconformers versus Osmoregulators

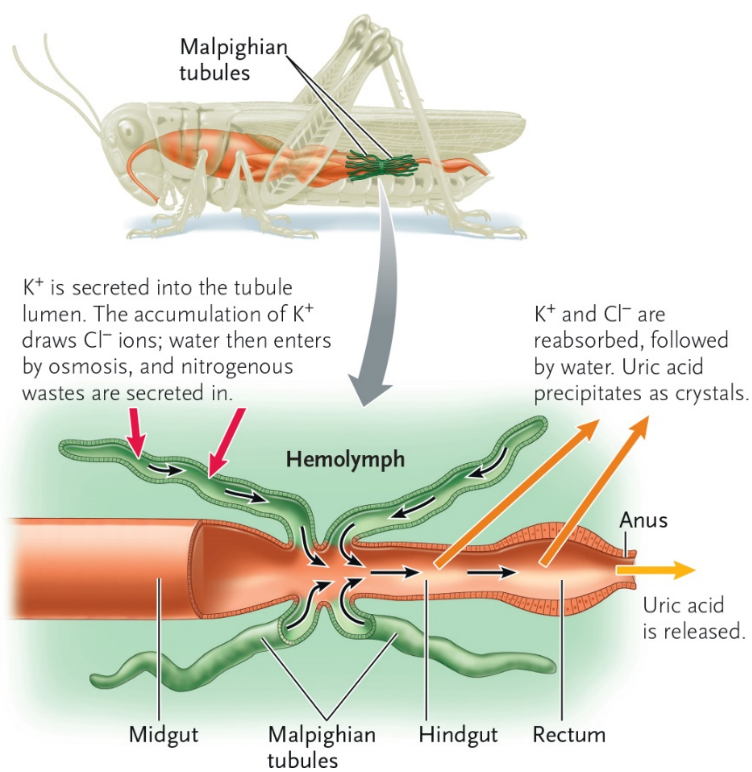
III. The Vertebrate Liver and Homeostasis *(1108, 1120-1121)*
   A. Structural Relationship to Circulatory System
   B. Regulation of Blood Sugar Level
   C. Production of Nitrogenous Wastes
      1. Protein catabolism
      2. Ammonium ions, urea, and uric acid
      3. Relationship to environmental physiology
   D. Osmoregulation and Nitrogen Excretion

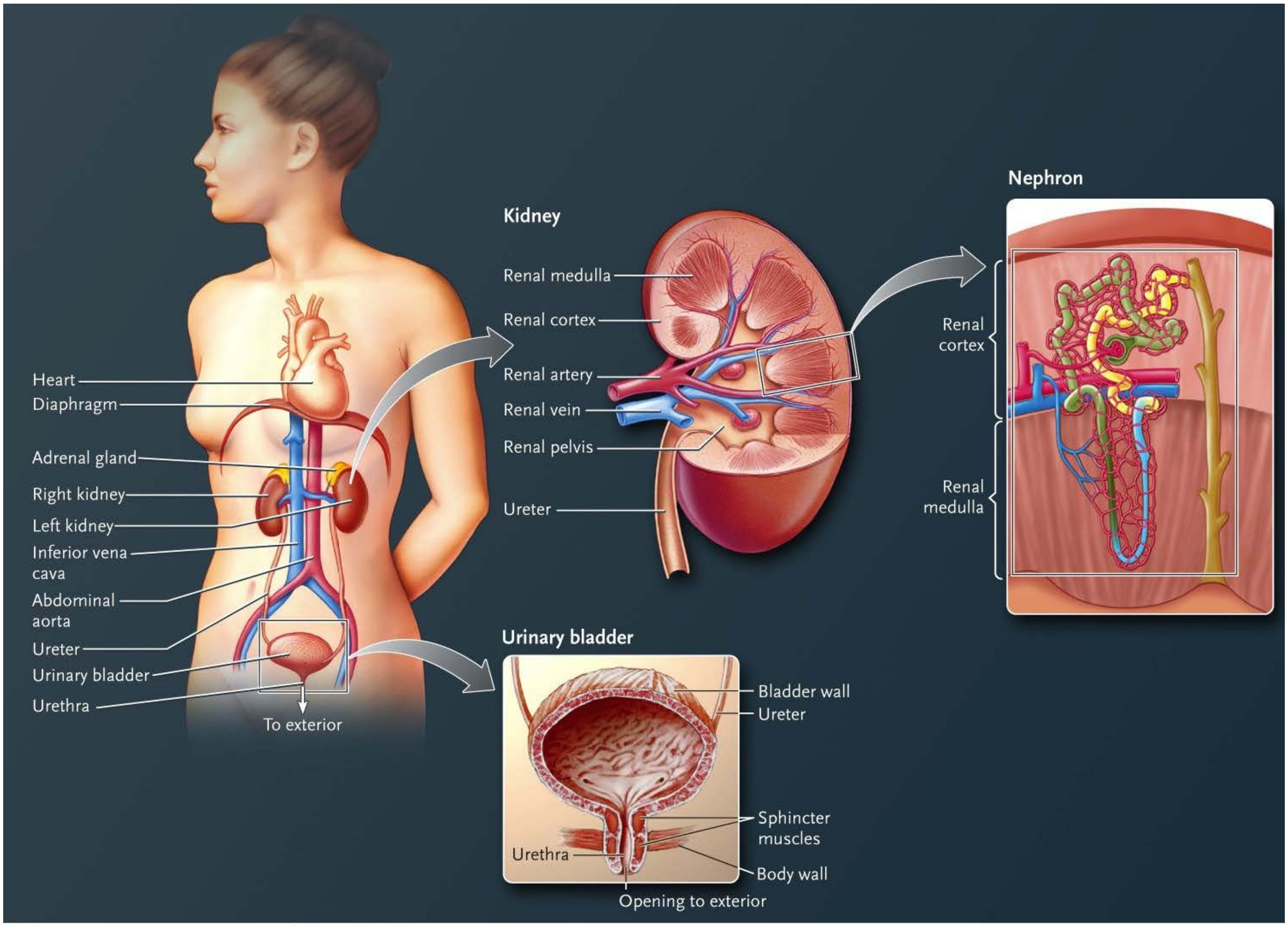
IV. Osmoregulatory and Excretory Systems *(1123-1132)*
   A. Insects
      1. Effects of an open circulatory system
      2. Malphigian tubules
   B. The Vertebrate Kidney
      1. General structure
      2. General function
   C. Freshwater and Marine Fishes
   D. Mammals


A. Marine teleosts
Water replacement by drinking
Some salt gain in food and water
Small volume of urine; excretion of divalent salt ions in feces
Gill tissue (lower osmolarity)
Salt gain by diffusion into gill tissue
Seawater (higher osmolarity)
Water loss by osmosis
Cl−, Na+, and K+ pumped out by chloride cells in gills.

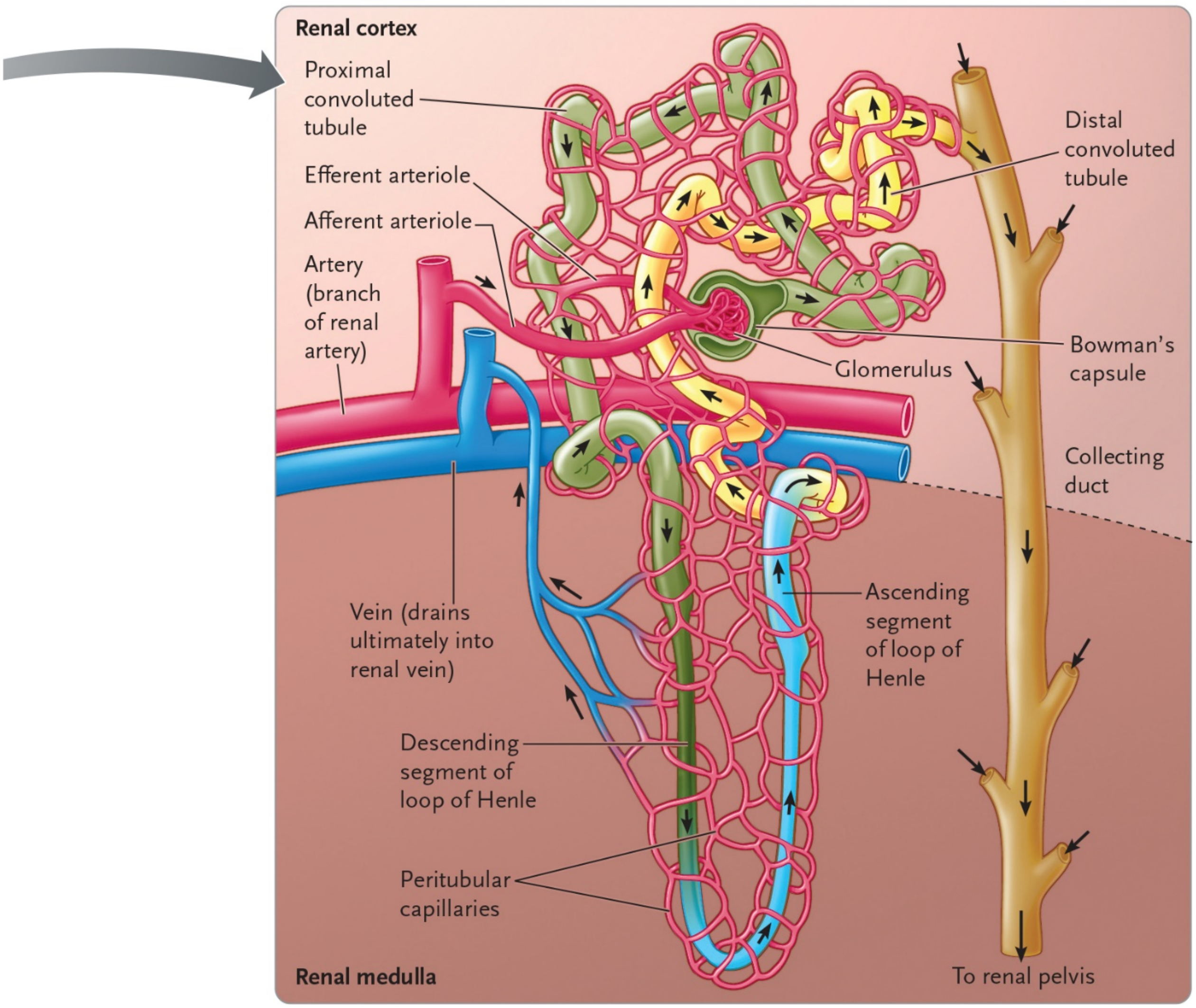

B. Freshwater teleosts
Little or no water replacement by drinking
Some salt gain in food
Large volume of dilute urine
Gill tissue (higher osmolarity)
Water gain by osmosis
Salt pumped in by cells in gills.
Freshwater (lower osmolarity)
Some salt loss by diffusion

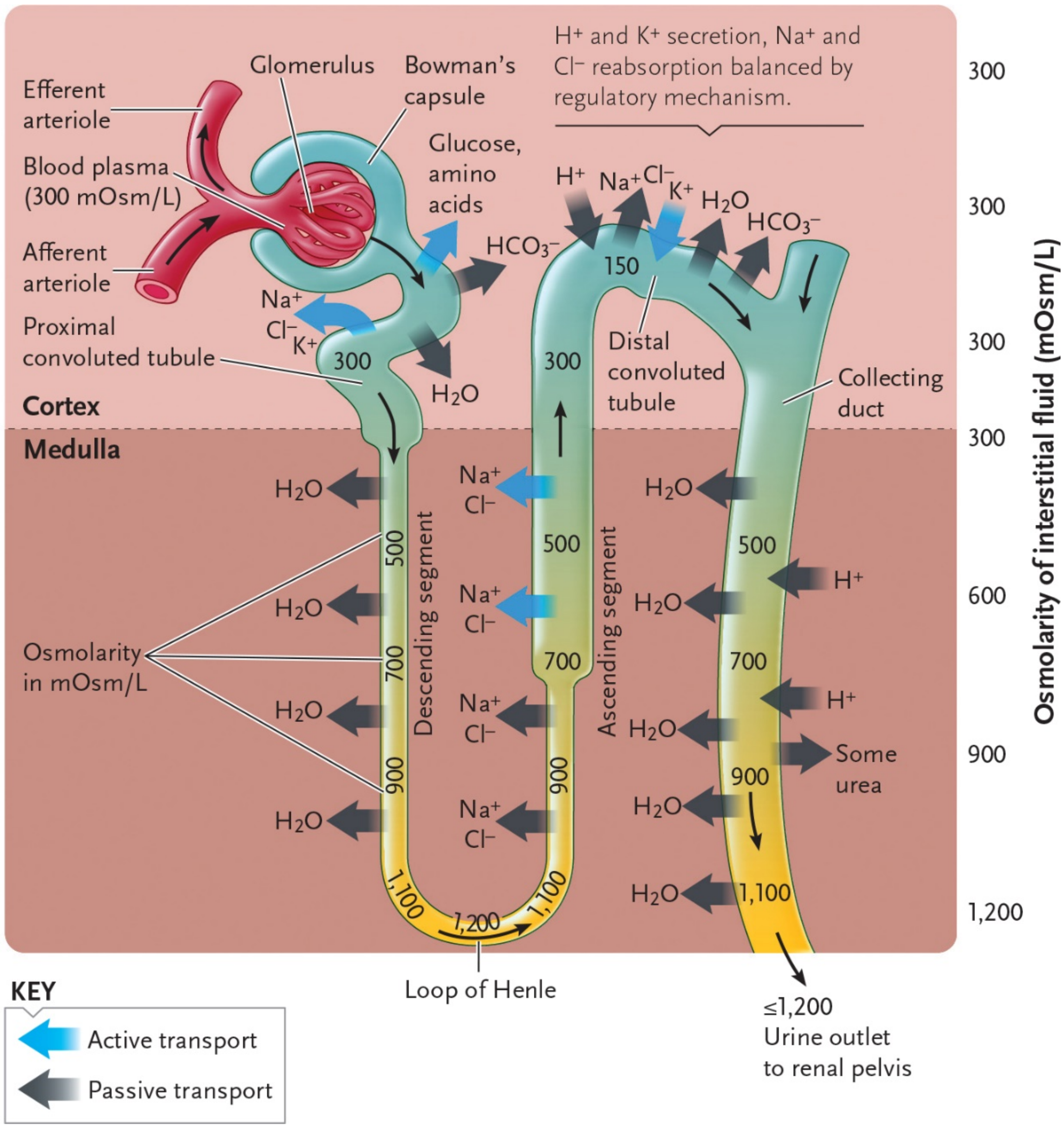

Proteins
Amino acids
Cellular fuels
Nucleic acids
—NH3+
Amino groups
NH3
Ammonia
(teleosts, larval amphibians, aquatic invertebrates)
NH2
O=C
NH2
Urea
(mammals, sharks and rays, turtles, adult amphibians)
Uric acid
(lizards and snakes, birds, insects)


Malpighian tubules
K+ is secreted into the tubule lumen. The accumulation of K+ draws Cl− ions; water then enters by osmosis, and nitrogenous wastes are secreted in.
K+ and Cl− are reabsorbed, followed by water. Uric acid precipitates as crystals.
Hemolymph
Anus
Uric acid is released.
Midgut
Malpighian tubules
Hindgut
Rectum


Heart
Diaphragm
Adrenal gland
Right kidney
Left kidney
Inferior vena cava
Abdominal aorta
Ureter
Urinary bladder
Urethra
To exterior
Kidney
Renal medulla
Renal cortex
Renal artery
Renal vein
Renal pelvis
Ureter
Nephron
Renal cortex
Renal medulla
Urinary bladder
Bladder wall
Ureter
Sphincter muscles
Urethra
Body wall
Opening to exterior

Nephron


Renal cortex
Proximal convoluted tubule
Efferent arteriole
Afferent arteriole
Artery (branch of renal artery)
Distal convoluted tubule
Bowman's capsule
Glomerulus
Collecting duct
Ascending segment of loop of Henle
Vein (drains ultimately into renal vein)
Descending segment of loop of Henle
Peritubular capillaries
Renal medulla
To renal pelvis



H+ and K+ secretion, Na+ and Cl− reabsorption balanced by regulatory mechanism.
Glomerulus
Bowman's capsule
Efferent arteriole
Blood plasma (300 mOsm/L)
Afferent arteriole
Glucose, amino acids
H+ Na+ Cl− K+ H2O HCO3−
HCO3−
150
Na+ Cl− K+
Proximal convoluted tubule
300
H2O
300
Distal convoluted tubule
Collecting duct
Cortex
Medulla
H2O
Na+ Cl−
500
700
900
1,100
1,200
Descending segment
Ascending segment
Osmolarity in mOsm/L
H+
Some urea
Loop of Henle
≤1,200 Urine outlet to renal pelvis
300
300
300
300
600
900
1,200
Osmolarity of interstitial fluid (mOsm/L)
KEY
Active transport
Passive transport

8. Temperature Regulation in Vertebrates *Chapter 01, 46*

I. Thermal Relations of Vertebrates *(1132-1136)*

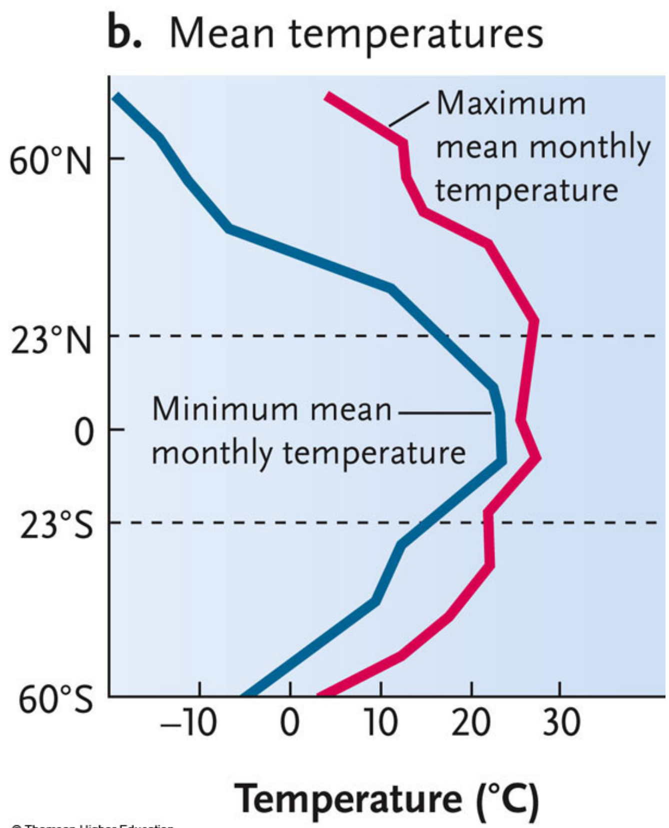
- A. Why Temperature is Important
  1. Range of temperatures on earth
  2. Temperature tolerances of living systems
  3. Thermal sensitivity of biochemical reaction
- B. Homeostasis and Temperature Regulation
  1. Value of regulation
  2. Concept of heat balance
- C. Paths of Heat Exchange for All Animals
  1. Radiation
  2. Conduction
  3. Convection
  4. Evaporation
- D. Thermoregulatory Strategies of Animals
  1. Ectothermy
  2. Endothermy

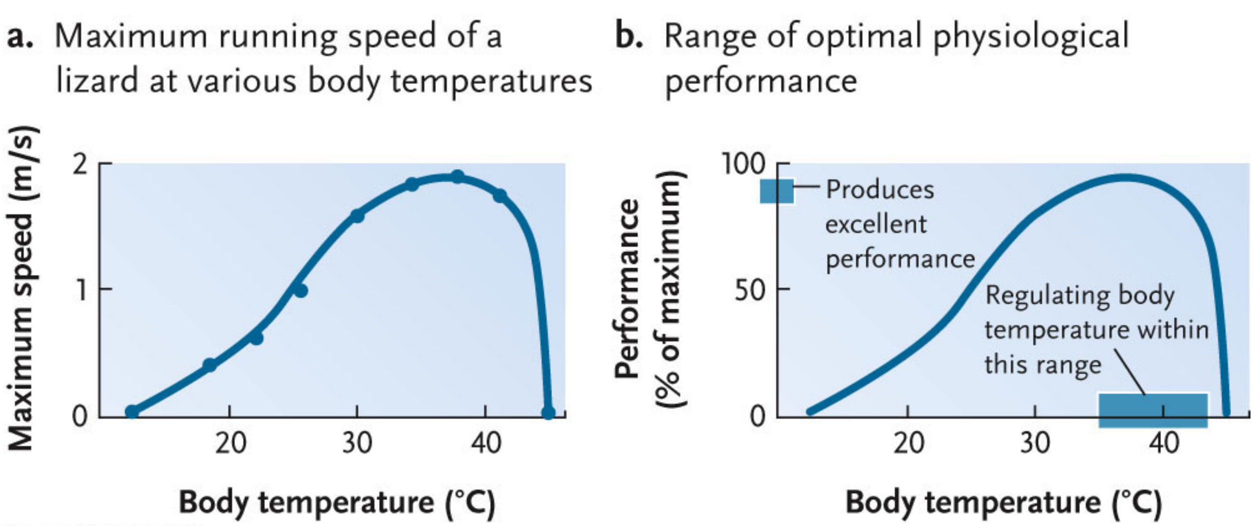
II. Endothermy *(1137-1140)*

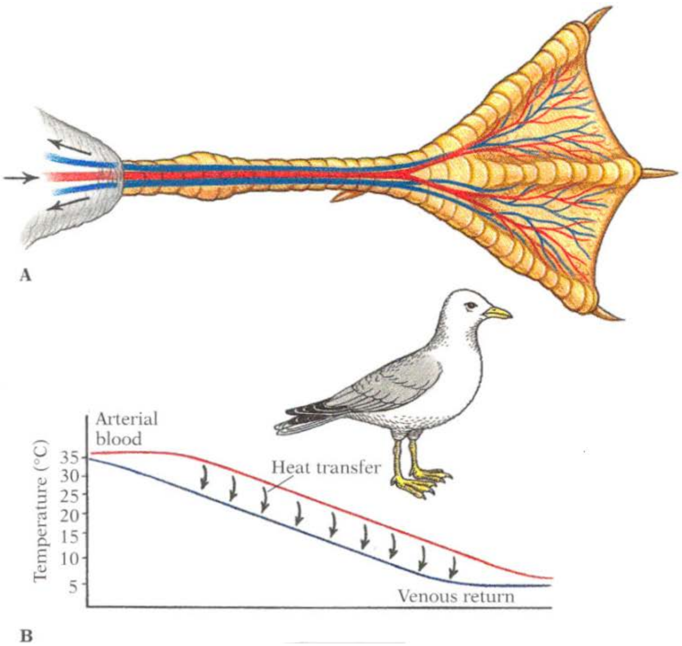
- A. Metabolic Rates and Heat Production
- B. Heat Conservation
  1. Insulation
  2. Piloerection
  3. Whole animal behaviors
  4. Circulatory system controls
- C. Anatomical Correlates of Endothermy
- D. Physiological Control of Temperature
  1. Role of the hypothalamus
  2. Precision of temperature control

III. Thermoregulation by Reptiles *(18-19, 1136-1137)*

- A. Behavioral Thermoregulation
  1. Exploitation of environmental opportunities
  2. Behavioral mechanisms promoting heat exchange
- B. Consequences of Thermoregulation
  1. Body temperature variation
  2. Relationship of body temperature to environmental temperatures
- C. Evaluating Temperature Regulation
  1. *Anolis cristatellus* and *A. gundlachi*
  2. Geographical and ecological distributions
  3. Using null hypotheses to demonstrate behavioral temperature regulation

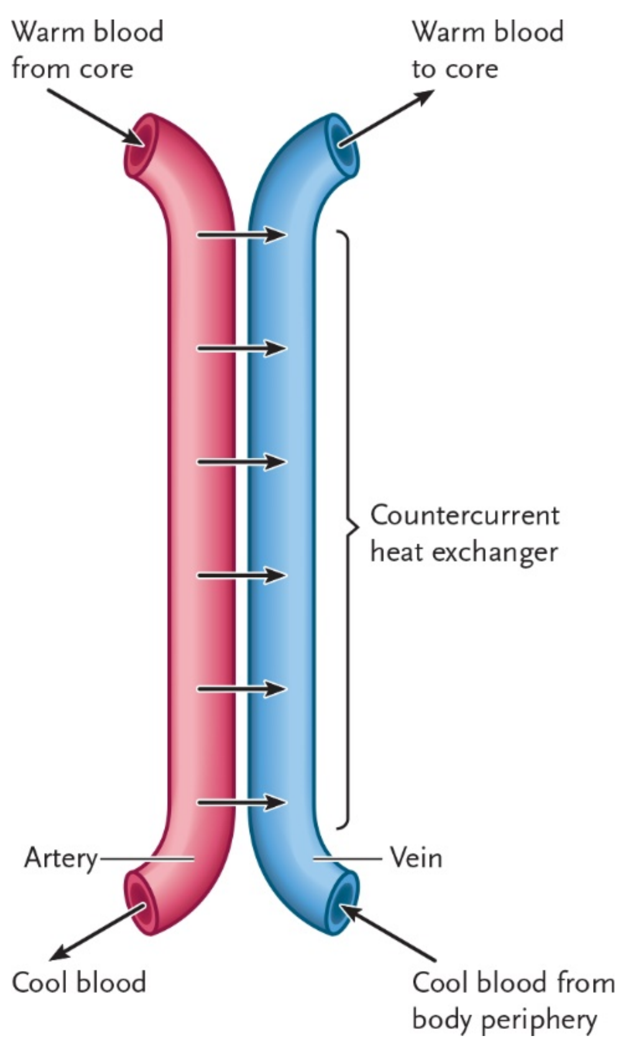

b. Mean temperatures
Maximum mean monthly temperature
Minimum mean monthly temperature
60°N
23°N
0
23°S
60°S
–10
0
10
20
30
Temperature (°C)

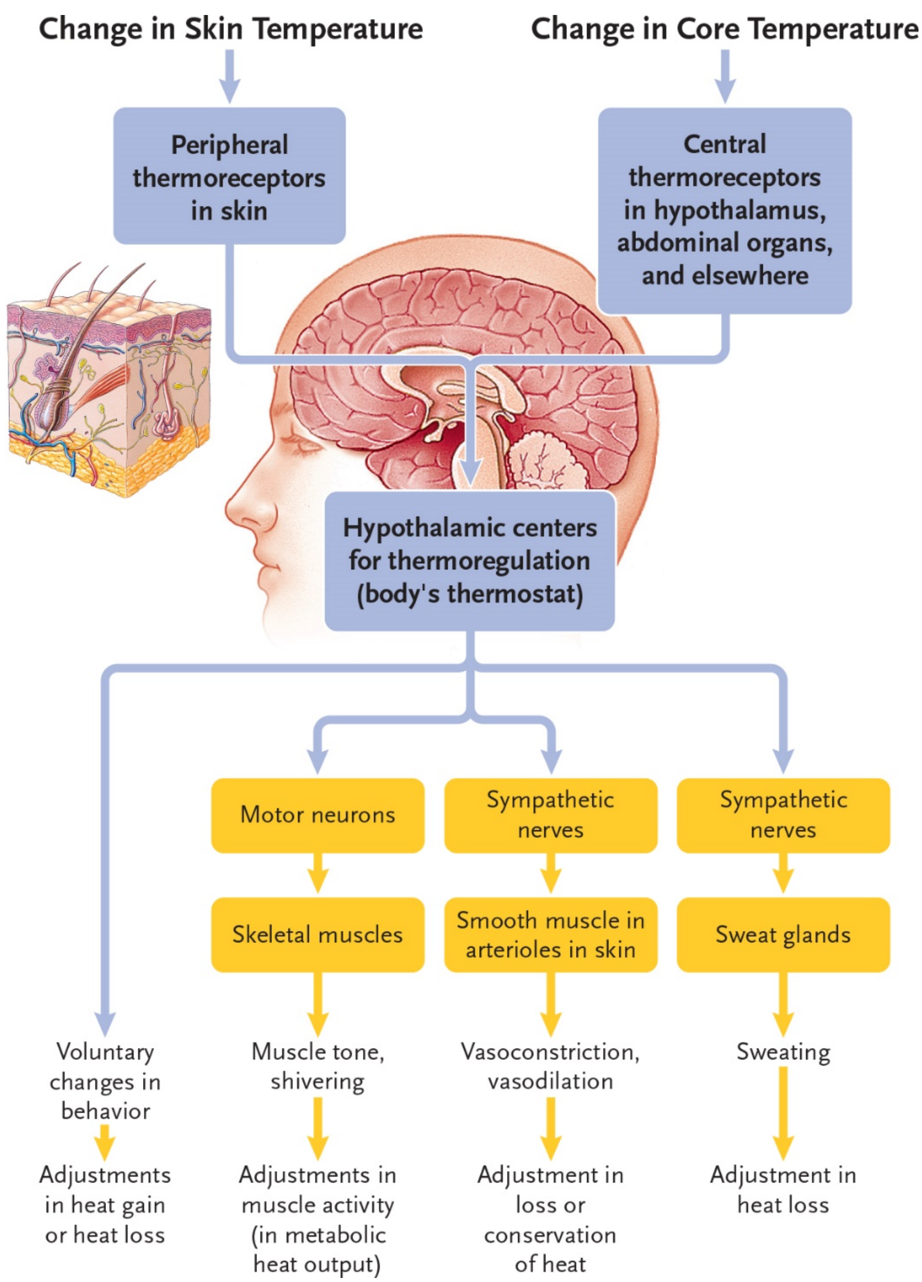

a. Maximum running speed of a lizard at various body temperatures
Maximum speed (m/s)
2
1
0
20
30
40
Body temperature (°C)
b. Range of optimal physiological performance
Performance (% of maximum)
100
50
0
Produces excellent performance
Regulating body temperature within this range
20
30
40
Body temperature (°C)



30.26 Use of countercurrent exchange to minimize heat loss

In cold weather, the temperature of the extremities of an animal like the Arctic gull is allowed to fall far below the animal's core temperature, a strategy known as spatial heterothermy. The gull further conserves heat through countercurrent exchange in its extremities between warm blood in the arteries and cool blood returning in the veins. As the graph shows, this arrangement sends much of the heat back into the body before it can be lost in the leg and foot.




Change in Skin Temperature
Change in Core Temperature
Peripheral thermoreceptors in skin
Central thermoreceptors in hypothalamus, abdominal organs, and elsewhere
Hypothalamic centers for thermoregulation (body's thermostat)
Motor neurons
Sympathetic nerves
Sympathetic nerves
Skeletal muscles
Smooth muscle in arterioles in skin
Sweat glands
Voluntary changes in behavior
Muscle tone, shivering
Vasoconstriction, vasodilation
Sweating
Adjustments in heat gain or heat loss
Adjustments in muscle activity (in metabolic heat output)
Adjustment in loss or conservation of heat
Adjustment in heat loss

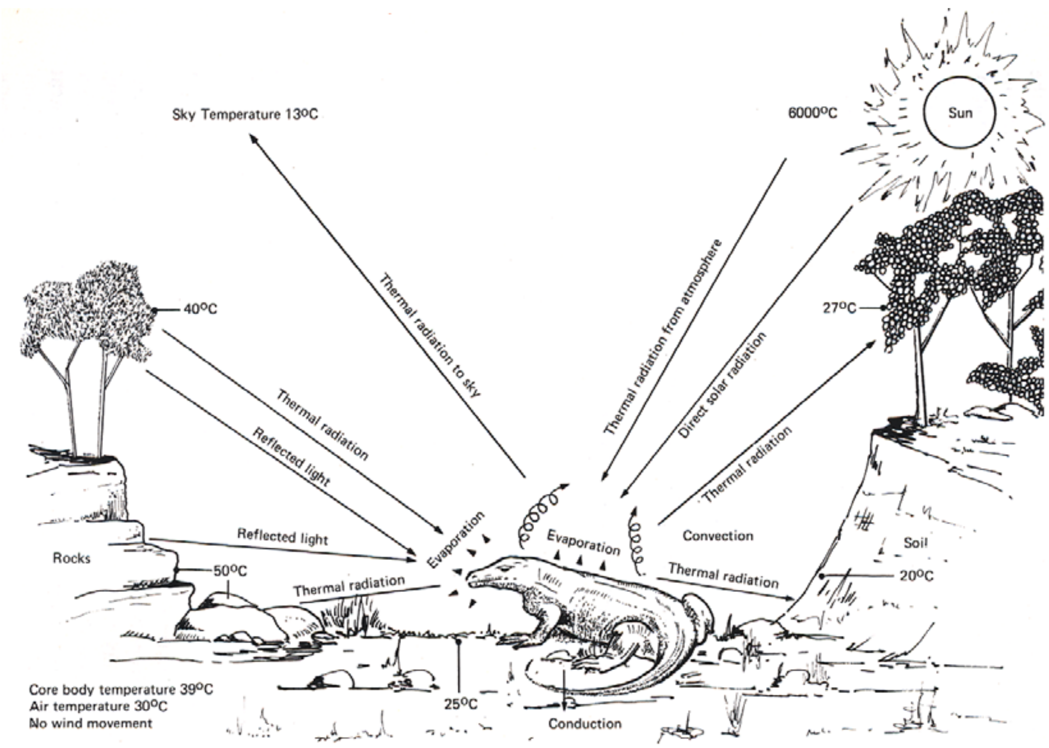
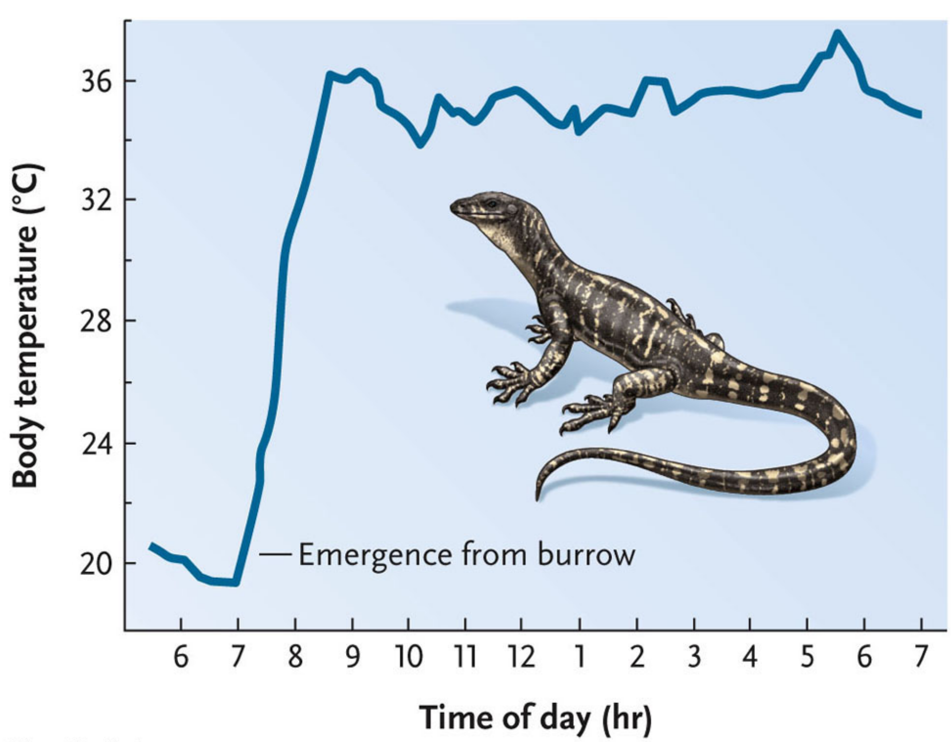
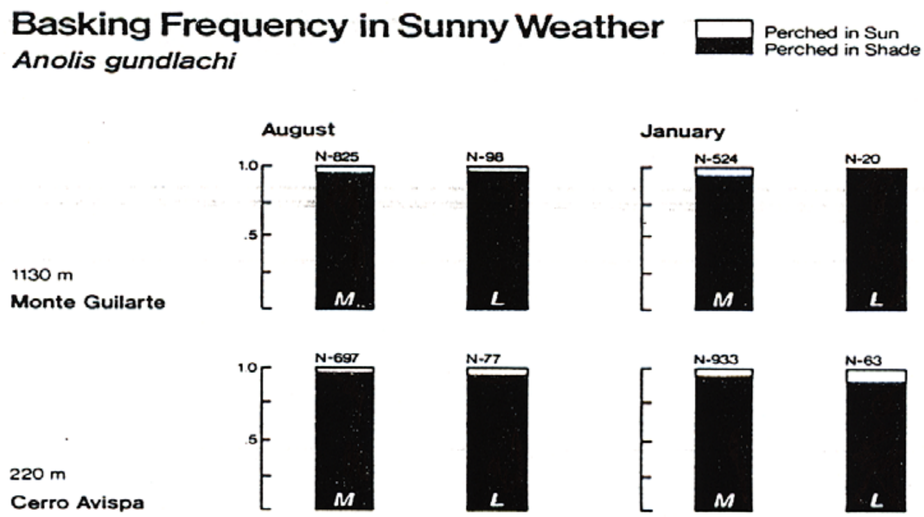
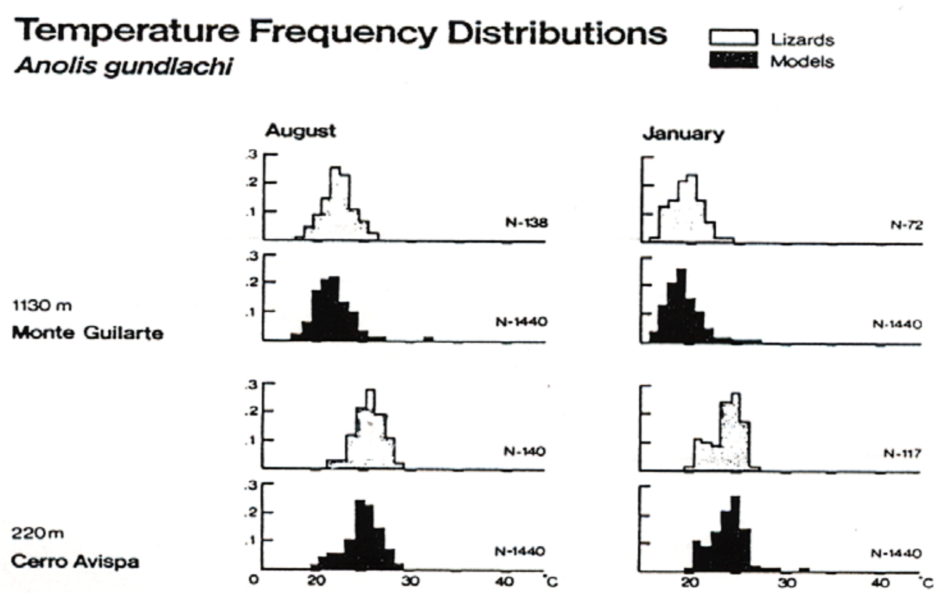


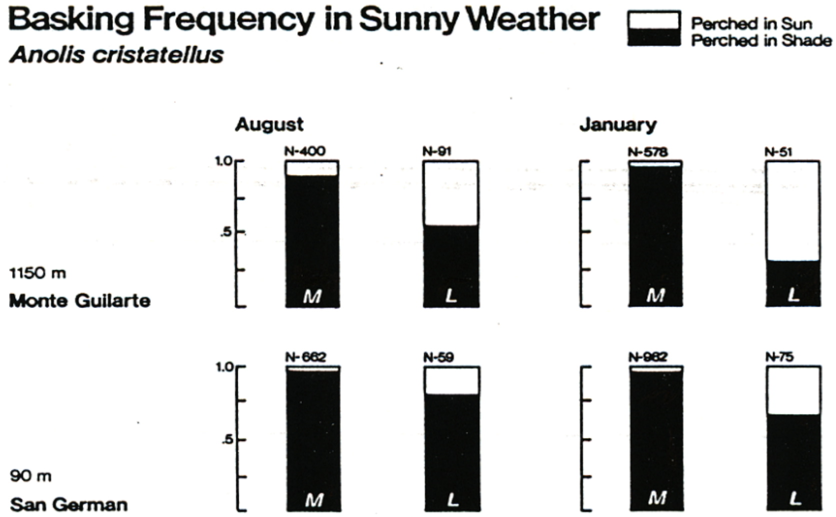
Figure 6. Diagrammatic representation of energy exchanges between a terrestrial reptile and its environment under moderately warm conditions. Modified from Gordon et al. (1968) by R. Hardy.



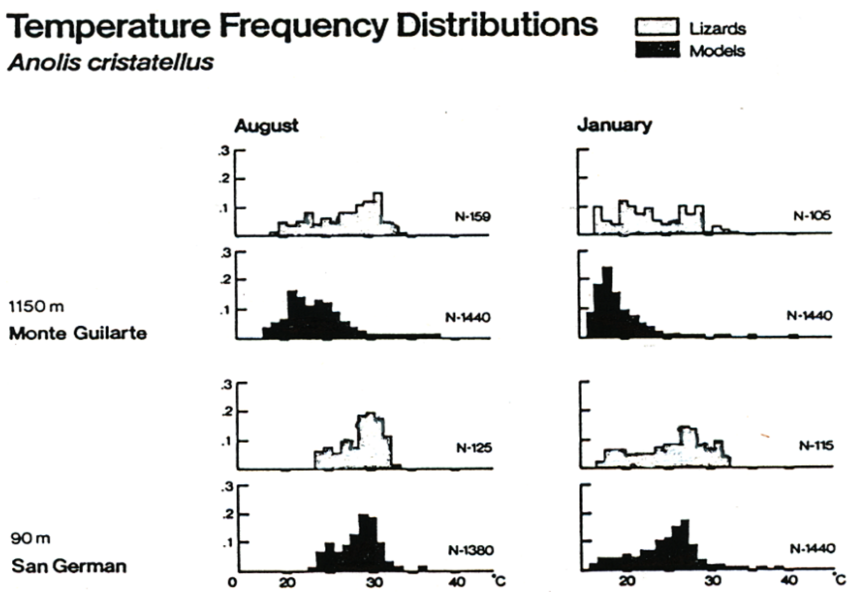

Basking Frequency in Sunny Weather
Anolis gundlachi
Perched in Sun
Perched in Shade
August
January
N-825
N-98
N-524
N-20
1.0
.5
1130 m
Monte Guilarte
M
L
N-697
N-77
N-933
N-63
220 m
Cerro Avispa


Temperature Frequency Distributions
Anolis gundlachi
Lizards
Models
August
January
N-138
N-72
1130 m
Monte Guilarte
N-1440
N-140
N-117
220m
Cerro Avispa
0
20
30
40
°C

Basking Frequency in Sunny Weather
Anolis cristatellus



Temperature Frequency Distributions
Anolis cristatellus



9. Metabolic Rates and Energetics of Vertebrates *Ch 48*

I. Metabolic Rates of Animals *(1135-1136)*

A. The Meaning of Metabolic Rate
1. The metabolism equation
2. How metabolic rates are measured
3. Resting metabolic rate
4. Relevance to ecology

B. Metabolic Rates and Environmental Temperatures
1. In ectotherms
2. In endotherms
3. Cost of endothermy

C. Effects of Body Size on Metabolic Rate
1. SA:V relationships
2. Total metabolic rate versus mass-specific metabolic rate
3. Size and metabolic rate
4. Effects on food needs of endotherms

II. Implications for Ecology and Behavior

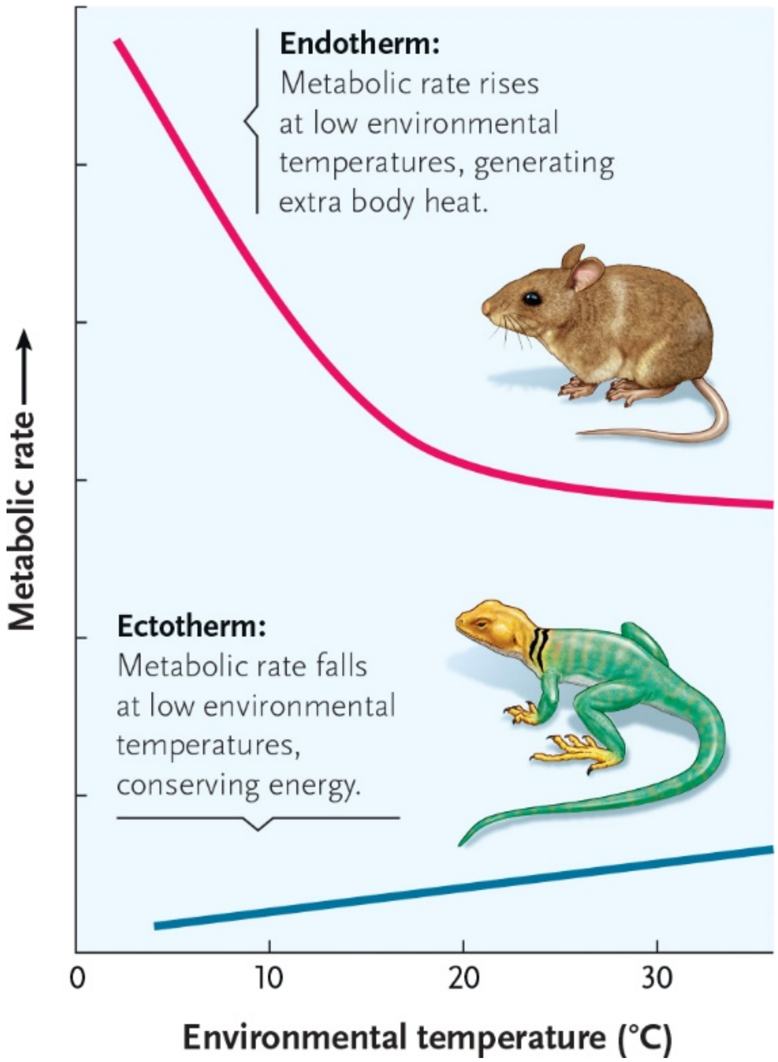
A. Metabolic Rates and Energy Requirements

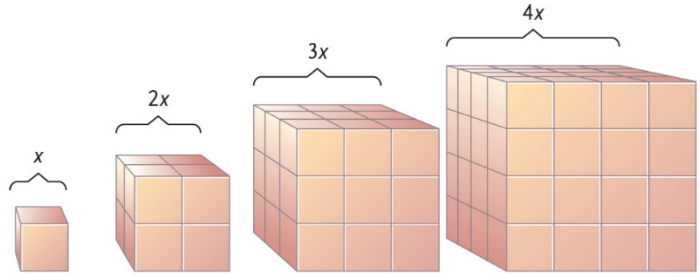
B. Ecological and Behavioral Consequences of Thermoregulatory Strategies
1. Food types
2. Hunting styles
3. Home range size and population density
4. Limits on body sizes
5. Times of activity

III. Metabolic Rates During Activity

A. Resting versus Active Metabolic Rate

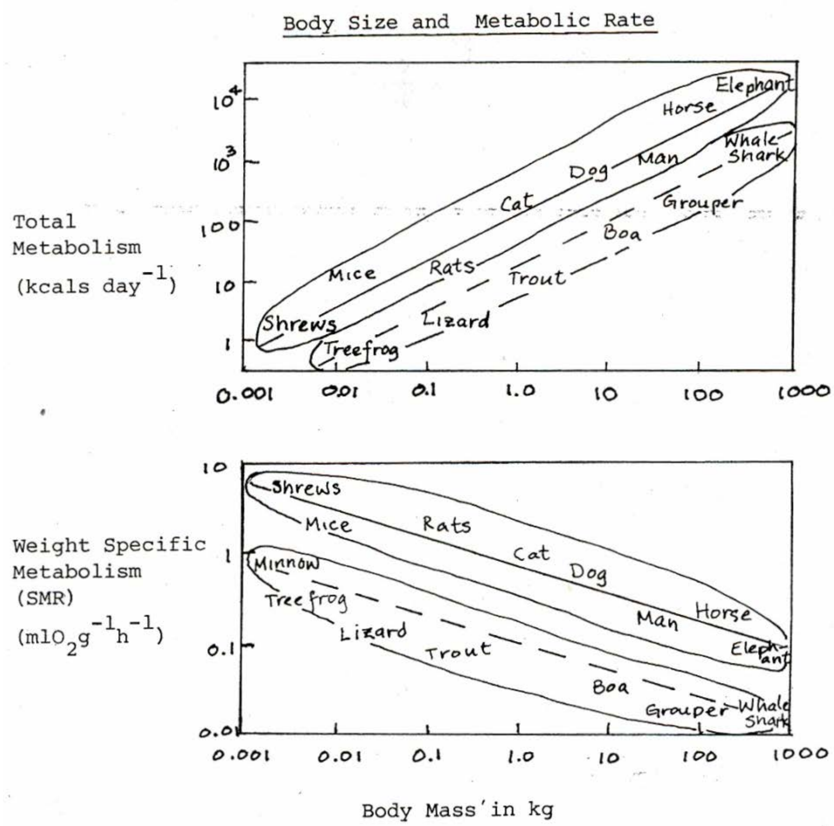
B. Aerobic versus Anaerobic Metabolism
1. Biochemical pathways
2. Aerobic capacity
3. Burst activity and anaerobic metabolism
4. Oxygen debt


Endotherm:
Metabolic rate rises at low environmental temperatures, generating extra body heat.
Ectotherm:
Metabolic rate falls at low environmental temperatures, conserving energy.
Metabolic rate
0
10
20
30
Environmental temperature (°C)



Total surface area	$\mathbf{6x^2}$	$6(2x)^2 = \mathbf{24x^2}$	$6(3x)^2 = \mathbf{54x^2}$	$6(4x)^2 = \mathbf{96x^2}$
Total volume	$\mathbf{x^3}$	$(2x)^3 = \mathbf{8x^3}$	$(3x)^3 = \mathbf{27x^3}$	$(4x)^3 = \mathbf{64x^3}$
Surface area/ volume ratio	**6:1**	**3:1**	**2:1**	**1.5:1**

–

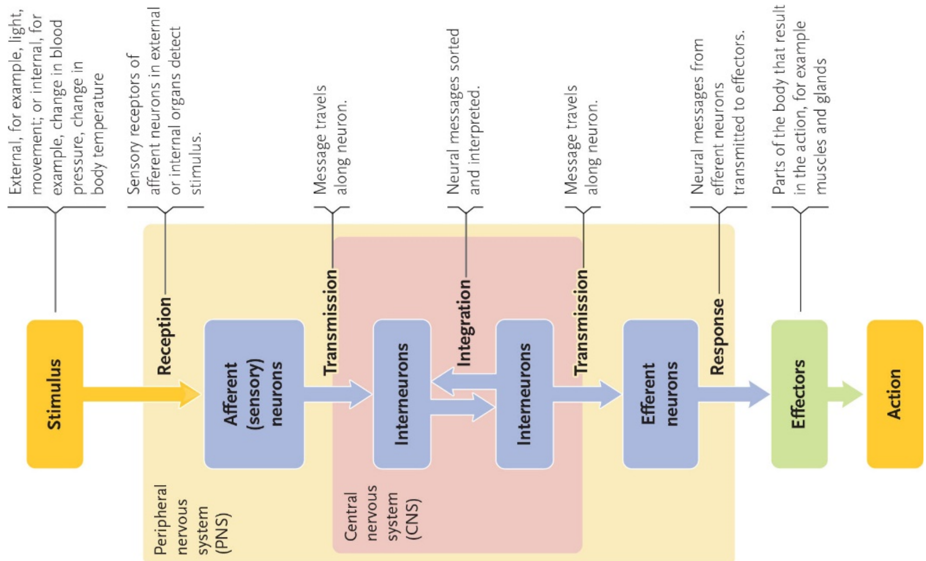


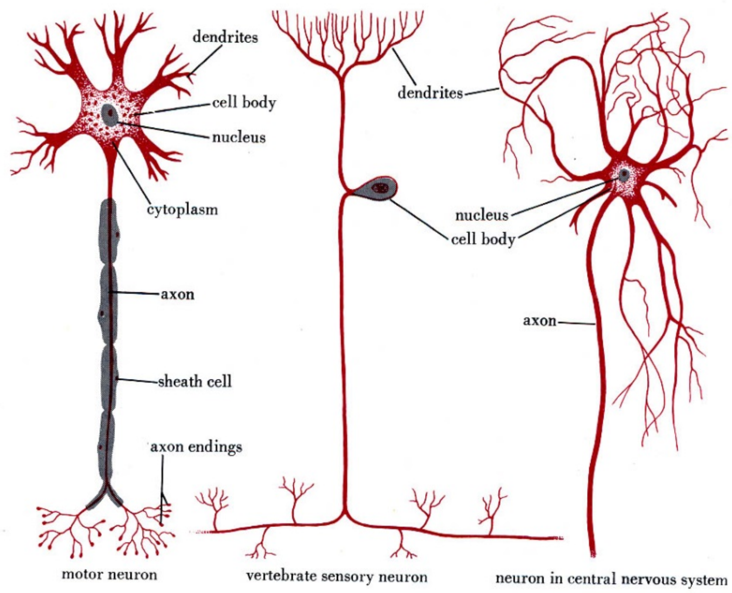
I. Introduction
- A. Integration
  1. Nervous system
  2. Endocrine system
- B. Functions of Nervous System
- C. Complementary Structures

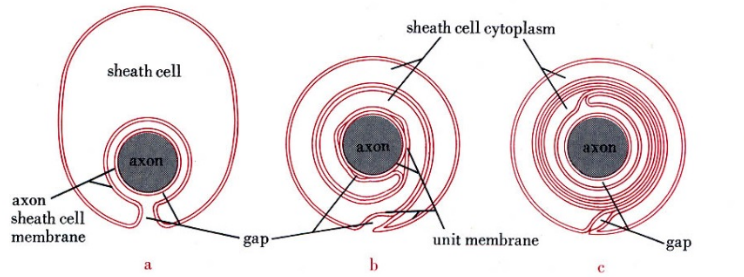
II. Neuron Anatomy *(930-935)*
- A. General Structure
- B. Diversity of Structure
  1. Sensory neurons
  2. Motor neurons
  3. Interneurons
- C. Supporting Cells

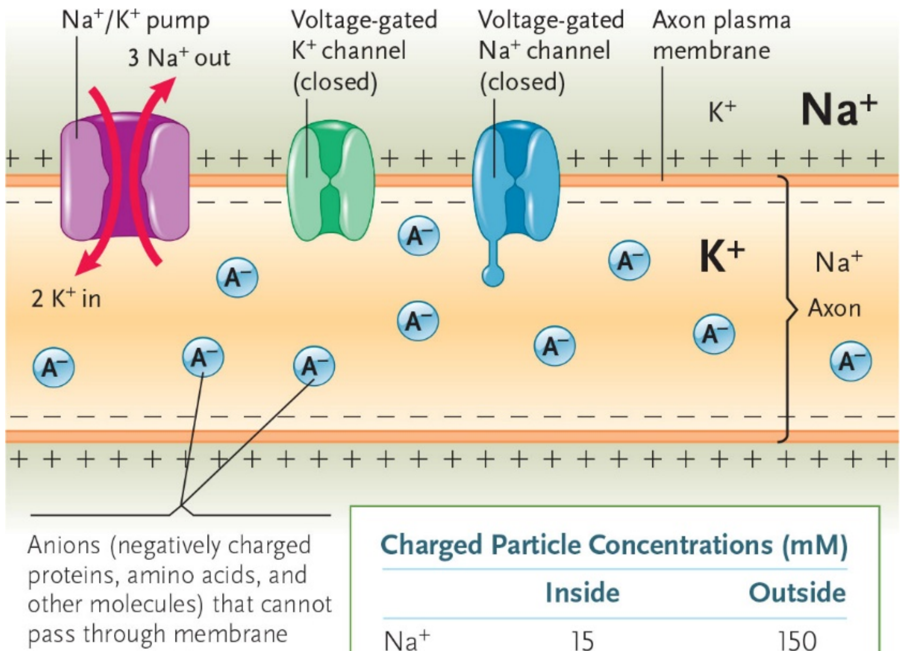
III. Transmission Along an Axon *(935-941)*
- A. Polarization of Resting Axon
  1. Ions and the nature of polarization
  2. Maintaining ion concentration gradients
  3. Resting state potential
- B. Action Potential
  1. Reversal of polarization
  2. Mechanism of reversal
  3. Restoration of resting state polarity
  4. Restoration of resting state ion concentrations
  5. The trigger for depolarization
- C. Characteristics of Axonal Transmission
  1. Self-propagation
  2. All or none response
  3. Speed of transmission
- D. Coding the Intensity of a Stimulus

IV. Transmission between Neurons *(941-947)*
- A. Synapses
- B. Stimulatory Transmitters
  1. Release of transmitters
  2. Depolarization of receiver
  3. Neurotransmitters
- C. Inhibitory Transmitters
  1. Presynaptic inhibitors
  2. Postsynaptic inhibitors
- D. Principle of summation


External, for example, light, movement; or internal, for example, change in blood pressure, change in body temperature
Sensory receptors of afferent neurons in external or internal organs detect stimulus.
Message travels along neuron.
Neural messages sorted and interpreted.
Message travels along neuron.
Neural messages from efferent neurons transmitted to effectors.
Parts of the body that result in the action, for example muscles and glands
Stimulus
Reception
Afferent (sensory) neurons
Transmission
Interneurons
Integration
Interneurons
Transmission
Efferent neurons
Response
Effectors
Action
Peripheral nervous system (PNS)
Central nervous system (CNS)

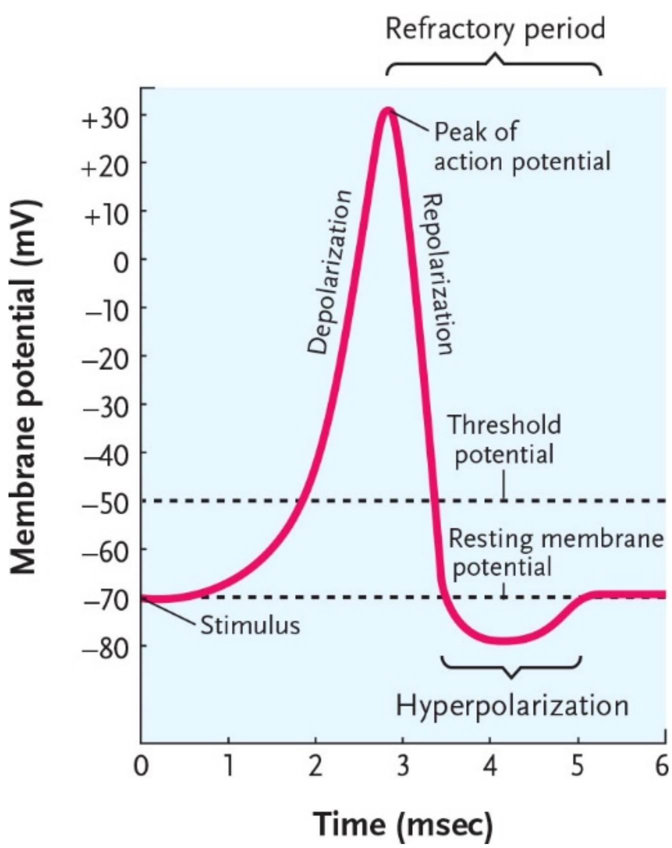

dendrites
cell body
nucleus
cytoplasm
axon
sheath cell
axon endings
motor neuron
dendrites
vertebrate sensory neuron
nucleus
cell body
axon
neuron in central nervous system

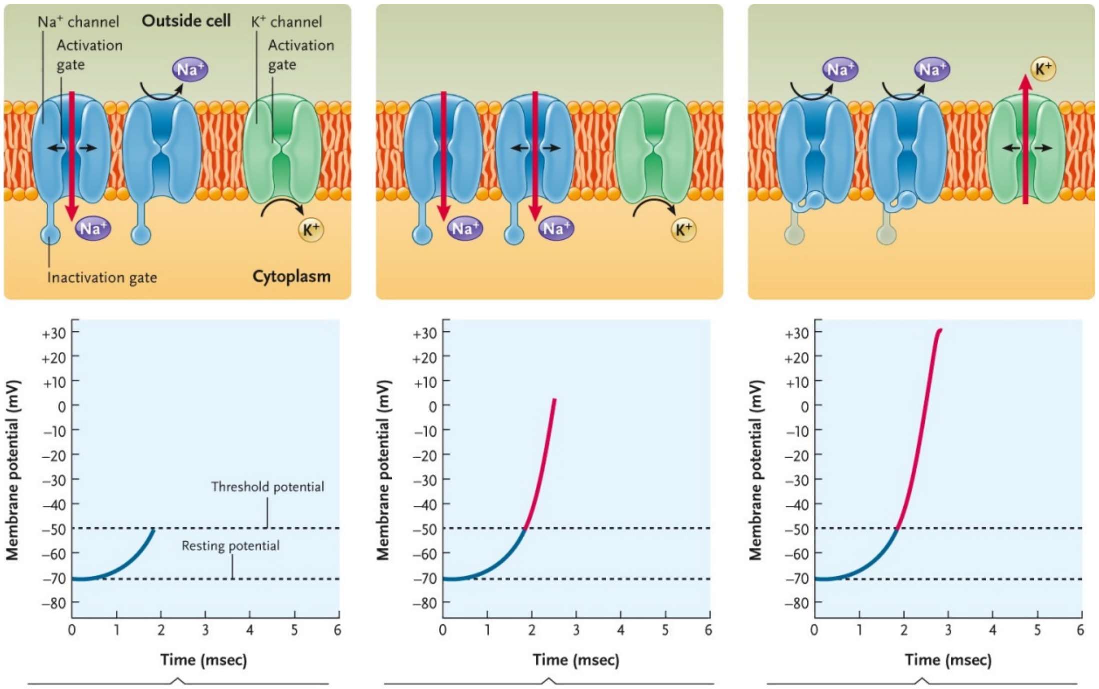

sheath cell
axon
axon sheath cell membrane
gap
a
sheath cell cytoplasm
axon
unit membrane
b
axon
gap
c



Charged Particle Concentrations (mM)

	Inside	Outside
Na^+	15	150
K^+	150	5
A^-	65	0

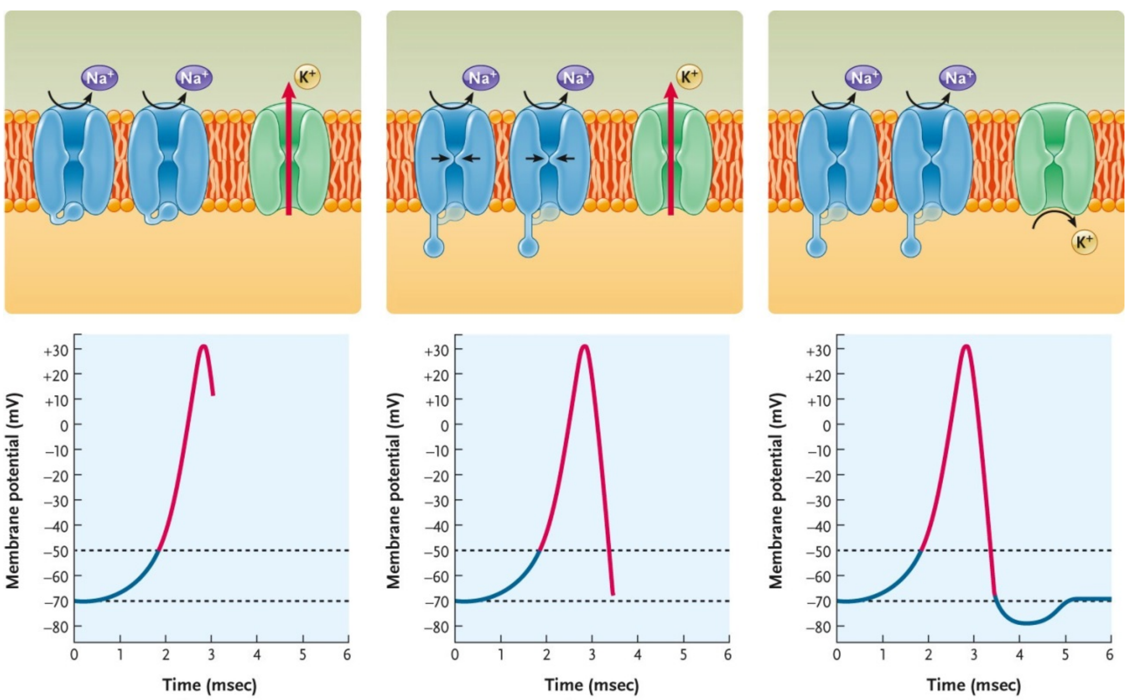




1 When the membrane is at the resting potential, the activation gates of both the Na^+ and K^+ channels are closed. As a depolarizing stimulus raises the membrane potential to threshold, the activation gates of the Na^+ channels open, causing a burst of Na^+ ions to flow into the axon along their concentration gradient.

2 Once above the threshold, more Na^+ channels open, causing a rapid inward flow of positive charges that raises the membrane potential toward the peak of the action potential.

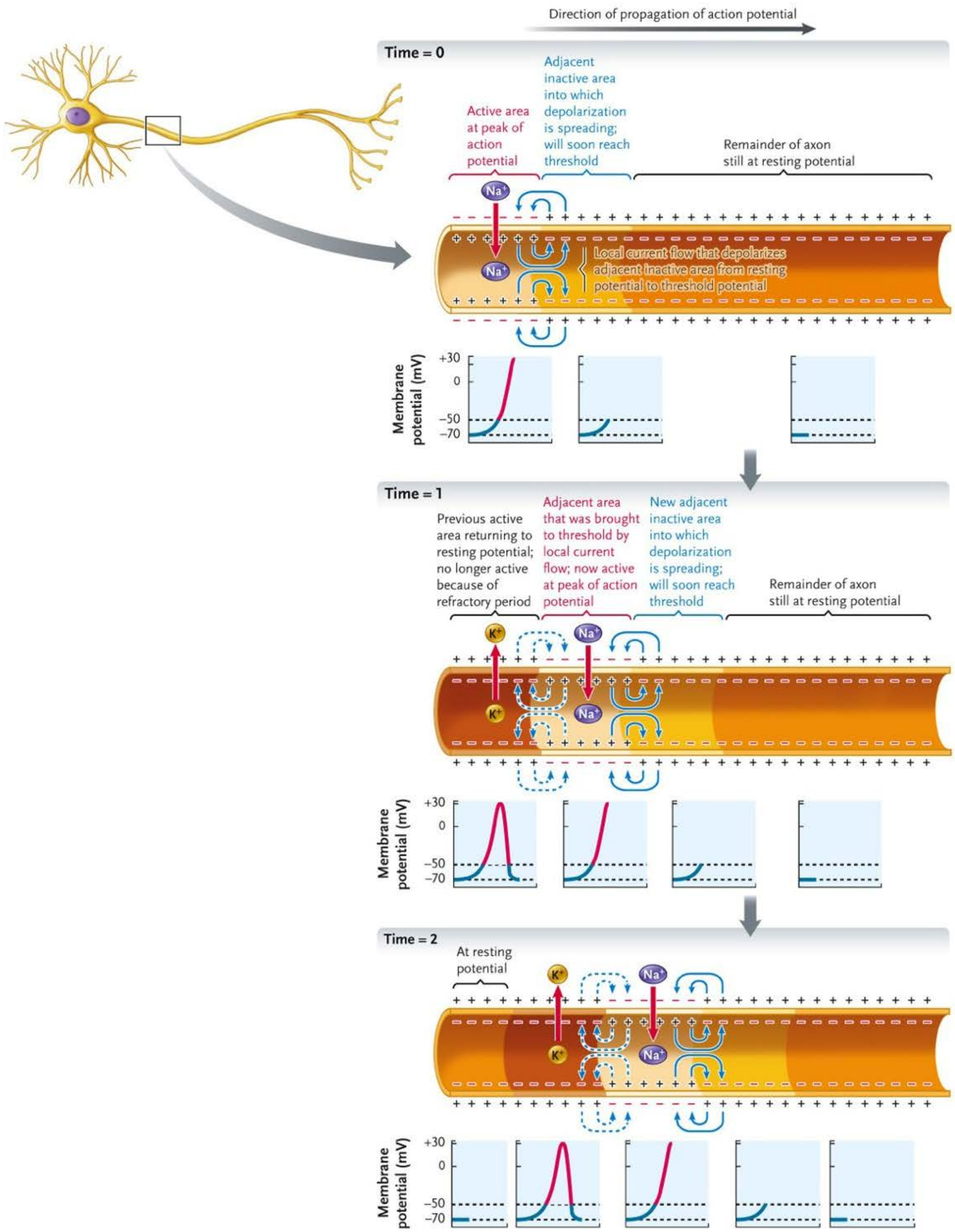
3 The onset of Na^+ channel inactivation (resembling putting a stopper into a sink) stops the inward flow of Na^+ and causes the action potential to peak. At the same time, activated K^+ channels allow K^+ to flow outward in response to their concentration gradient. The refractory period now begins.



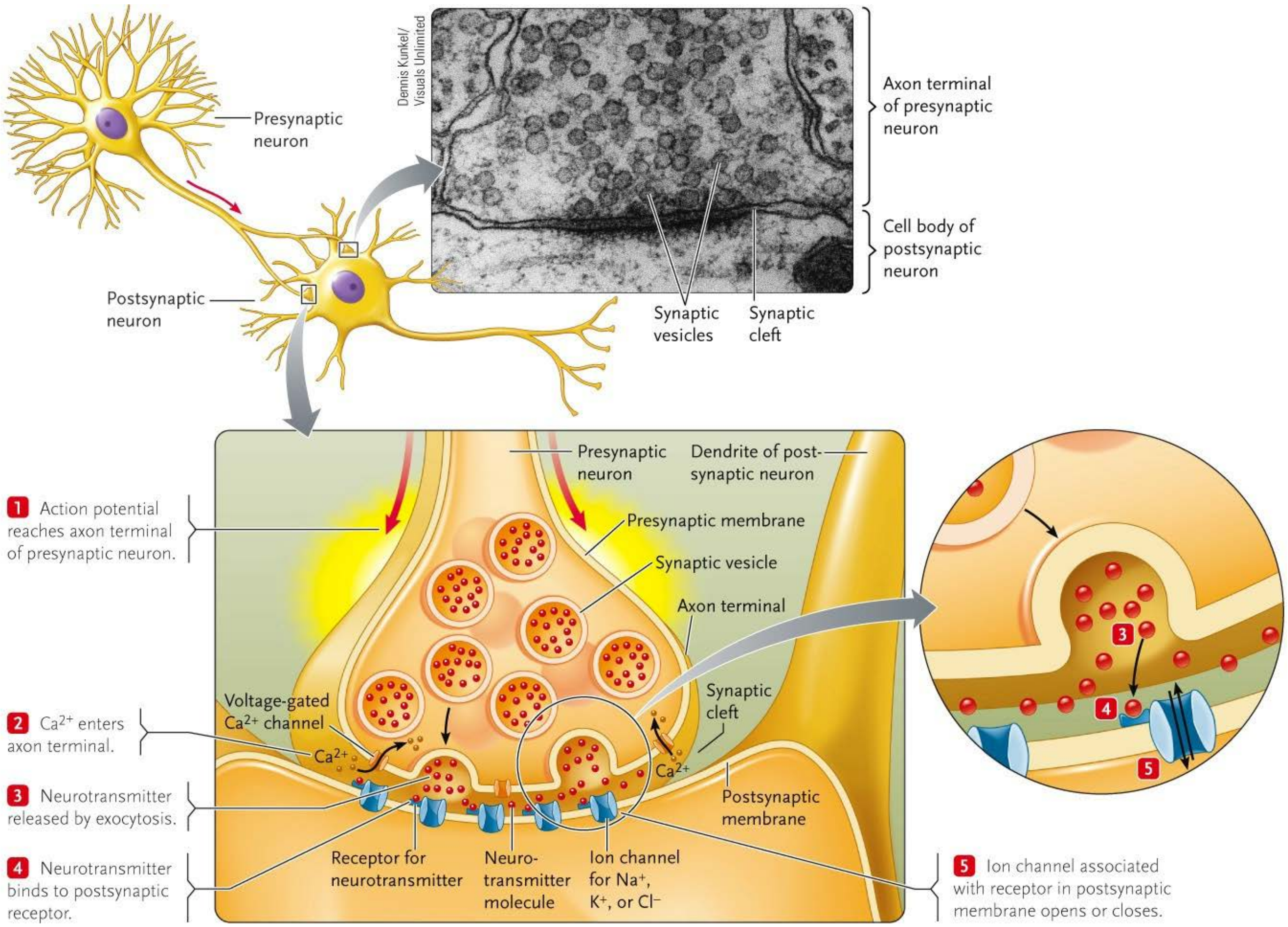
4 The outward flow of K^+ along its concentration gradient compensates for the inward movement of Na^+ ions and causes the membrane potential to begin to fall.

5 As the membrane potential reaches the resting value, the activation gate of the Na^+ channel closes and the inactivation gate opens. In most neurons, the K^+ activation gate remains open and K^+ continues to flow outward for a brief time after the membrane reaches the resting potential. This excess outward flow causes hyperpolarization, in which the membrane potential dips briefly below the resting potential (the dip is seen in step 6).

6 Closure of the K^+ activation gate stabilizes the membrane potential at the resting value. The refractory period has now ended, and the membrane is ready for another action potential.



Direction of propagation of action potential
Time = 0
Active area at peak of action potential
Adjacent inactive area into which depolarization is spreading; will soon reach threshold
Remainder of axon still at resting potential
Local current flow that depolarizes adjacent inactive area from resting potential to threshold potential
Membrane potential (mV)
+30
0
–50
–70
Time = 1
Previous active area returning to resting potential; no longer active because of refractory period
Adjacent area that was brought to threshold by local current flow; now active at peak of action potential
New adjacent inactive area into which depolarization is spreading; will soon reach threshold
Remainder of axon still at resting potential
Time = 2
At resting potential


Presynaptic neuron
Postsynaptic neuron
Dennis Kunkel/ Visuals Unlimited
Axon terminal of presynaptic neuron
Cell body of postsynaptic neuron
Synaptic vesicles
Synaptic cleft
Presynaptic neuron
Dendrite of post-synaptic neuron
1 Action potential reaches axon terminal of presynaptic neuron.
Presynaptic membrane
Synaptic vesicle
Axon terminal
Voltage-gated Ca^{2+} channel
Synaptic cleft
2 Ca^{2+} enters axon terminal.
Ca^{2+}
Ca^{2+}
3 Neurotransmitter released by exocytosis.
Postsynaptic membrane
4 Neurotransmitter binds to postsynaptic receptor.
Receptor for neurotransmitter
Neuro-transmitter molecule
Ion channel for Na^+, K^+, or Cl^-
5 Ion channel associated with receptor in postsynaptic membrane opens or closes.
3
4
5

11. Sensory Input and Integration *Chapters 40, 41*

I. Sensory Systems *(972-974, 977-985)*

A. Introduction
1. Function
2. General action
3. Sensory modalities

B. Visual Receptors
1. Evolution of light sensing organs
2. Camera eye

C. Sound Receptors
1. Occurrence in the Animal Kingdom
2. The human ear

II. Integration *(951-957)*

A. Introduction

B. Nervous Systems in Invertebrates
1. Nerve nets and radial systems
2. Bilateral nervous systems

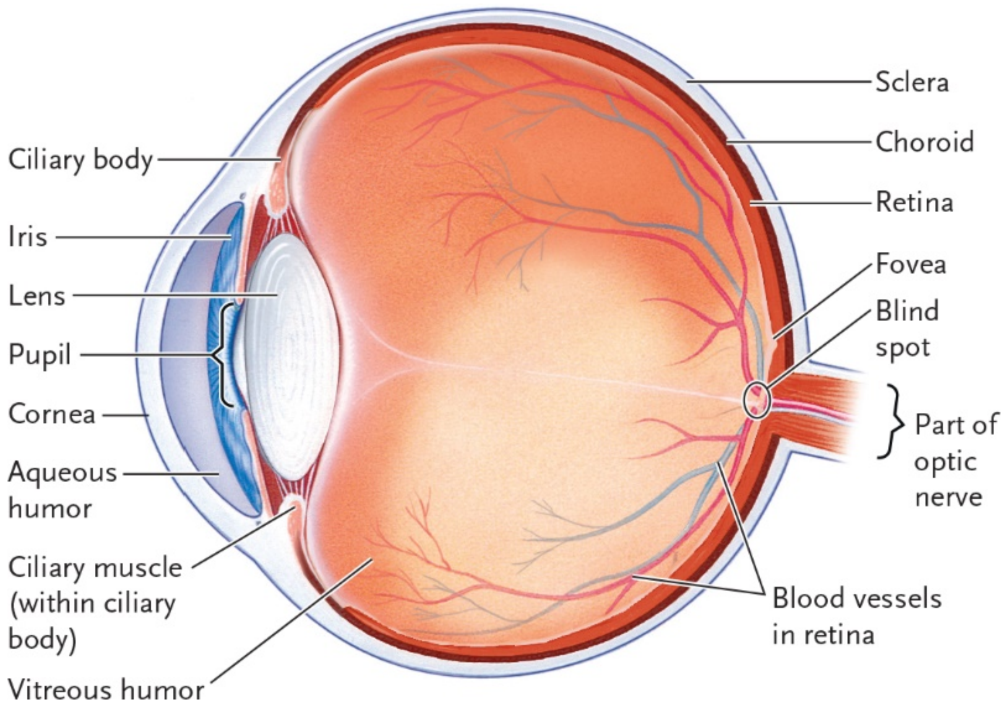
C. Nervous Pathways in Vertebrates
1. General organization
2. Motor System
    a. Autonomic system
    b. Somatic System

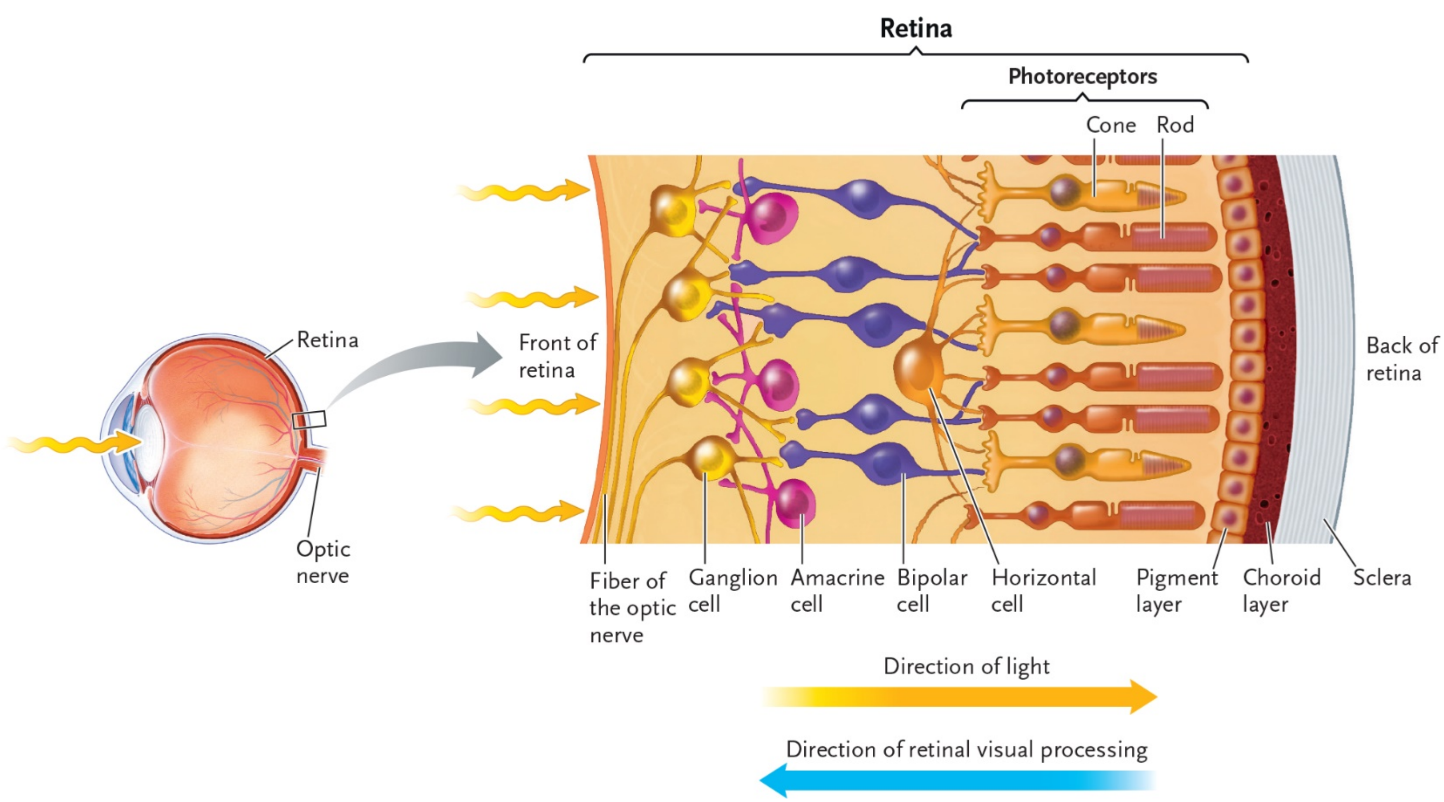
III. Integration in the Brain *(957-963)*

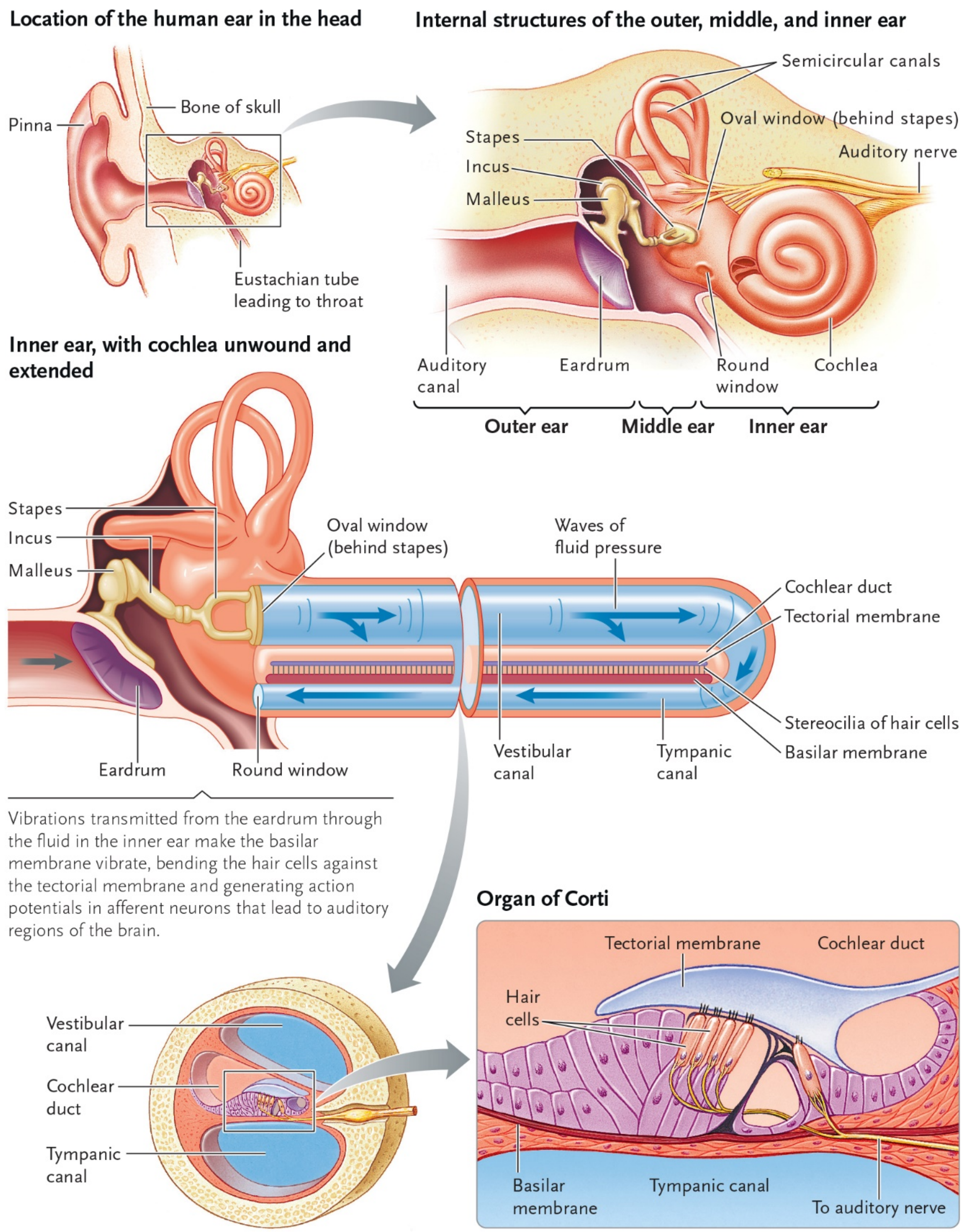
A. Evolutionary Trends in Cephalization

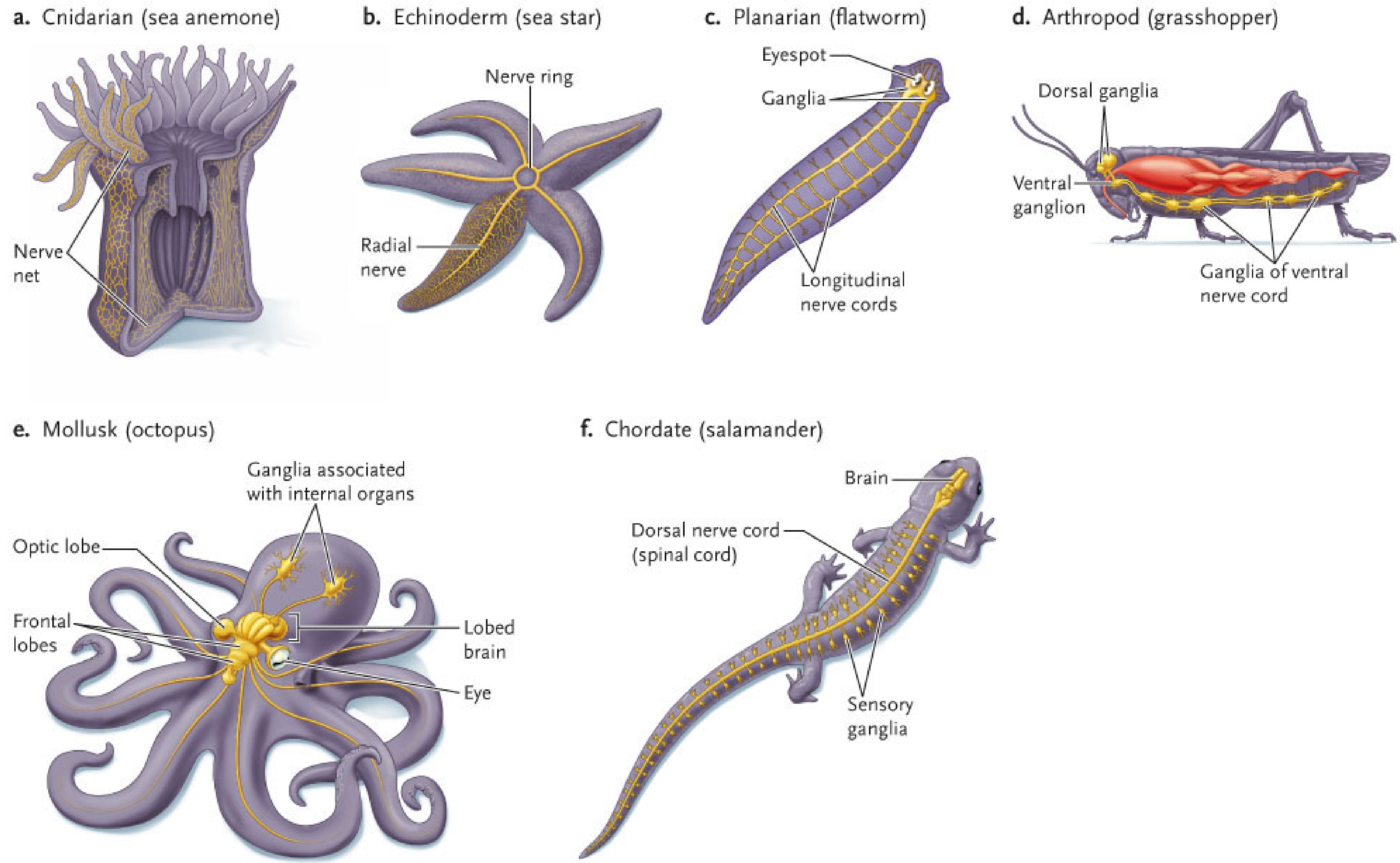
B. The Cerebral Cortex in Humans
1. Gross anatomy
2. Localization of functions

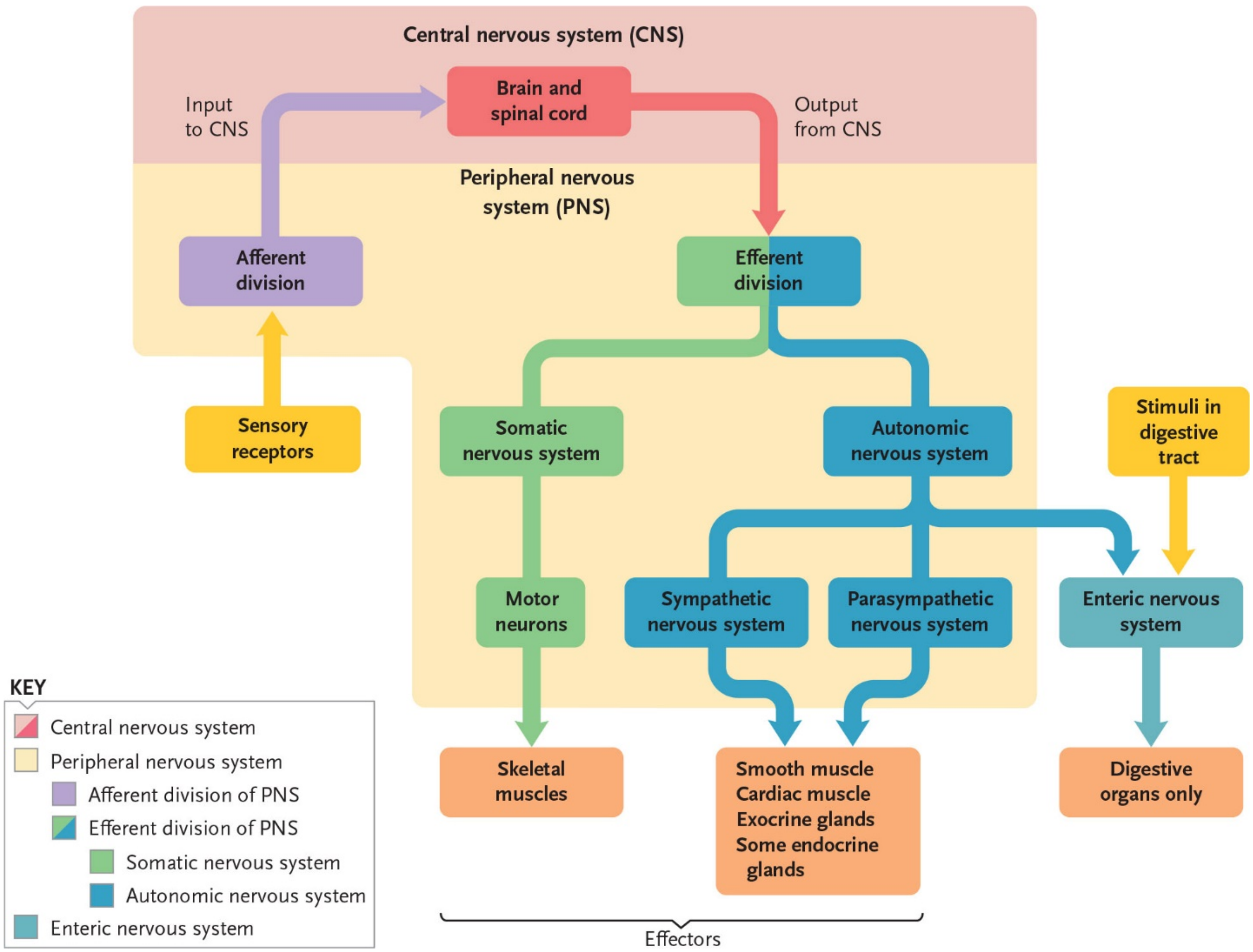
C. Other Structures and Functions of the Human Brain


Ciliary body
Iris
Lens
Pupil
Cornea
Aqueous humor
Ciliary muscle (within ciliary body)
Vitreous humor
Sclera
Choroid
Retina
Fovea
Blind spot
Part of optic nerve
Blood vessels in retina


Retina
Optic nerve
Front of retina
Retina
Photoreceptors
Cone
Rod
Back of retina
Fiber of the optic nerve
Ganglion cell
Amacrine cell
Bipolar cell
Horizontal cell
Pigment layer
Choroid layer
Sclera
Direction of light
Direction of retinal visual processing

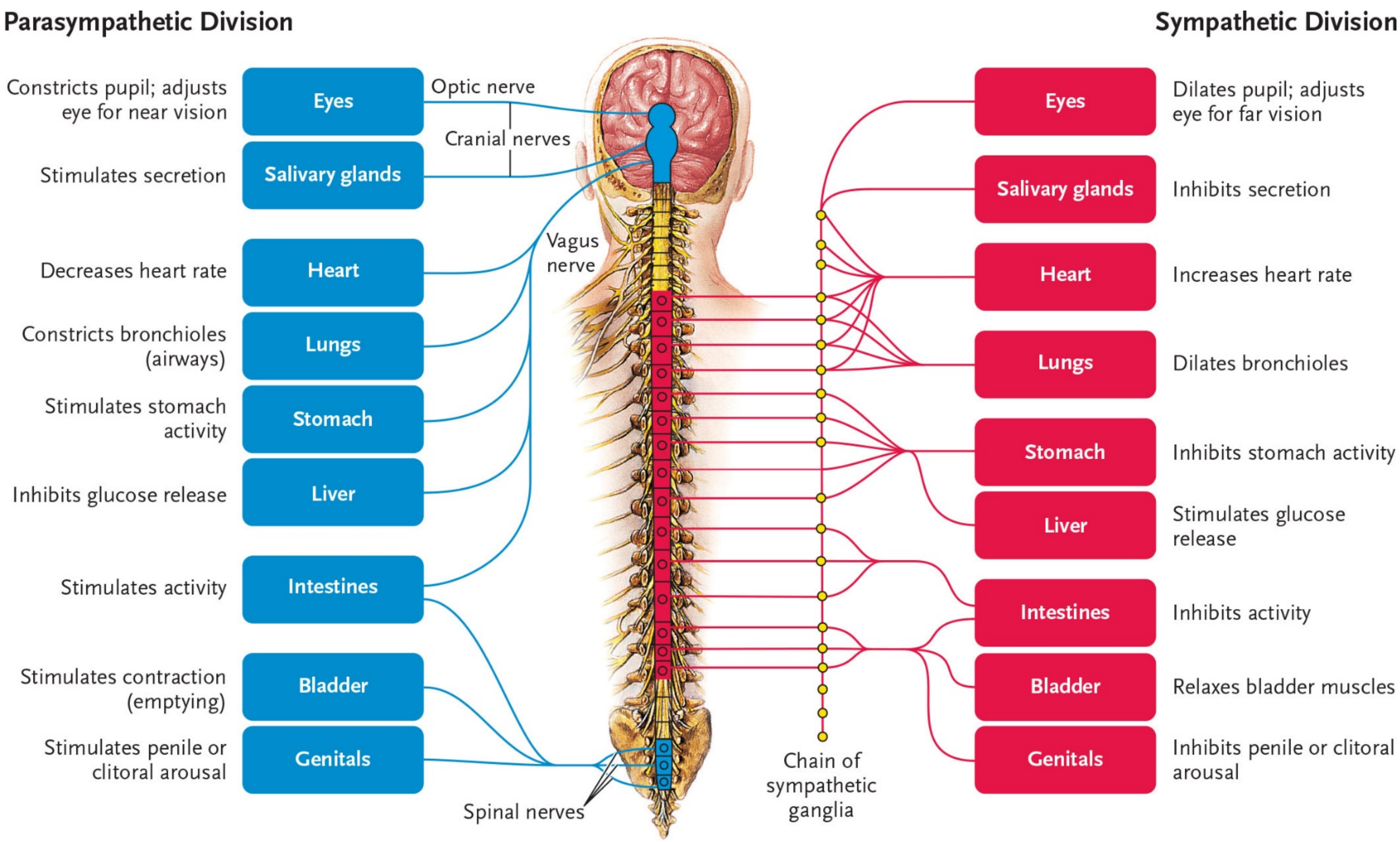

Location of the human ear in the head
Pinna
Bone of skull
Eustachian tube leading to throat
Internal structures of the outer, middle, and inner ear
Semicircular canals
Oval window (behind stapes)
Auditory nerve
Stapes
Incus
Malleus
Auditory canal
Eardrum
Round window
Cochlea
Outer ear
Middle ear
Inner ear
Inner ear, with cochlea unwound and extended
Stapes
Incus
Malleus
Oval window (behind stapes)
Waves of fluid pressure
Cochlear duct
Tectorial membrane
Stereocilia of hair cells
Basilar membrane
Eardrum
Round window
Vestibular canal
Tympanic canal
Vibrations transmitted from the eardrum through the fluid in the inner ear make the basilar membrane vibrate, bending the hair cells against the tectorial membrane and generating action potentials in afferent neurons that lead to auditory regions of the brain.
Organ of Corti
Vestibular canal
Cochlear duct
Tympanic canal
Tectorial membrane
Cochlear duct
Hair cells
Basilar membrane
Tympanic canal
To auditory nerve

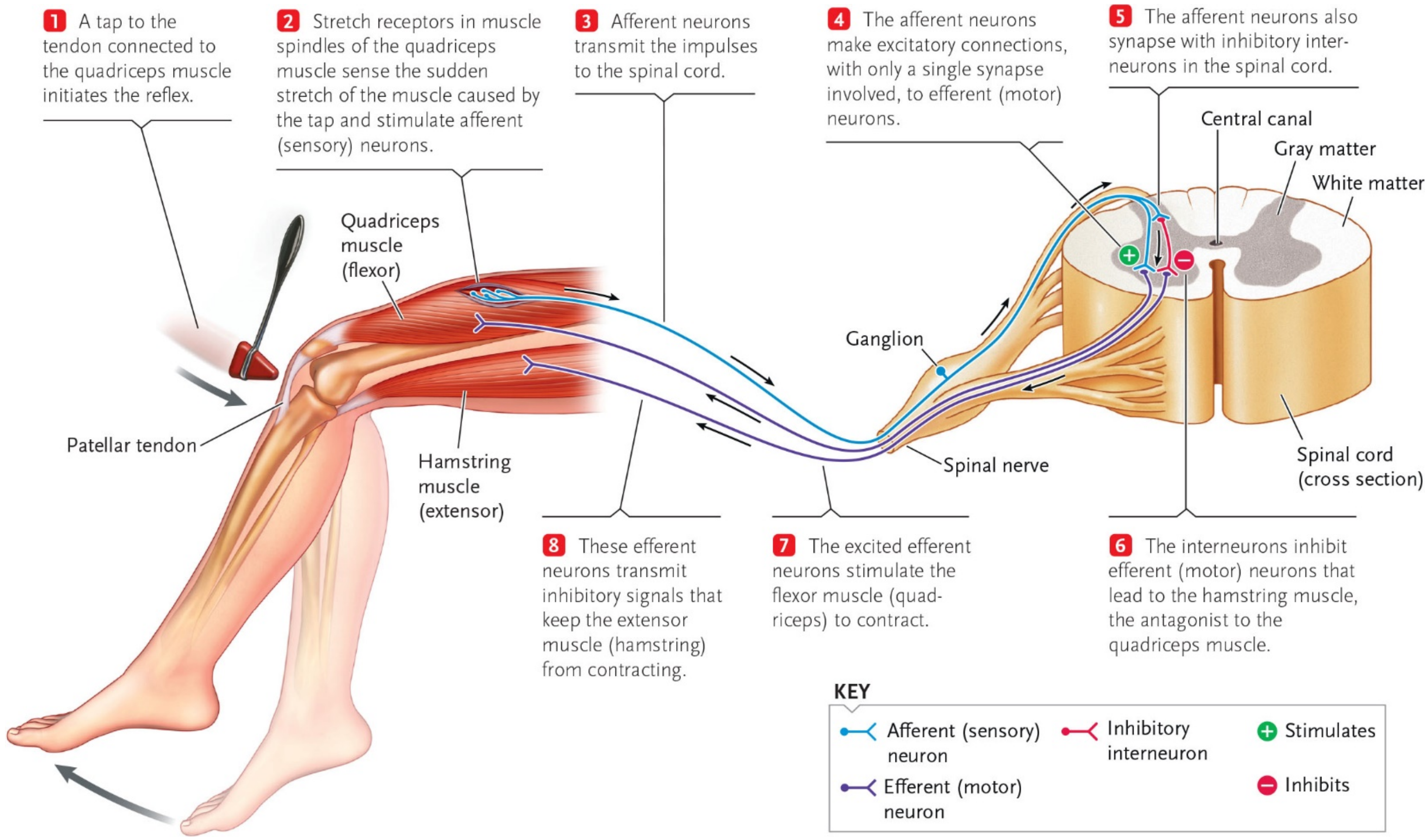

a. Cnidarian (sea anemone)
Nerve net
b. Echinoderm (sea star)
Nerve ring
Radial nerve
c. Planarian (flatworm)
Eyespot
Ganglia
Longitudinal nerve cords
d. Arthropod (grasshopper)
Dorsal ganglia
Ventral ganglion
Ganglia of ventral nerve cord
e. Mollusk (octopus)
Ganglia associated with internal organs
Optic lobe
Frontal lobes
Lobed brain
Eye
f. Chordate (salamander)
Brain
Dorsal nerve cord (spinal cord)
Sensory ganglia

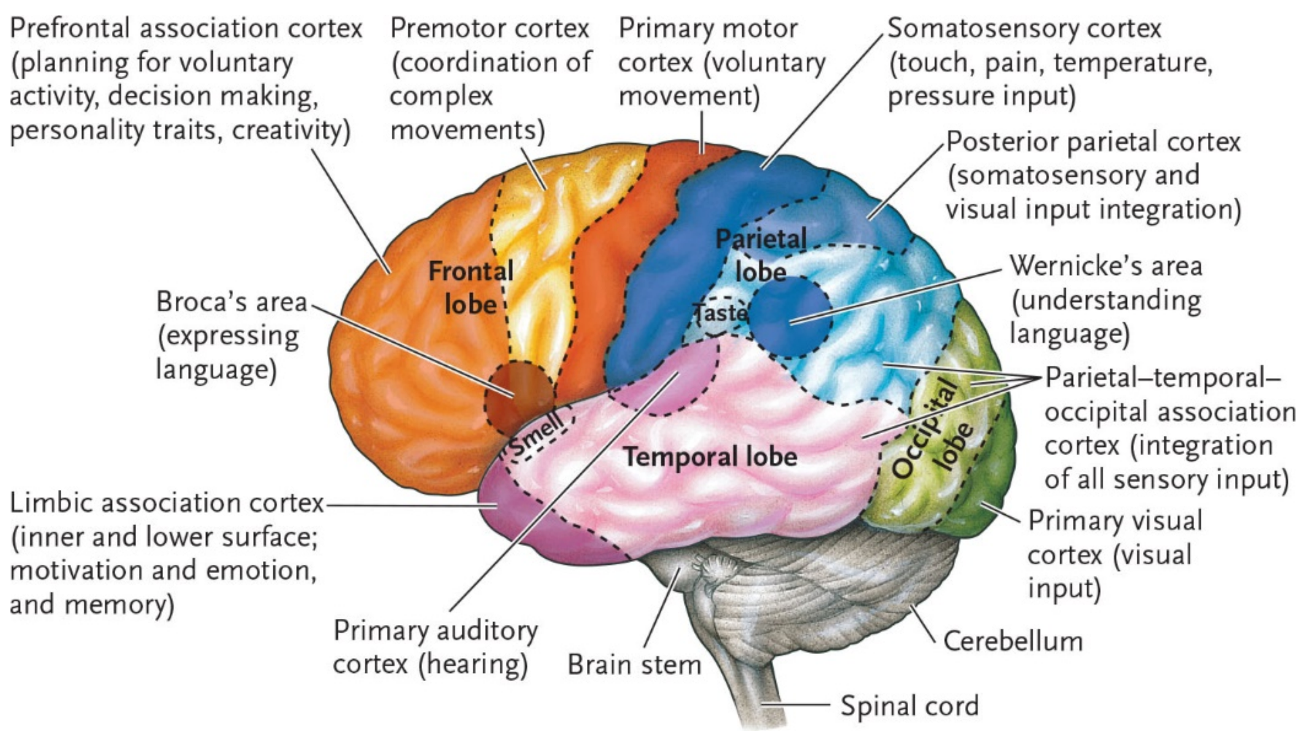


Central nervous system (CNS)
Input to CNS
Brain and spinal cord
Output from CNS
Peripheral nervous system (PNS)
Afferent division
Efferent division
Sensory receptors
Somatic nervous system
Autonomic nervous system
Stimuli in digestive tract
Motor neurons
Sympathetic nervous system
Parasympathetic nervous system
Enteric nervous system
Skeletal muscles
Smooth muscle
Cardiac muscle
Exocrine glands
Some endocrine glands
Digestive organs only
Effectors
KEY
Central nervous system
Peripheral nervous system
Afferent division of PNS
Efferent division of PNS
Somatic nervous system
Autonomic nervous system
Enteric nervous system

AUTONOMIC NERVOUS SYSTEM




1 A tap to the tendon connected to the quadriceps muscle initiates the reflex.
2 Stretch receptors in muscle spindles of the quadriceps muscle sense the sudden stretch of the muscle caused by the tap and stimulate afferent (sensory) neurons.
3 Afferent neurons transmit the impulses to the spinal cord.
4 The afferent neurons make excitatory connections, with only a single synapse involved, to efferent (motor) neurons.
5 The afferent neurons also synapse with inhibitory interneurons in the spinal cord.
Central canal
Gray matter
White matter
Quadriceps muscle (flexor)
Ganglion
Patellar tendon
Hamstring muscle (extensor)
Spinal nerve
Spinal cord (cross section)
8 These efferent neurons transmit inhibitory signals that keep the extensor muscle (hamstring) from contracting.
7 The excited efferent neurons stimulate the flexor muscle (quadriceps) to contract.
6 The interneurons inhibit efferent (motor) neurons that lead to the hamstring muscle, the antagonist to the quadriceps muscle.
KEY
Afferent (sensory) neuron
Inhibitory interneuron
Stimulates
Efferent (motor) neuron
Inhibits


Prefrontal association cortex (planning for voluntary activity, decision making, personality traits, creativity)
Premotor cortex (coordination of complex movements)
Primary motor cortex (voluntary movement)
Somatosensory cortex (touch, pain, temperature, pressure input)
Posterior parietal cortex (somatosensory and visual input integration)
Frontal lobe
Parietal lobe
Taste
Broca's area (expressing language)
Wernicke's area (understanding language)
Parietal–temporal–occipital association cortex (integration of all sensory input)
Smell
Temporal lobe
Occipital lobe
Limbic association cortex (inner and lower surface; motivation and emotion, and memory)
Primary visual cortex (visual input)
Primary auditory cortex (hearing)
Brain stem
Cerebellum
Spinal cord

12. Motor Systems *Chapters 38, 43*

I. Introduction *(1016-1017, 1023-1025)*

- A. Output Messages
- B. Skeletons and Muscles
  1. Hydrostatic skeletons
  2. External skeletons
  3. Internal skeletons

II. Components of Vertebrate Systems *(917-920)*

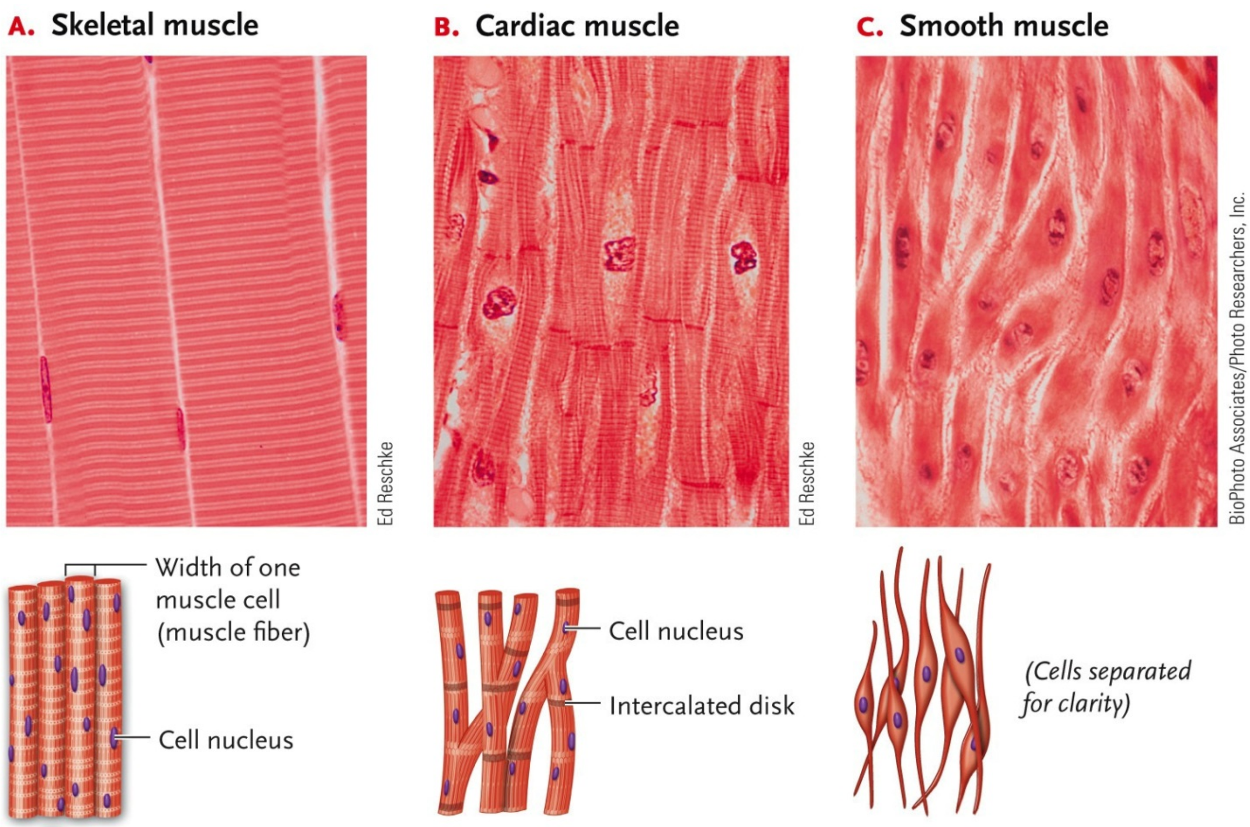
- A. Bone
- B. Cartilage
- C. Tendons and Ligaments
- D. Muscles
  1. Smooth muscle
  2. Skeletal muscle
  3. Cardiac muscle

III. Muscle Action *(1017-1018, 1025-1027)*

- A. Antagonism of Paired Muscles
- B. Response of Single Muscles
  1. Whole muscle graded response
  2. Muscle fibers and innervation
  3. Time course of contraction
  4. Summation

IV. Molecular Basis of Muscle Contraction *(1017-1023)*

- A. Fine Structure of Skeleta; Muscle
  1. Fibers
  2. Bundles
  3. Sarcomeres
- B. Sarcomere Anatomy
  1. Distinctive zones
  2. Distinctive biochemistry
- C. Sarcomere Action
  1. Telescoping of components
  2. Changes in the zones
  3. Sliding filament theory
  4. Mechanism of sliding
  5. Innervation and control of sliding



Description: Bundles of long, cylindrical, striated, contractile, multinucleate cells called muscle fibers

Typical location: Attached to bones of skeleton

Function: Locomotion, movement of body parts

Description: Interlinked network of short and branched cylindrical, striated cells stabilized by anchoring junctions and gap junctions

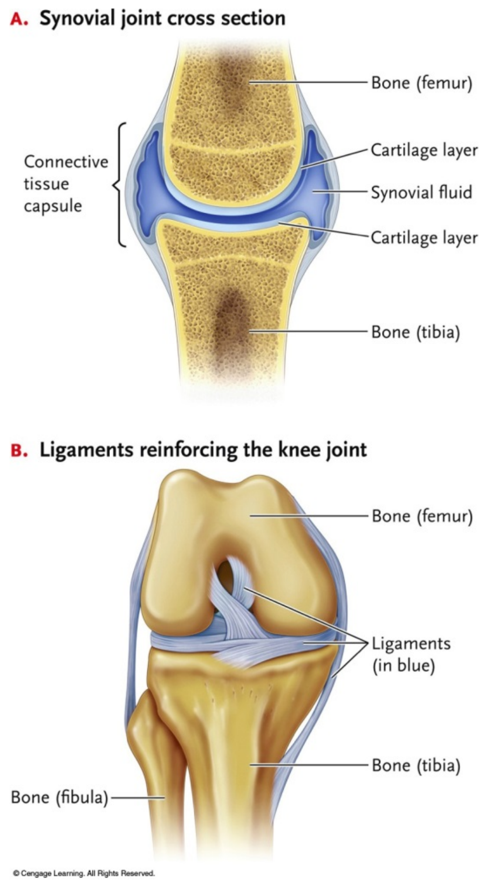
Location: Wall of heart

Function: Pumping of blood within circulatory system

Description: Loose network of contractile cells with tapered ends

Typical location: Wall of internal organs, such as stomach

Function: Movement of internal organs


A. Synovial joint cross section
Bone (femur)
Connective tissue capsule
Cartilage layer
Synovial fluid
Cartilage layer
Bone (tibia)
B. Ligaments reinforcing the knee joint
Bone (femur)
Ligaments (in blue)
Bone (tibia)
Bone (fibula)
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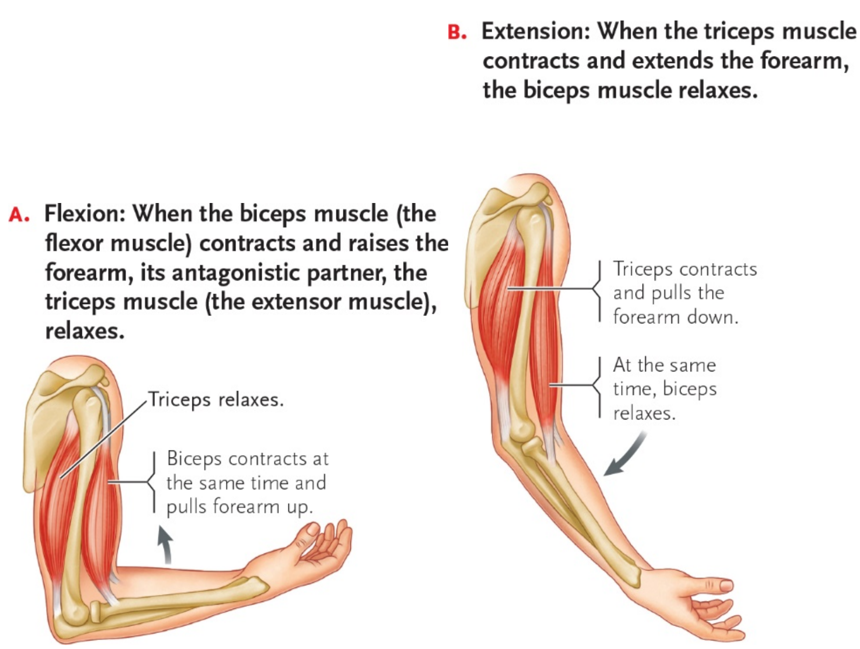
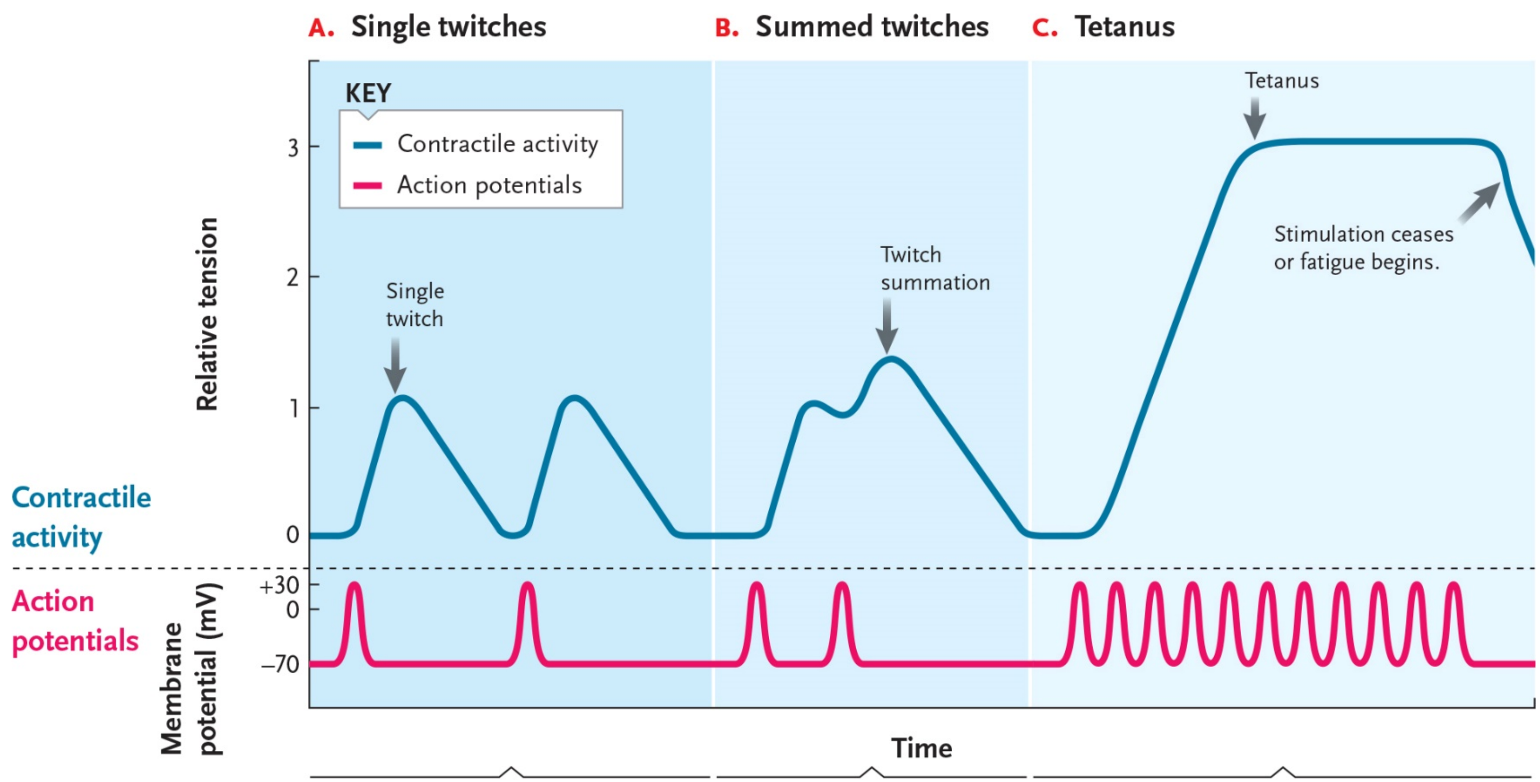
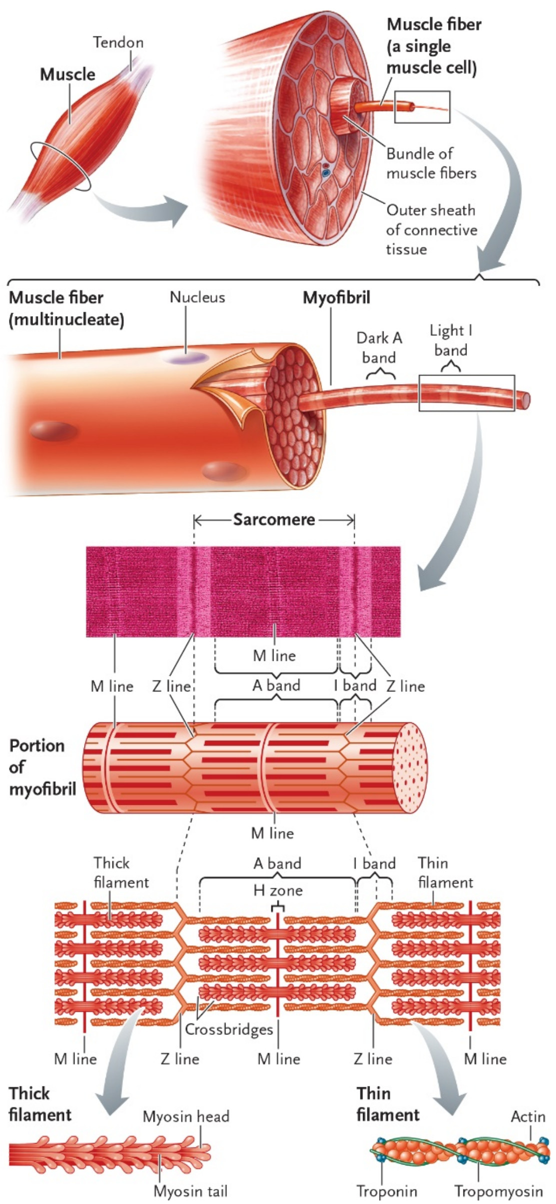

B. Extension: When the triceps muscle contracts and extends the forearm, the biceps muscle relaxes.
Triceps contracts and pulls the forearm down.
At the same time, biceps relaxes.
A. Flexion: When the biceps muscle (the flexor muscle) contracts and raises the forearm, its antagonistic partner, the triceps muscle (the extensor muscle), relaxes.
Triceps relaxes.
Biceps contracts at the same time and pulls forearm up.



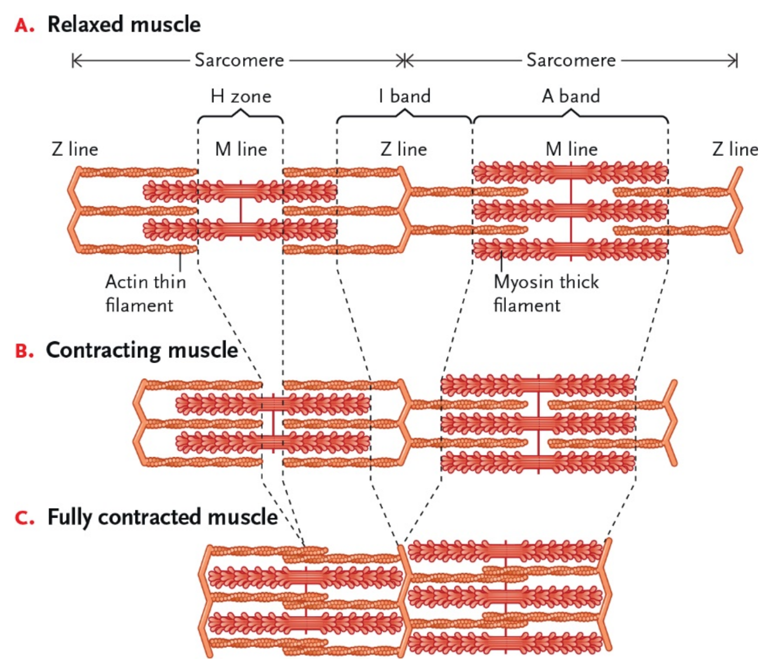
If a muscle fiber is restimulated after it has completely relaxed, the second twitch generated is identical to the first twitch.

If a muscle fiber is restimulated before it has completely relaxed, the second twitch is added to the first twitch, resulting in summation, essentially a summed, stronger contraction.

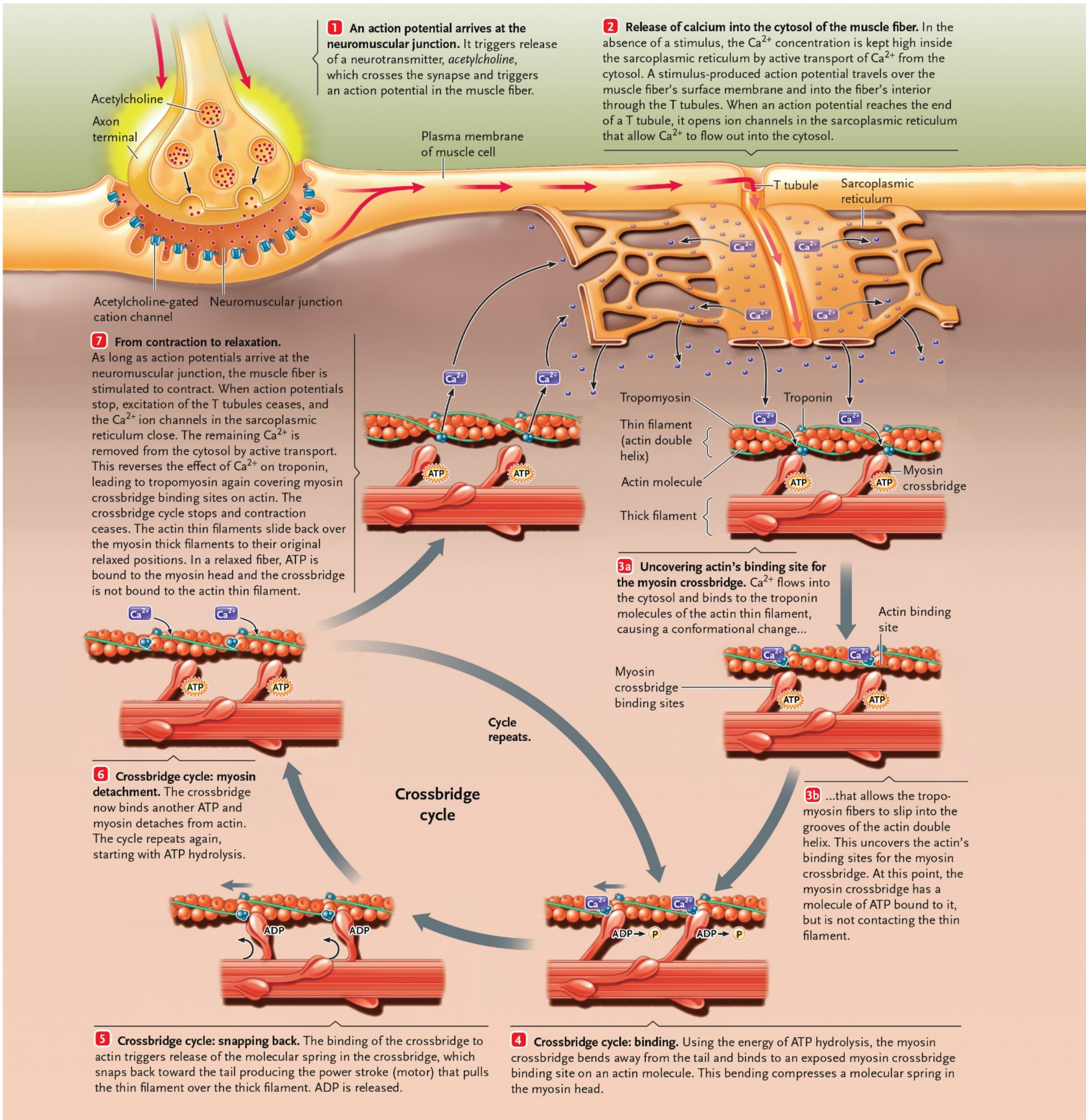
If a muscle fiber is stimulated so rapidly that it does not have an opportunity to relax at all between stimuli, a peak level of continuous contraction known as *tetanus* occurs.



Tendon
Muscle
Muscle fiber (a single muscle cell)
Bundle of muscle fibers
Outer sheath of connective tissue
Muscle fiber (multinucleate)
Nucleus
Myofibril
Dark A band
Light I band
Sarcomere
M line
Z line
A band
I band
Z line
Portion of myofibril
M line
Thick filament
A band
H zone
I band
Thin filament
Crossbridges
M line
Z line
M line
Z line
M line
Thick filament
Myosin head
Myosin tail
Thin filament
Actin
Troponin
Tropomyosin



A. Relaxed muscle
Sarcomere
Sarcomere
H zone
I band
A band
Z line
M line
Z line
M line
Z line
Actin thin filament
Myosin thick filament
B. Contracting muscle
C. Fully contracted muscle



Acetylcholine
Axon terminal
Acetylcholine-gated cation channel
Neuromuscular junction
1 An action potential arrives at the neuromuscular junction. It triggers release of a neurotransmitter, acetylcholine, which crosses the synapse and triggers an action potential in the muscle fiber.
Plasma membrane of muscle cell
2 Release of calcium into the cytosol of the muscle fiber. In the absence of a stimulus, the Ca^{2+} concentration is kept high inside the sarcoplasmic reticulum by active transport of Ca^{2+} from the cytosol. A stimulus-produced action potential travels over the muscle fiber's surface membrane and into the fiber's interior through the T tubules. When an action potential reaches the end of a T tubule, it opens ion channels in the sarcoplasmic reticulum that allow Ca^{2+} to flow out into the cytosol.
T tubule
Sarcoplasmic reticulum
Ca^{2+}
Tropomyosin
Troponin
Thin filament (actin double helix)
Actin molecule
Myosin crossbridge
ATP
Thick filament
3a Uncovering actin's binding site for the myosin crossbridge. Ca^{2+} flows into the cytosol and binds to the troponin molecules of the actin thin filament, causing a conformational change...
Actin binding site
Myosin crossbridge binding sites
3b ...that allows the tropomyosin fibers to slip into the grooves of the actin double helix. This uncovers the actin's binding sites for the myosin crossbridge. At this point, the myosin crossbridge has a molecule of ATP bound to it, but is not contacting the thin filament.
7 From contraction to relaxation. As long as action potentials arrive at the neuromuscular junction, the muscle fiber is stimulated to contract. When action potentials stop, excitation of the T tubules ceases, and the Ca^{2+} ion channels in the sarcoplasmic reticulum close. The remaining Ca^{2+} is removed from the cytosol by active transport. This reverses the effect of Ca^{2+} on troponin, leading to tropomyosin again covering myosin crossbridge binding sites on actin. The crossbridge cycle stops and contraction ceases. The actin thin filaments slide back over the myosin thick filaments to their original relaxed positions. In a relaxed fiber, ATP is bound to the myosin head and the crossbridge is not bound to the actin thin filament.
Cycle repeats.
Crossbridge cycle
6 Crossbridge cycle: myosin detachment. The crossbridge now binds another ATP and myosin detaches from actin. The cycle repeats again, starting with ATP hydrolysis.
ADP
ADP → P
5 Crossbridge cycle: snapping back. The binding of the crossbridge to actin triggers release of the molecular spring in the crossbridge, which snaps back toward the tail producing the power stroke (motor) that pulls the thin filament over the thick filament. ADP is released.
4 Crossbridge cycle: binding. Using the energy of ATP hydrolysis, the myosin crossbridge bends away from the tail and binds to an exposed myosin crossbridge binding site on an actin molecule. This bending compresses a molecular spring in the myosin head.

13. Chemical Integration: Hormones and the Endocrine System *(RHM: Chapter 42)*

I. Integration of Physiological and Behavioral Functions *(994-997)*

- A. Role of the Nervous System
- B. Role of the Endocrine System
  1. Endocrine glands
  2. Hormones
  3. Target organs
- C. Basic Principles of Endocrine Function
  1. Function at low concentrations
  2. Response determined by target organ
  3. Antagonistic hormones provide precise regulation

II. Regulation of Body Chemistry and Physiology: Role of Hypothalamus *(1001-1005)*

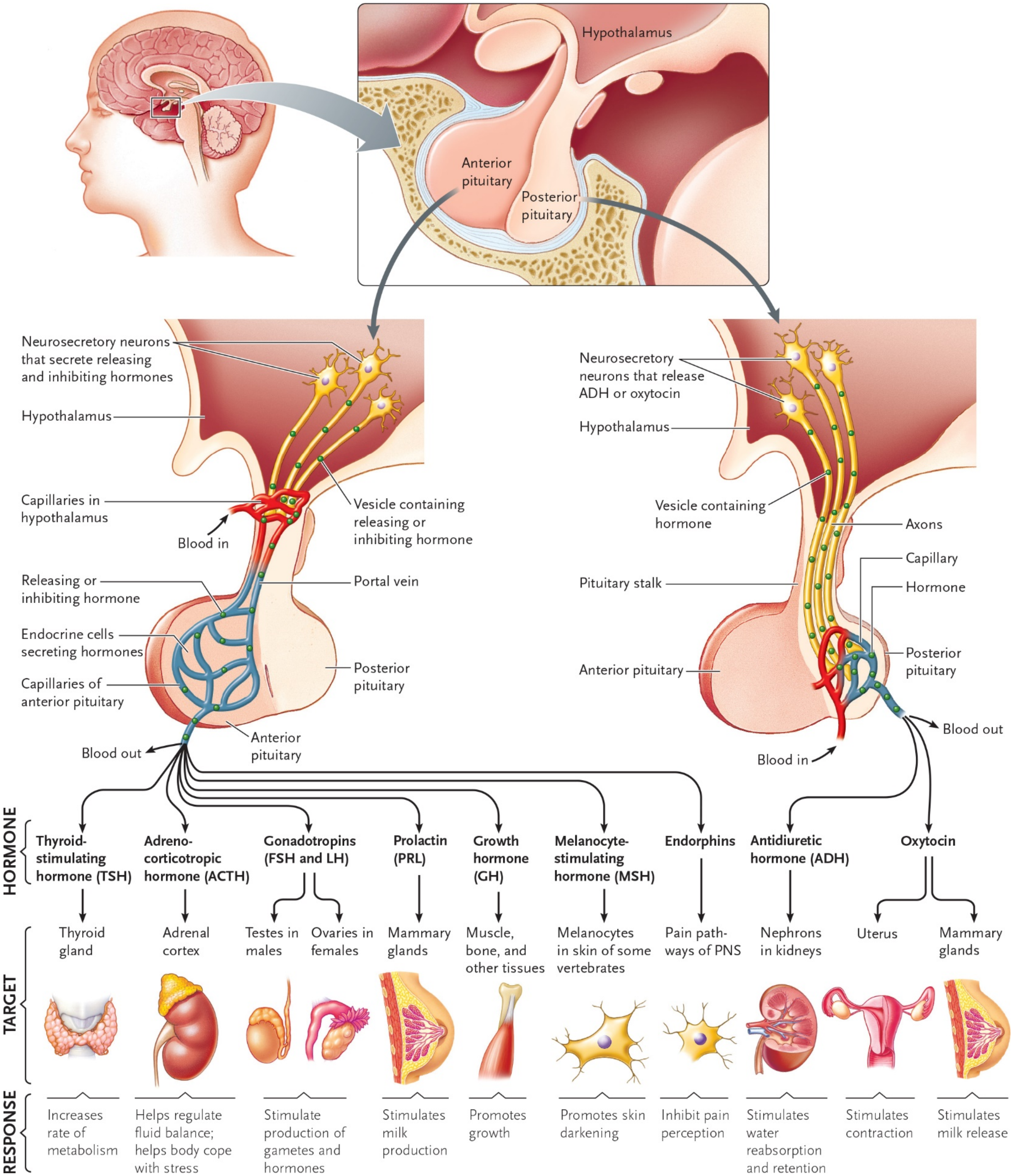
- A. Functions
- B. Monitoring and Control in the Brain
  1. The hypothalamus
  2. The portal system
  3. The anterior pituitary
- C. Stimulating Hormones
- D. Principle of Negative Feedback

III. Endocrine Systems Not Under Direct Hypothalamic Control *(1005-1011)*

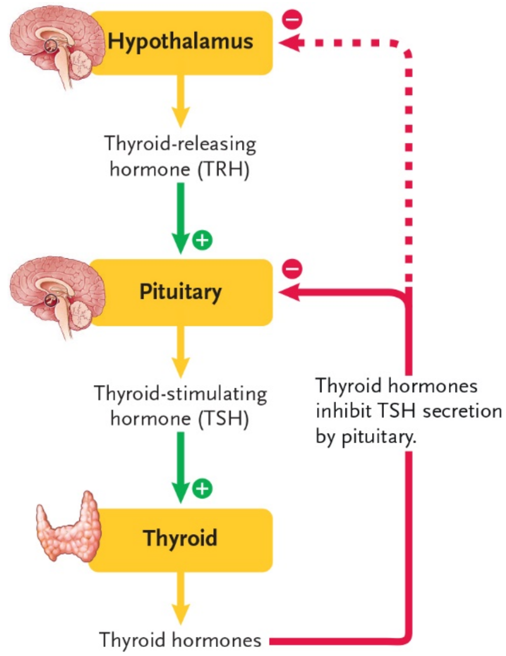
- A. Introduction
- B. Digestion
  1. Hormones of the stomach and intestine
  2. Hormone action
- C. Endocrine Functions of the Pancreas
  1. Structure of pancreatic tissue
  2. Insulin
  3. Glucagons
- D. Adrenal Medulla: Adrenalin and noradrenalin
- E. Parathyroids: Parathyroid hormone and mineral balance

IV. Regulation of Development *(1011-1012)*

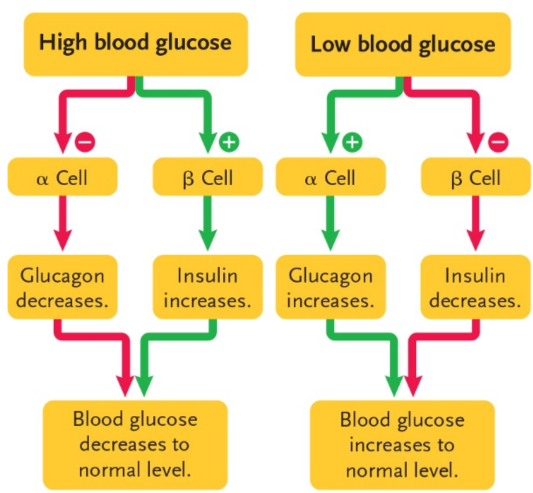
- A. Life Cycles and Regulation
- B. Control of Metamorphosis in Insects
  1. Insect life cycles
  2. Brain anatomy and endocrine glands
  3. Antagonistic hormones controlling development
- C. Control of Metamorphosis in Amphibians
  1. Changes in metamorphosis
  2. Hormonal control of metamorphosis
  3. Specificity of responses

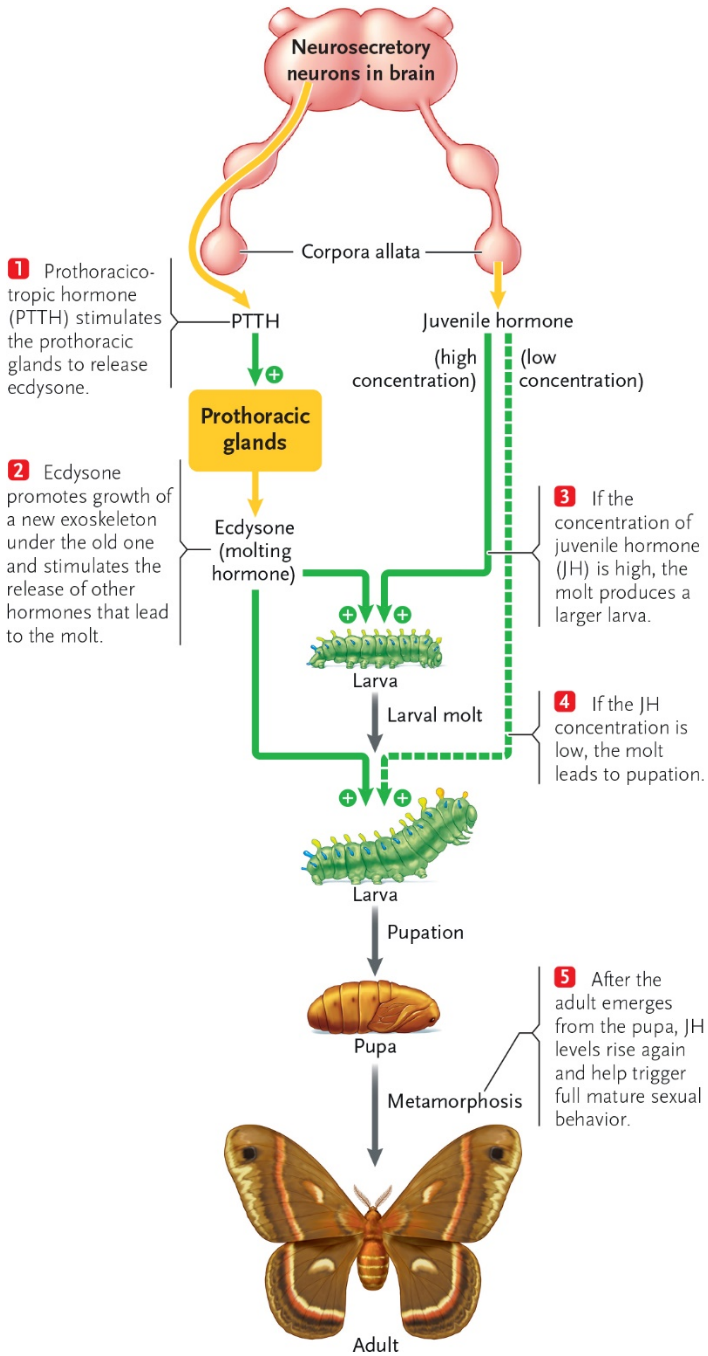

Hypothalamus
Anterior pituitary
Posterior pituitary
Neurosecretory neurons that secrete releasing and inhibiting hormones
Hypothalamus
Capillaries in hypothalamus
Blood in
Vesicle containing releasing or inhibiting hormone
Releasing or inhibiting hormone
Portal vein
Endocrine cells secreting hormones
Capillaries of anterior pituitary
Posterior pituitary
Anterior pituitary
Blood out
Neurosecretory neurons that release ADH or oxytocin
Hypothalamus
Vesicle containing hormone
Axons
Capillary
Pituitary stalk
Hormone
Anterior pituitary
Posterior pituitary
Blood out
Blood in
HORMONE
Thyroid-stimulating hormone (TSH)
Adreno-corticotropic hormone (ACTH)
Gonadotropins (FSH and LH)
Prolactin (PRL)
Growth hormone (GH)
Melanocyte-stimulating hormone (MSH)
Endorphins
Antidiuretic hormone (ADH)
Oxytocin
TARGET
Thyroid gland
Adrenal cortex
Testes in males
Ovaries in females
Mammary glands
Muscle, bone, and other tissues
Melanocytes in skin of some vertebrates
Pain path-ways of PNS
Nephrons in kidneys
Uterus
Mammary glands
RESPONSE
Increases rate of metabolism
Helps regulate fluid balance; helps body cope with stress
Stimulate production of gametes and hormones
Stimulates milk production
Promotes growth
Promotes skin darkening
Inhibit pain perception
Stimulates water reabsorption and retention
Stimulates contraction
Stimulates milk release

NEGATIVE FEEDBACK



NEGATIVE & POSITIVE FEEDBACK




Neurosecretory neurons in brain
Corpora allata
1 Prothoracicotropic hormone (PTTH) stimulates the prothoracic glands to release ecdysone.
PTTH
Juvenile hormone
(high concentration)
(low concentration)
Prothoracic glands
2 Ecdysone promotes growth of a new exoskeleton under the old one and stimulates the release of other hormones that lead to the molt.
Ecdysone (molting hormone)
3 If the concentration of juvenile hormone (JH) is high, the molt produces a larger larva.
Larva
Larval molt
4 If the JH concentration is low, the molt leads to pupation.
Larva
Pupation
Pupa
5 After the adult emerges from the pupa, JH levels rise again and help trigger full mature sexual behavior.
Metamorphosis
Adult

14. Endocrine Control of Mammalian Reproduction *(RHM: Chapters 49, 50)*

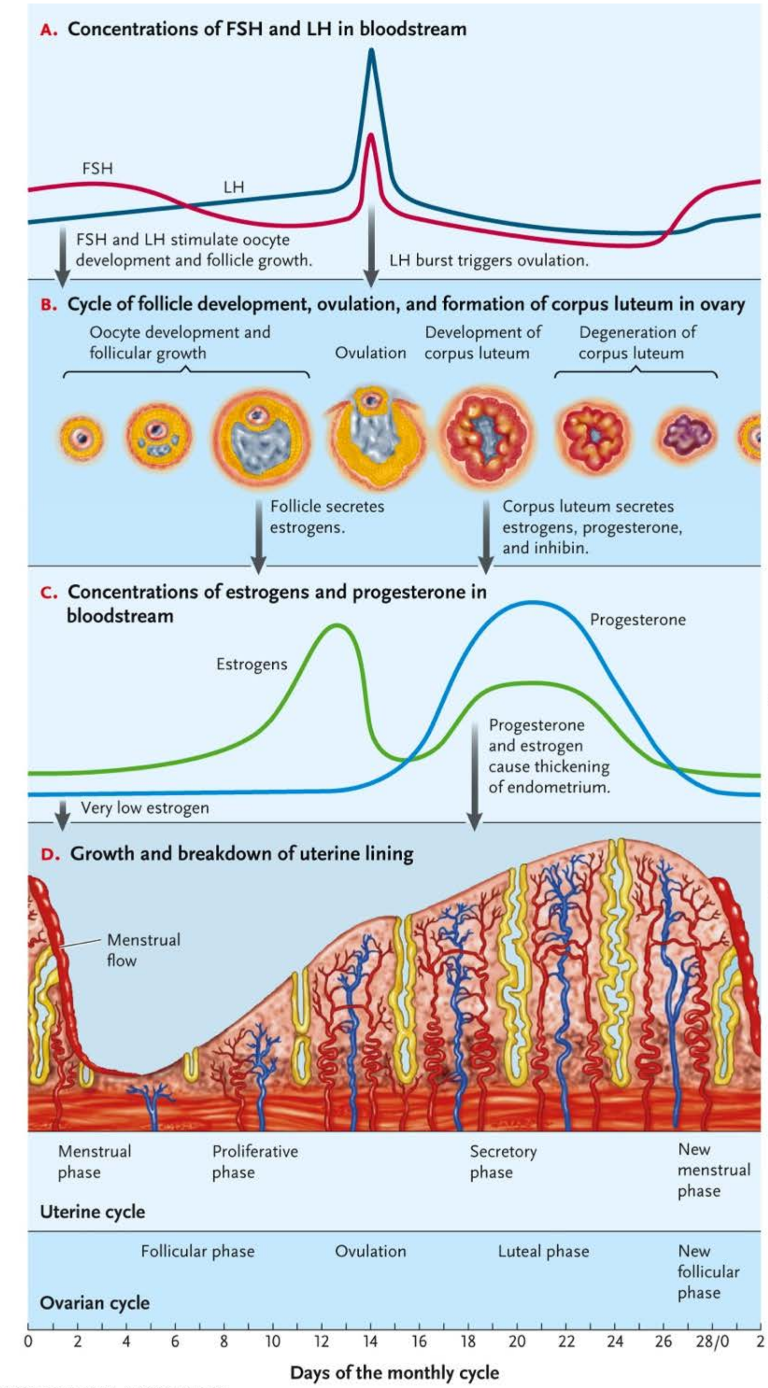
I. Development of Sexual Characters
- A. Early Development
- B. Hormonal Initiation of Puberty

II. The Human Menstrual Cycle *(1152-1160)*
- A. Sites of Important Changes
- B. Flow Phase
- C. Follicular Phase
  1. Post-menses condition
  2. Follicle stimulating hormone (FSH) / luteinizing hormone (LH)
  3. Estrogen
- D. Ovulation
  1. Effects of estrogen
  2. Luteinizing hormone (LH) and ovulation
  3. Production of corpus luteum
- E. Luteal Phase
  1. Estrogen concentration reduction
  2. Progesterone production
  3. Effects of progesterone
- F. Reinitiation of Menses
  1. Shedding of endometrium
  2. Deinhibition of hypothalamus
  3. Feedback system

III. Action of Birth Control Pills *(1160-1161)*

IV. Reproductive Cycles in Other Mammals
- A. Periodicities of Cycles
- B. Changes Induced in Advance of Ovulation
- C. Timing of Ovulation
- D. Uniqueness of the Human Cycle

V. Hormonal Control of Pregnancy *(1176-1181)*
- A. Fertilization
  1. Timing
  2. Location
  3. Movement of zygote
- B. Implantation and Maintenance of Fetus
  1. Placenta
  2. Fetal membranes
- C. Hormone Production

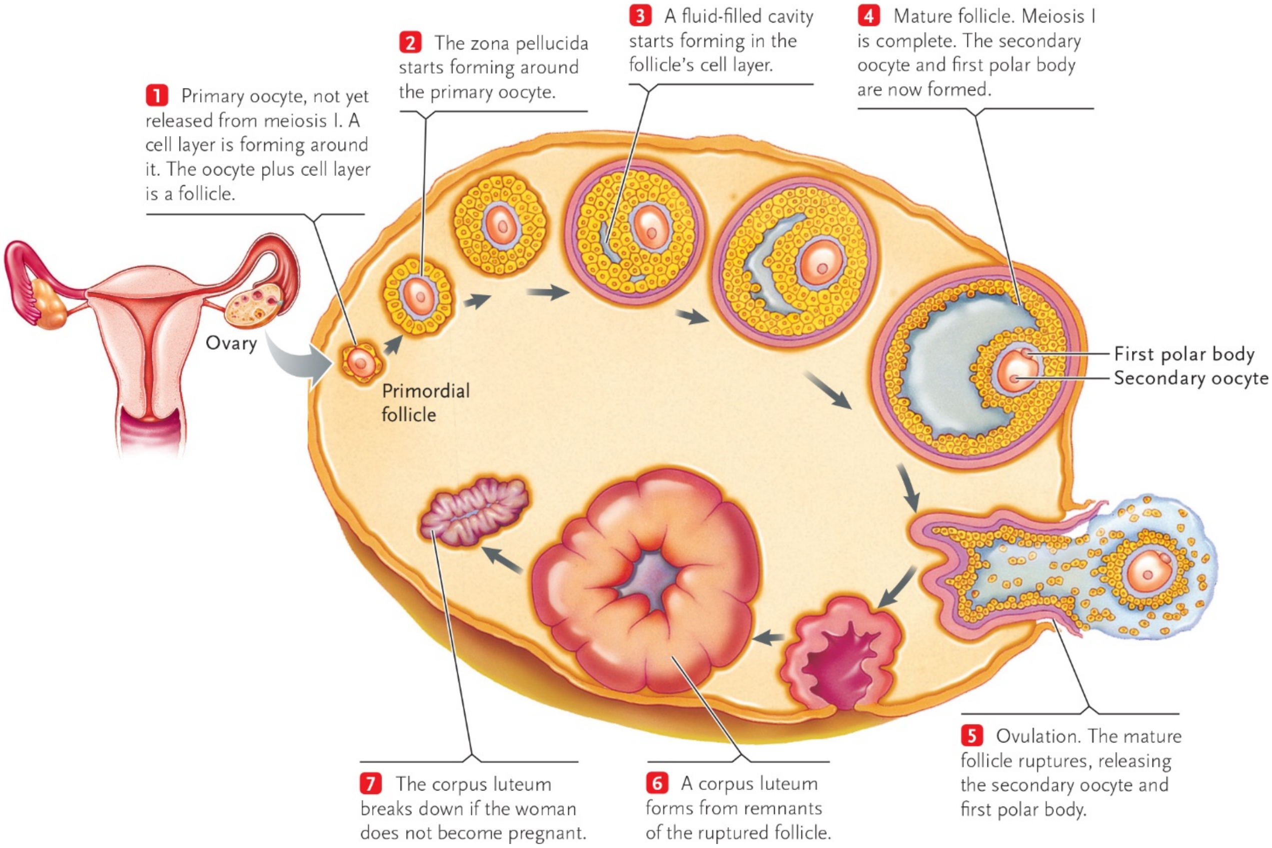


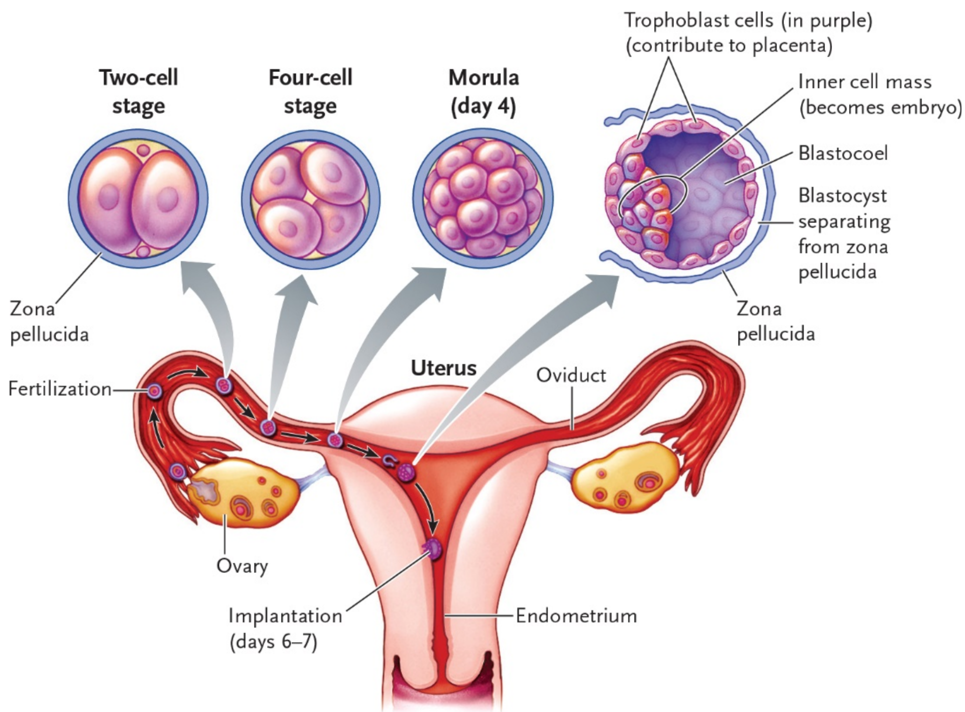
The ovarian cycle begins with an increase in the release of GnRH by the hypothalamus, which stimulates the release of FSH and LH from the anterior pituitary. The changes in concentrations of FSH and LH in the bloodstream play important roles in follicle development and ovulation.

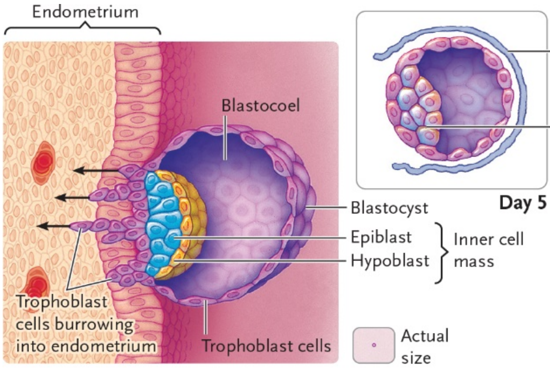
In the follicular phase, FSH stimulates follicle growth. As the follicle enlarges, FSH and LH interact and stimulate cells of the follicle to secrete estrogens. Initially the estrogens inhibit secretion of FSH by the pituitary, causing a decrease in FSH concentration. When the estrogens reach a high concentration, they then stimulate the hypothalamus and pituitary to increase GnRH release, thereby stimulating the pituitary to produce a burst of LH and FSH. The burst in LH secretion causes ovulation and initiates the luteal phase, the development of the corpus luteum.

The concentrations of estrogens and progesterone are low during the follicular phase. The increase in estrogens late in that phase brings about ovulation and then their level drops. In the luteal phase, the corpus luteum secretes estrogens and large amounts of progesterone which stimulates growth of the uterine lining (the endometrium). In the absence of fertilization, the corpus luteum degenerates gradually and hormone levels fall bringing about menstruation.

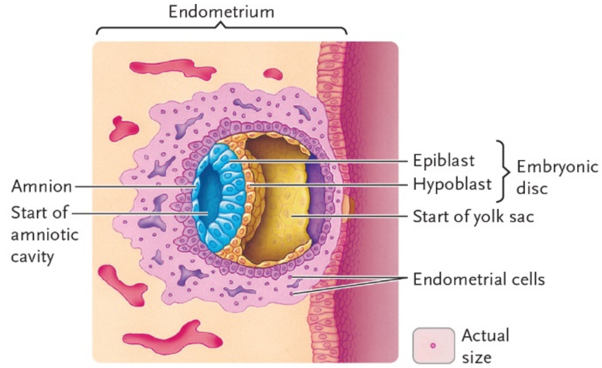
The same hormones that control the ovarian cycle control the uterine cycle, which involves endometrium growth (proliferative phase), further uterine lining growth if there is no fertilization (the secretory phase), and break down of the endometrium (the menstrual phase).


1 Primary oocyte, not yet released from meiosis I. A cell layer is forming around it. The oocyte plus cell layer is a follicle.
2 The zona pellucida starts forming around the primary oocyte.
3 A fluid-filled cavity starts forming in the follicle's cell layer.
4 Mature follicle. Meiosis I is complete. The secondary oocyte and first polar body are now formed.
Ovary
Primordial follicle
First polar body
Secondary oocyte
5 Ovulation. The mature follicle ruptures, releasing the secondary oocyte and first polar body.
6 A corpus luteum forms from remnants of the ruptured follicle.
7 The corpus luteum breaks down if the woman does not become pregnant.

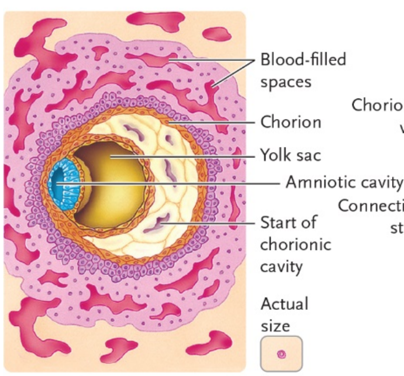

Trophoblast cells (in purple) (contribute to placenta)
Two-cell stage
Four-cell stage
Morula (day 4)
Inner cell mass (becomes embryo)
Blastocoel
Blastocyst separating from zona pellucida
Zona pellucida
Zona pellucida
Fertilization
Uterus
Oviduct
Ovary
Implantation (days 6–7)
Endometrium



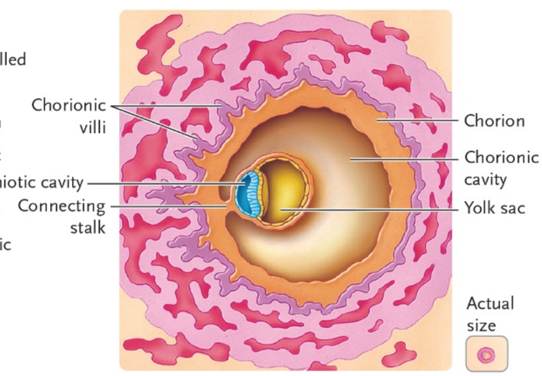
1 Days 6–7: Surface cells of the blastocyst attach to the endometrium and start to burrow into it. Implantation is under way.



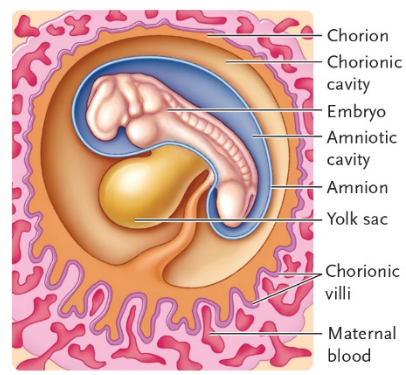
2 Days 10–11: A layer of epiblast cells separates, producing the amniotic cavity. The cells above the cavity become the amnion, which eventually surrounds the embryo. The hypoblast begins to form around the yolk sac.



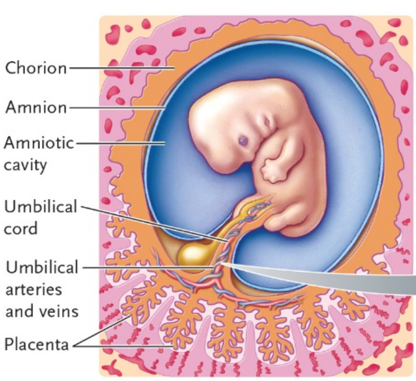
3 Day 12: Blood-filled spaces form in maternal tissue. The chorion forms, derived from trophoblast cells, and encloses the chorionic cavity.



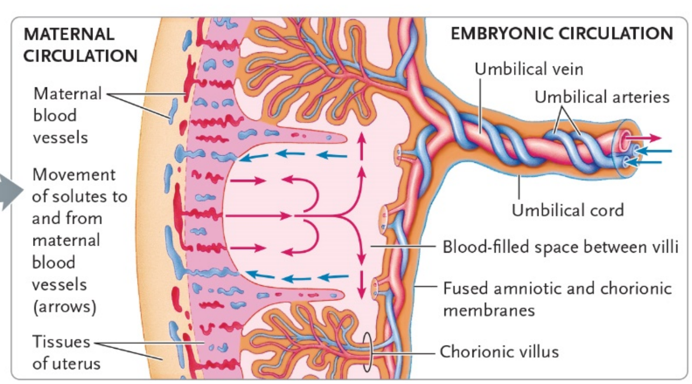
4 Day 14: A connecting stalk has formed between the embryonic disk and chorion. Chorionic villi, which will be features of a placenta, start to form.



5 Day 25: The chorion continues to grow into the endometrium, producing the chorionic villi. The chorion growth stimulates blood vessels of the endometrium to grow into the maternal circulation of the placenta.



6 Day 45: Blood circulation has been established through the umbilical cord to the placenta.



15. Sexual Reproduction and Development in Animals I *(RHM: Chapters 49, 50)*

I. Introduction *(1145-1147)*

- A. Asexual vs. Sexual Reproduction
- B. Developmental Biology and Embryology
- C. Early Stages of the Life Cycle
    1. Gametogenesis
    2. Fertilization
    3. Cleavage
    4. Gastrulation
    5. Morphogenesis and organogenesis
- D. Principles of Development

II. Gametogenesis *(1147-1148)*

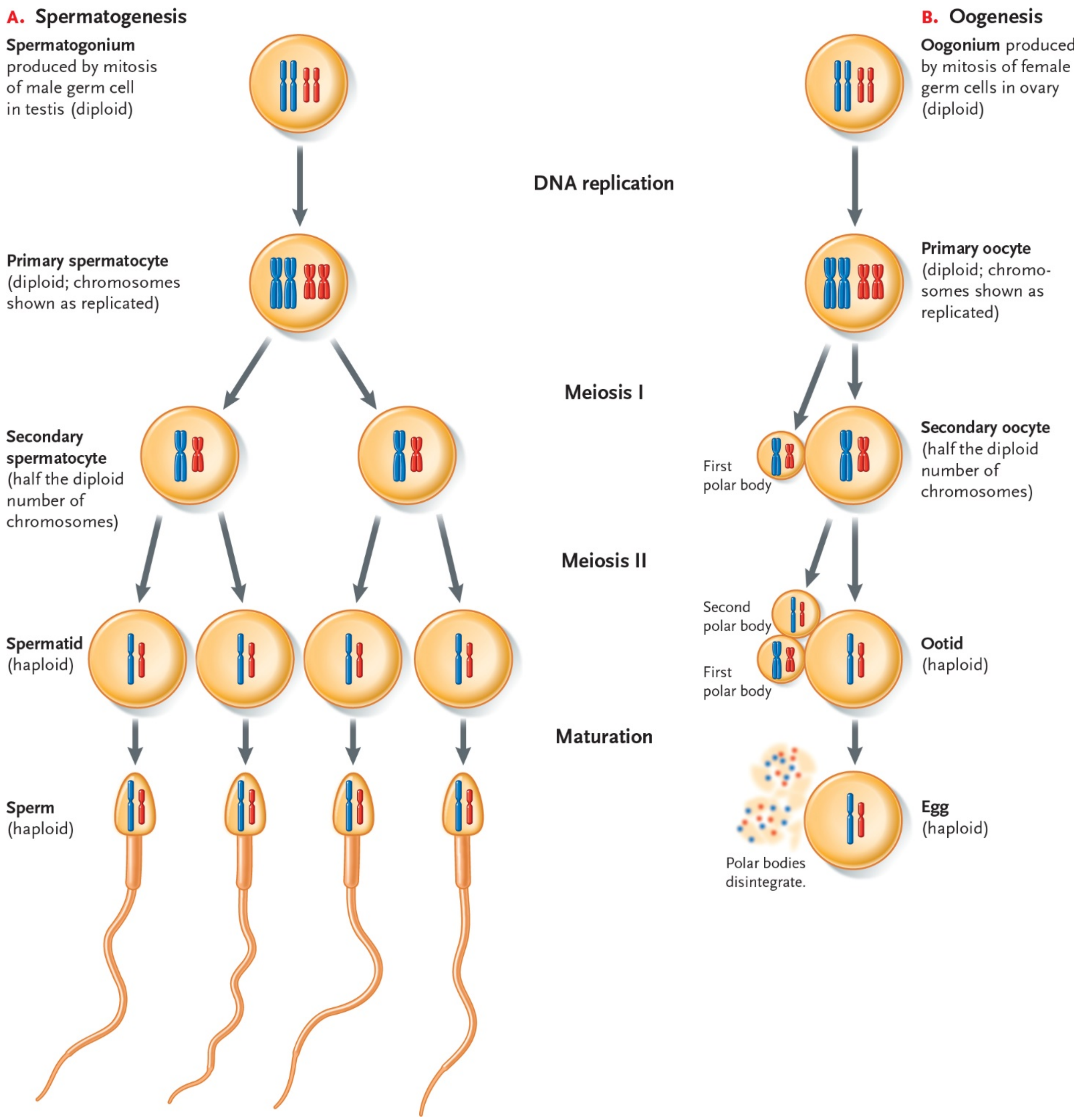
- A. Spermatogenesis
    1. Origin of sperm
    2. Structure of sperm
- B. Oogenesis
    1. Origin of ova
    2. Structure of ova
    3. Variability among species and habitats

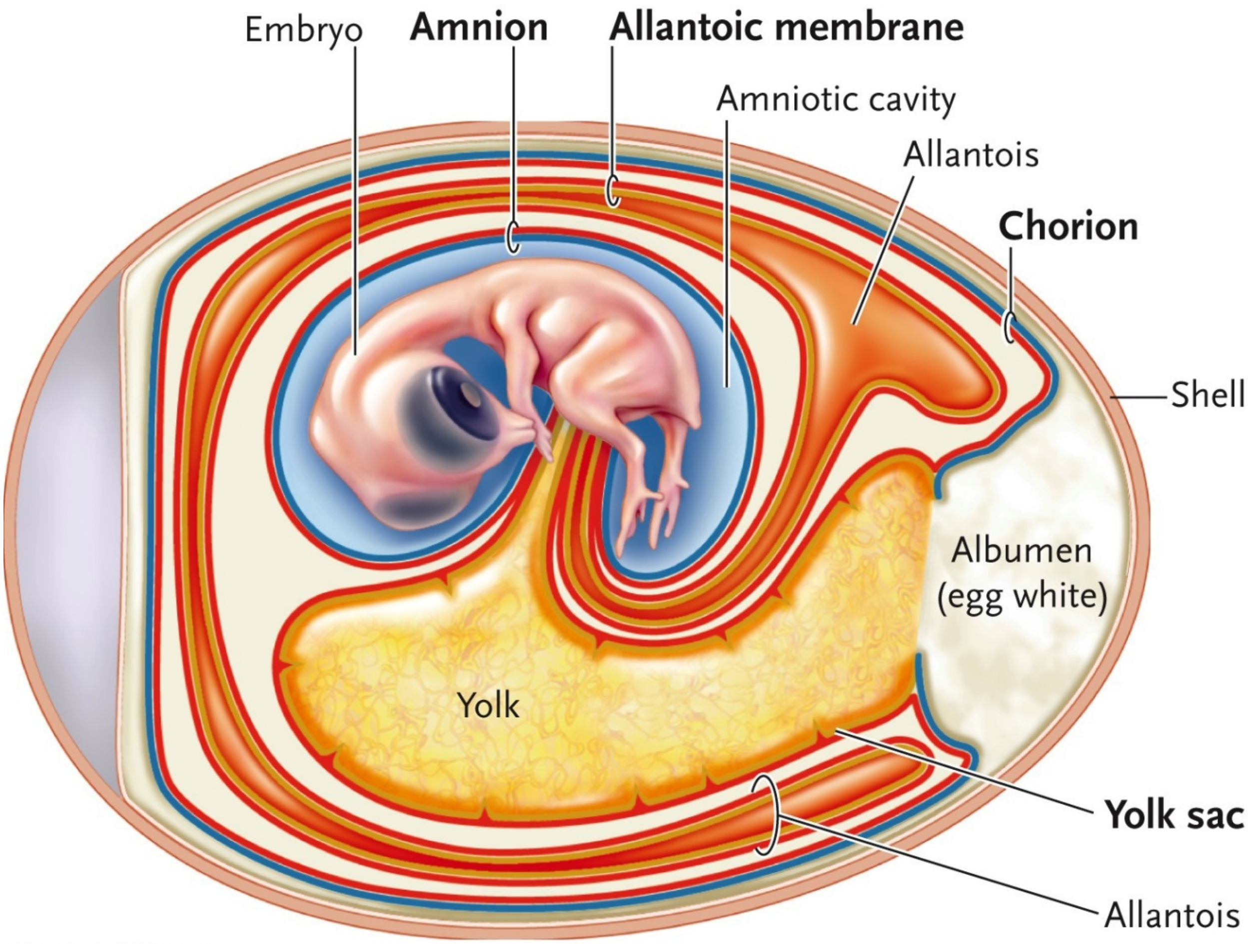
III. Fertilization *(1148-1151)*

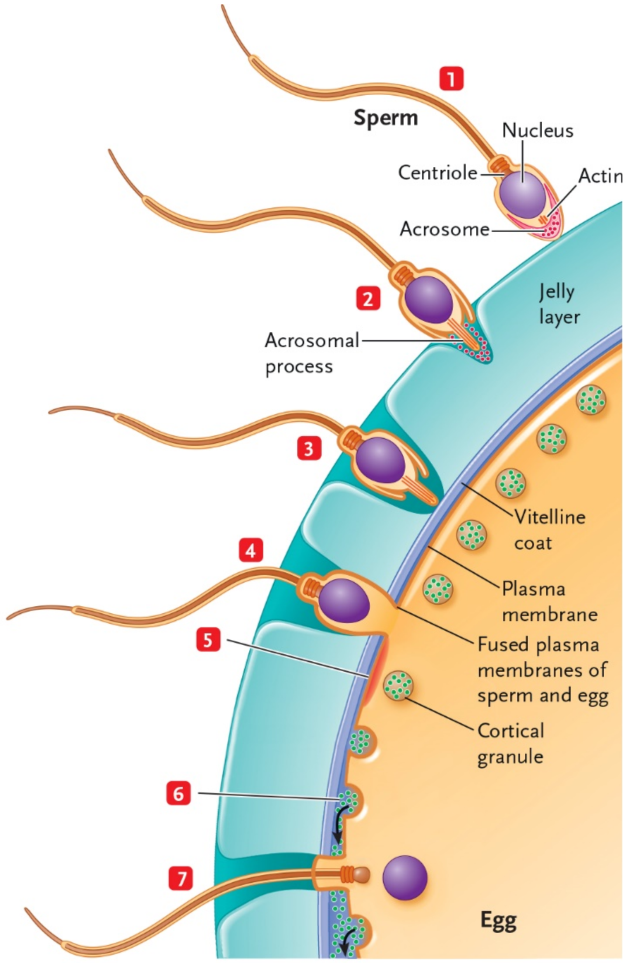
- A. Behaviors that Promote Contact of Gametes
- B. Fertilization
    1. Receptor substances
    2. Sperm activation / acrosome reaction
    3. Cortical reaction of the egg
    4. Blocks to polyspermy
    5. Egg activation
    6. Fusion of nuclei

IV. Cleavage *(1167-1173)*

- A. Cellular Events
    1. Genome replicaton
    2. Membrane production
    3. Production of blastula
- B. Patterns of Cleavage
    1. Radial cleavage in Deuterostomes
    2. Spiral cleavage in Protostomes


A. Spermatogenesis
Spermatogonium produced by mitosis of male germ cell in testis (diploid)
Primary spermatocyte (diploid; chromosomes shown as replicated)
Secondary spermatocyte (half the diploid number of chromosomes)
Spermatid (haploid)
Sperm (haploid)
DNA replication
Meiosis I
Meiosis II
Maturation
B. Oogenesis
Oogonium produced by mitosis of female germ cells in ovary (diploid)
Primary oocyte (diploid; chromosomes shown as replicated)
First polar body
Secondary oocyte (half the diploid number of chromosomes)
Second polar body
First polar body
Ootid (haploid)
Polar bodies disintegrate.
Egg (haploid)


Embryo
Amnion
Allantoic membrane
Amniotic cavity
Allantois
Chorion
Shell
Albumen
(egg white)
Yolk
Yolk sac
Allantois



1 A sperm contacts the jelly layer of the egg.

2 The acrosomal reaction begins: enzymes contained in the acrosome are released and dissolve a path through the jelly layer.

3 Proteins in its plasma membrane bind the sperm to the vitelline coat.

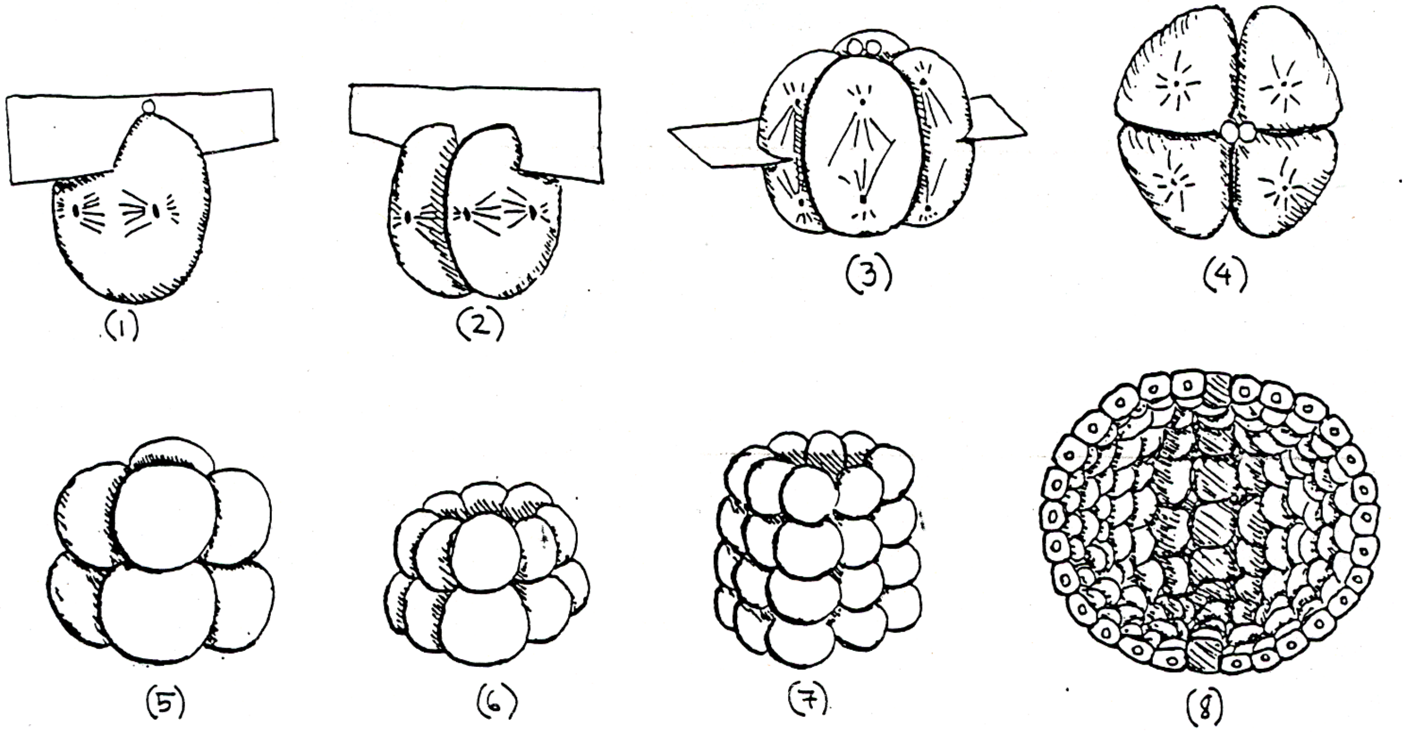
4 The sperm lyses a hole in the vitelline coat. The sperm and egg plasma membranes fuse.

5 Membrane depolarization produces the fast block to polyspermy.

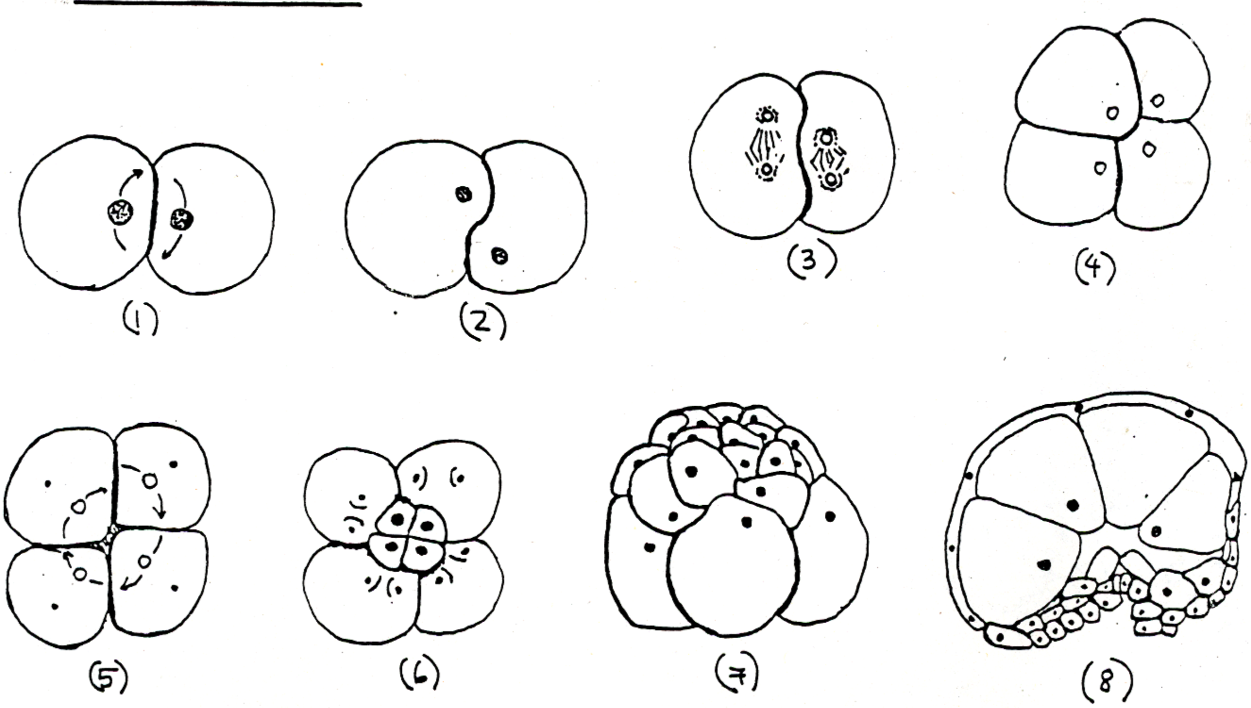
6 The fusion of egg and sperm triggers the release of Ca^{2+} ions, which trigger the cortical reaction, the fusion of secretory cortical granules with the egg's plasma membrane. The enzymes of the granules released to the outside alter the egg coats, producing the slow block to polyspermy.

7 The sperm nucleus enters the egg. The sperm nucleus fuses with the egg nucleus (not shown).

RADIAL CLEAVAGE



SPIRAL CLEAVAGE



16. Sexual Reproduction and Development in Animals II *(RHM: Chapter 50)*

V. Gastrulation *(1173-1175)*

- A. Definition and Functions
- B. In Deuterostomes
- C. In Protostomes

VI. Early Amphibian Development *(1169-1175)*

- A. Structure of Egg
- B. Cleavage
- C. Gastrulation

VII. Early Avian Development *(1169-1175)*

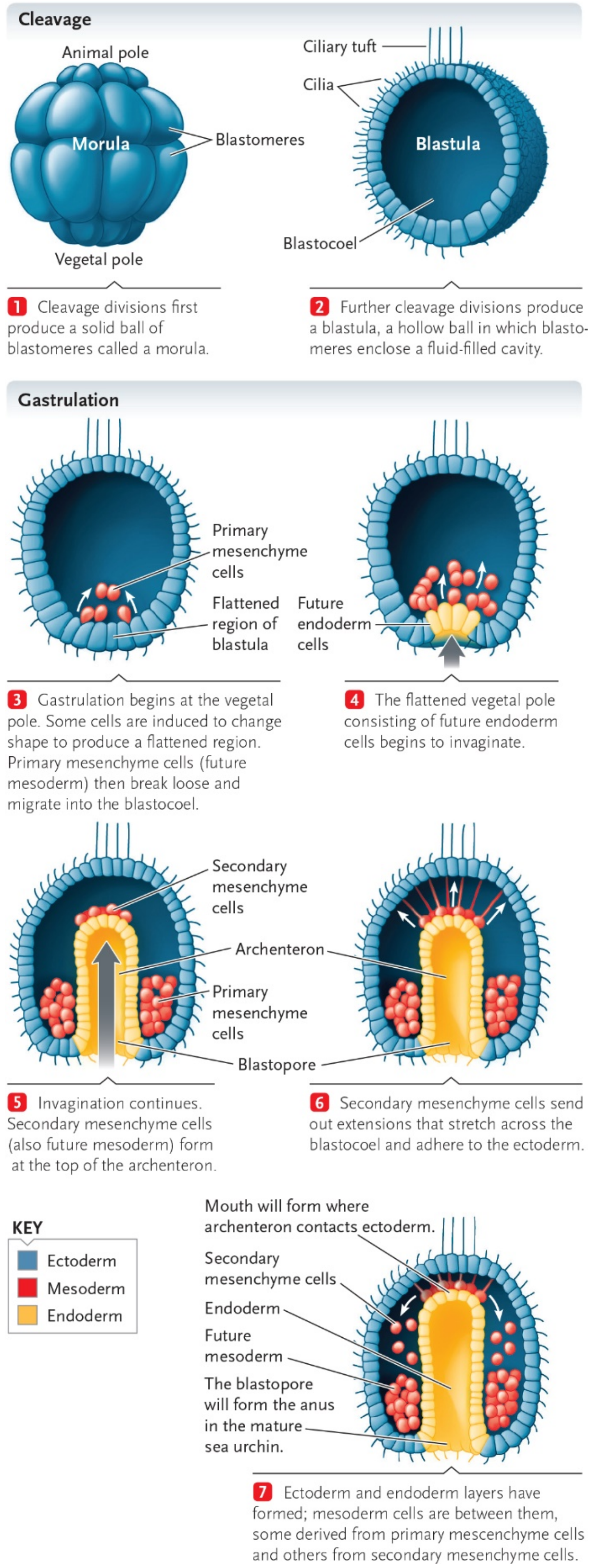
- A. Fertilization
- B. Cleavage
- C. Gastrulation

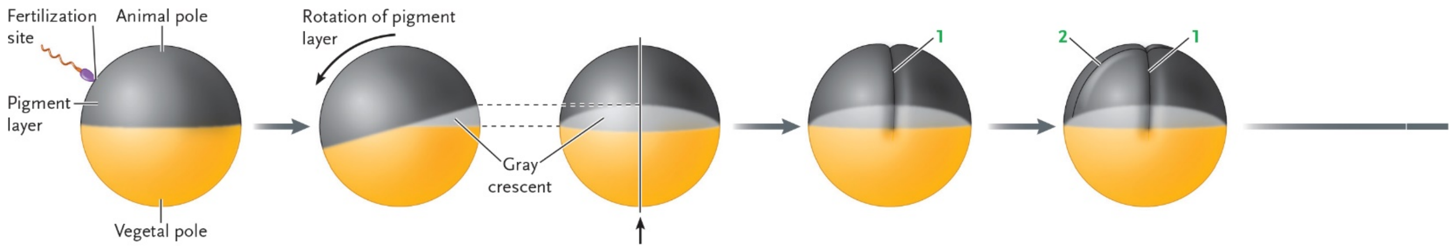
VIII. Early Mammalian Development *(1176-1181)*

- A. Fertilization
- B. Cleavage
- C. Implantation
- D. Extracellular Membranes

IX. Morphogenesis and Organogenesis *(1181-1185)*

- A. Introduction
- B. Morphogenetic Movements
- C. Importance of Triploblastic Construction


Cleavage
Animal pole
Morula
Blastomeres
Vegetal pole
Ciliary tuft
Cilia
Blastula
Blastocoel
1 Cleavage divisions first produce a solid ball of blastomeres called a morula.
2 Further cleavage divisions produce a blastula, a hollow ball in which blastomeres enclose a fluid-filled cavity.
Gastrulation
Primary mesenchyme cells
Flattened region of blastula
Future endoderm cells
3 Gastrulation begins at the vegetal pole. Some cells are induced to change shape to produce a flattened region. Primary mesenchyme cells (future mesoderm) then break loose and migrate into the blastocoel.
4 The flattened vegetal pole consisting of future endoderm cells begins to invaginate.
Secondary mesenchyme cells
Archenteron
Primary mesenchyme cells
Blastopore
5 Invagination continues. Secondary mesenchyme cells (also future mesoderm) form at the top of the archenteron.
6 Secondary mesenchyme cells send out extensions that stretch across the blastocoel and adhere to the ectoderm.
KEY
Ectoderm
Mesoderm
Endoderm
Mouth will form where archenteron contacts ectoderm.
Secondary mesenchyme cells
Endoderm
Future mesoderm
The blastopore will form the anus in the mature sea urchin.
7 Ectoderm and endoderm layers have formed; mesoderm cells are between them, some derived from primary mescenchyme cells and others from secondary mesenchyme cells.

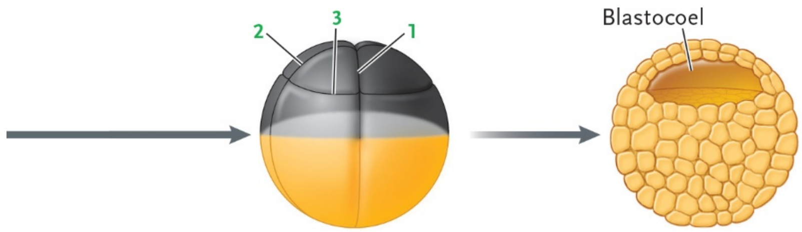


1 Fertilization. The animal pole contains yolk-free cytoplasm. The yolk is in the vegetal pole.

2 Pigment layer rotates toward site of fertilization, exposing some of underlying cytoplasm (the gray crescent).

3 Two-cell stage: First cleavage division (1) is in the vertical plane and divides the animal half into two, as well as dividing gray crescent equally between daughter cells. Yolk in the vegetal half slows the cleavage in that part of the egg.

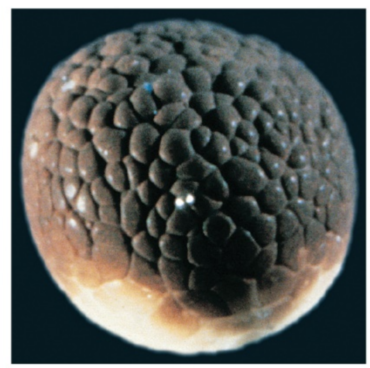
4 Four-cell stage: Second cleavage division (2), also in the vertical plane, is at 90 degrees to that of the first division.



5 Eight-cell stage: Third cleavage division (3) is in the horizontal plane within the animal half of the cell. Divisions 1 and 2 have now continued through the vegetal half of the egg.

6 Blastula stage (cross section): More cleavage divisions produce the blastula, which contains at least 128 cells and has a fluid-filled blastocoel.

Blastula



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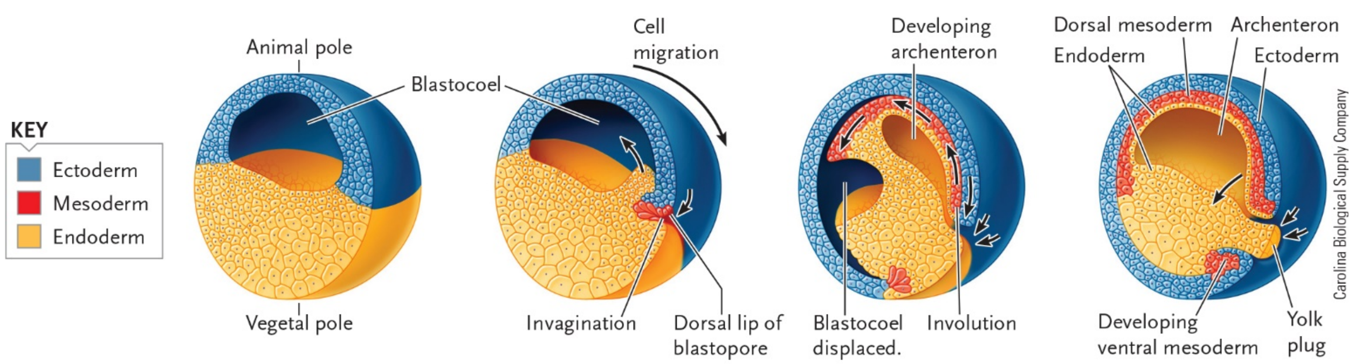
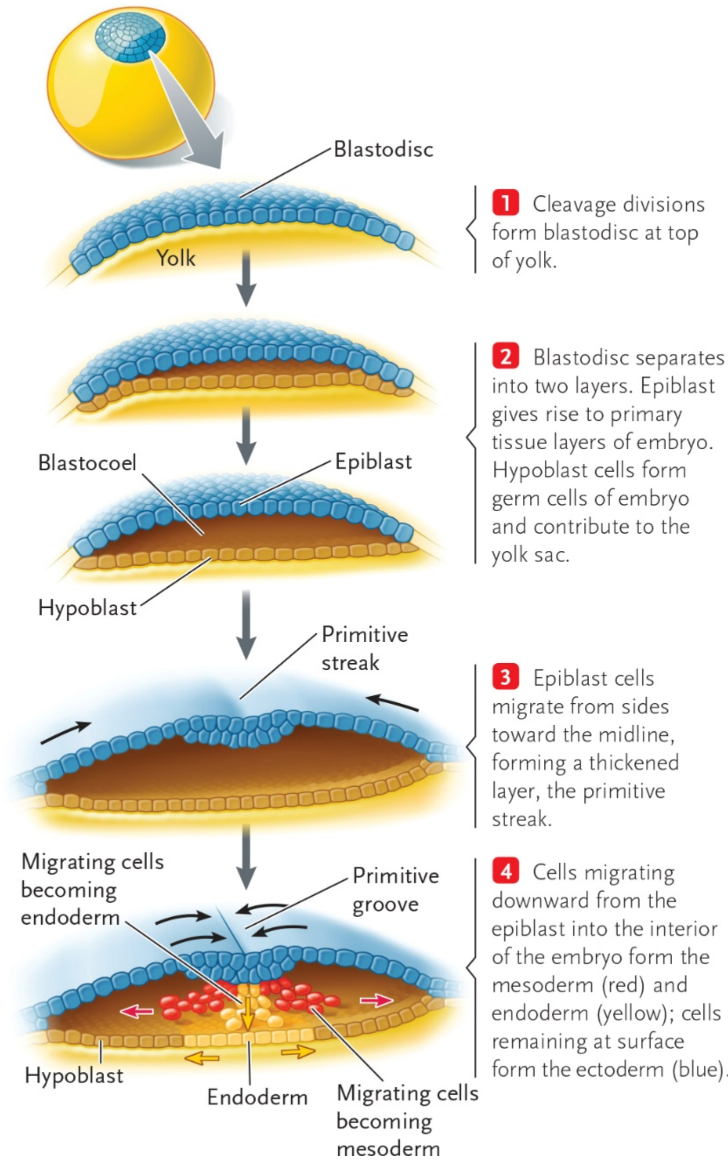


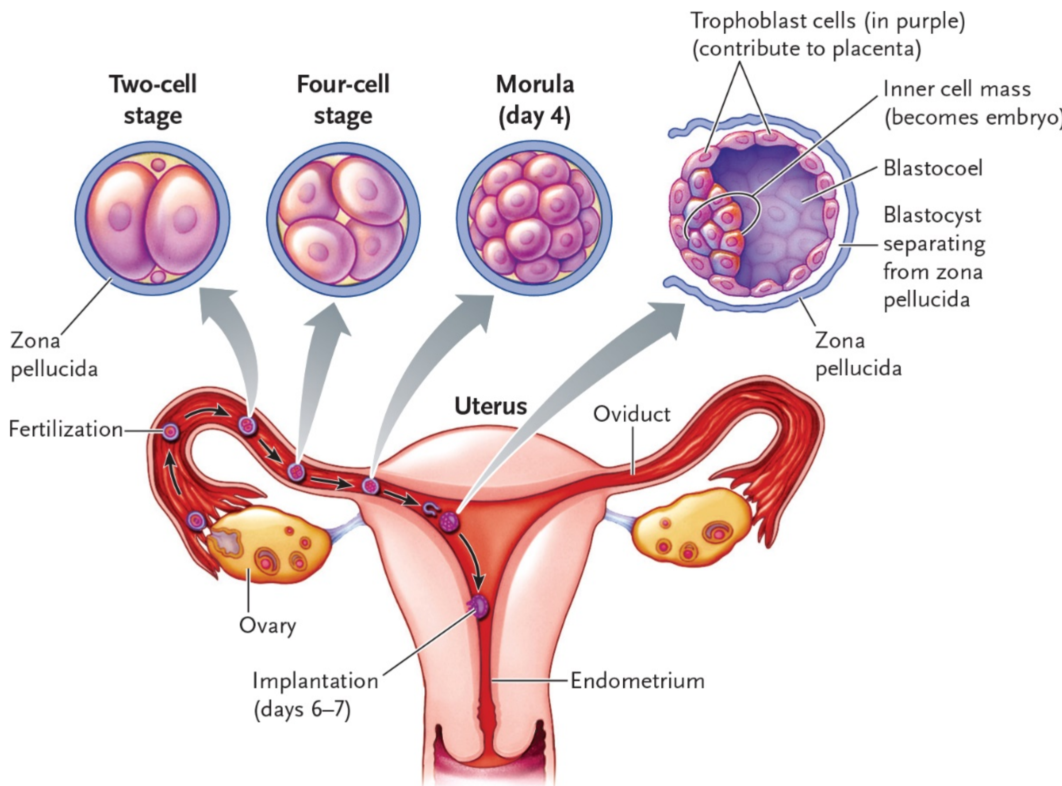
1 Blastula

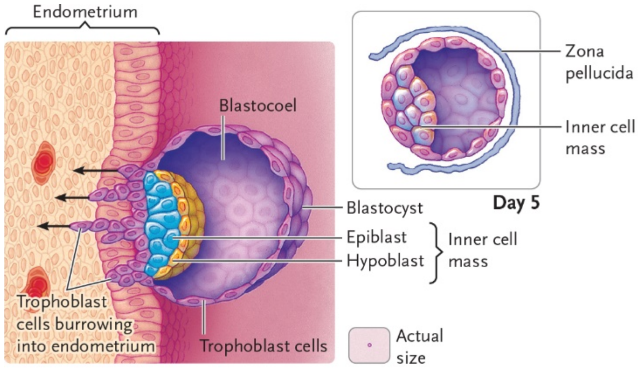
2 Gastrulation begins; cells from the animal pole reach the dorsal lip of the blastopore and invaginate.

3 Cells migrate into the blastopore (involution); pigmented cells of the animal half expand over the entire embryo surface.

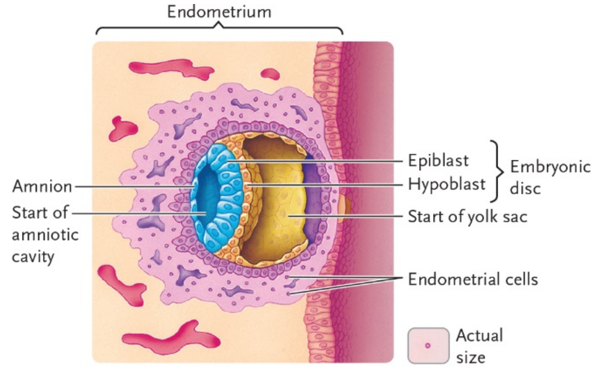
4 Movement of animal half cells encloses the vegetal half cells, which are seen as a yolk plug.


Blastodisc
Yolk
1 Cleavage divisions form blastodisc at top of yolk.
2 Blastodisc separates into two layers. Epiblast gives rise to primary tissue layers of embryo. Hypoblast cells form germ cells of embryo and contribute to the yolk sac.
Blastocoel
Epiblast
Hypoblast
Primitive streak
3 Epiblast cells migrate from sides toward the midline, forming a thickened layer, the primitive streak.
Migrating cells becoming endoderm
Primitive groove
4 Cells migrating downward from the epiblast into the interior of the embryo form the mesoderm (red) and endoderm (yellow); cells remaining at surface form the ectoderm (blue).
Hypoblast
Endoderm
Migrating cells becoming mesoderm

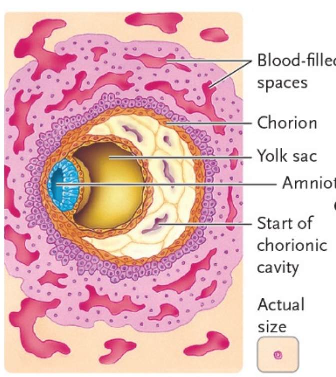

Trophoblast cells (in purple)
(contribute to placenta)
Two-cell
stage
Four-cell
stage
Morula
(day 4)
Inner cell mass
(becomes embryo)
Blastocoel
Blastocyst
separating
from zona
pellucida
Zona
pellucida
Zona
pellucida
Uterus
Oviduct
Fertilization
Ovary
Implantation
(days 6–7)
Endometrium



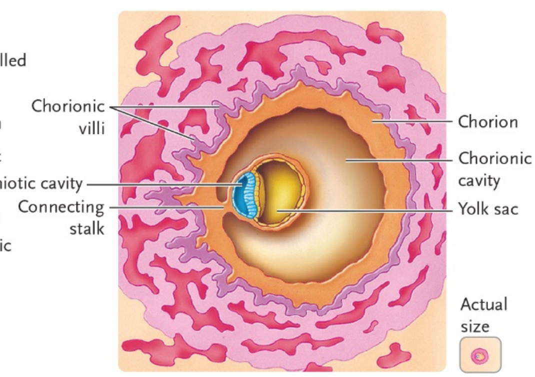
1 Days 6–7: Surface cells of the blastocyst attach to the endometrium and start to burrow into it. Implantation is under way.



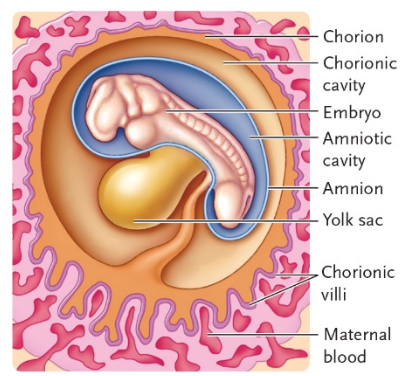
2 Days 10–11: A layer of epiblast cells separates, producing the amniotic cavity. The cells above the cavity become the amnion, which eventually surrounds the embryo. The hypoblast begins to form around the yolk sac.



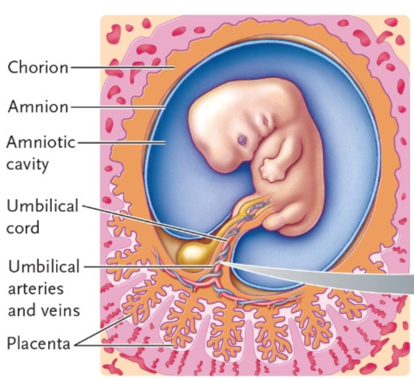
3 Day 12: Blood-filled spaces form in maternal tissue. The chorion forms, derived from trophoblast cells, and encloses the chorionic cavity.



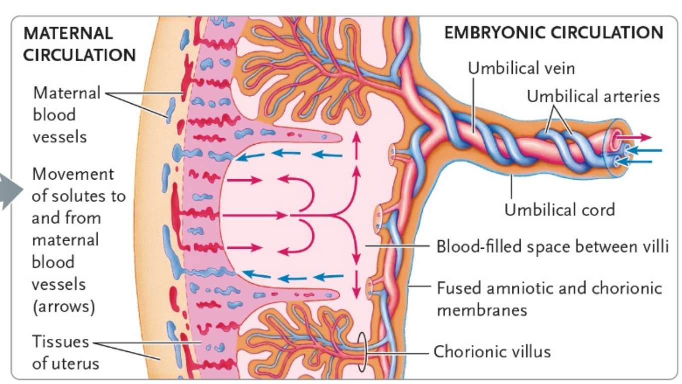
4 Day 14: A connecting stalk has formed between the embryonic disk and chorion. Chorionic villi, which will be features of a placenta, start to form.



5 Day 25: The chorion continues to grow into the endometrium, producing the chorionic villi. The chorion growth stimulates blood vessels of the endometrium to grow into the maternal circulation of the placenta.



6 Day 45: Blood circulation has been established through the umbilical cord to the placenta.



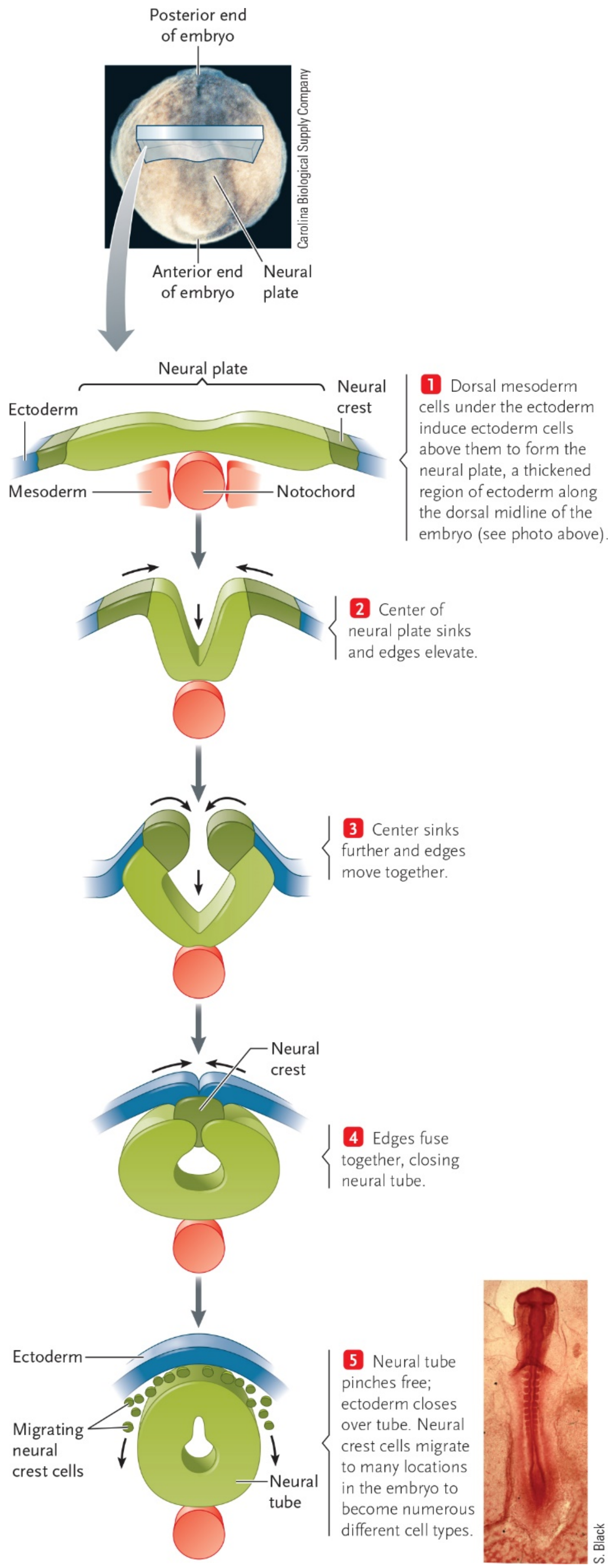
17. Sexual Reproduction and Development in Animals III *(RHM: Chapter 50)*

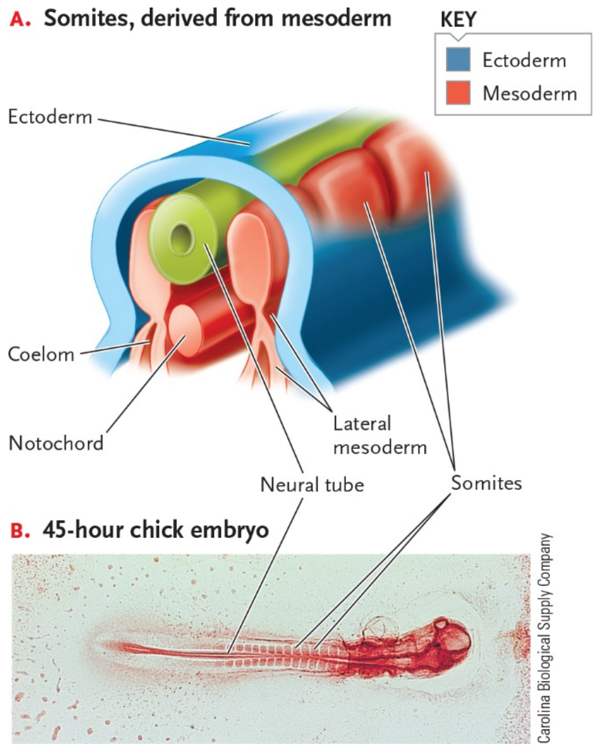
X. From Germ Layers to Organ Systems *(1173-1180)*

- A. Triploblastic Organization
- B. Ectoderm Derivatives
  1. Nervous system
  2. Sensory organs
  3. Other derivatives
- C. Mesoderm Derivatives
  1. Notochord
  2. Somites
  3. Other derivatives
- D. Endoderm Derivatives
  1. Digestive tube
  2. Pharynx and respiratory system
- E. Summary of Body Architecture

XI. Cellular Basis of Development *(1181-1188)*

- A. Introduction
- B. Determination
  1. Genetic control
  2. Timing of determination
- C. Differentiation
  1. Discontinuity of cell populations
  2. Stability of differentiated states
  3. Association of similar cells
- D. Determination in the Egg and Early Embryo
  1. Cytoplasmic determinants
  2. Polarity in the egg
  3. Variations in timing of determination
- E. Induction
  1. Definition
  2. Hierarchies of induction
  3. Genetic basis
  4. Reciprocal action of induction systems


Posterior end
of embryo
Carolina Biological Supply Company
Anterior end
of embryo
Neural
plate
Neural plate
Ectoderm
Neural
crest
Mesoderm
Notochord
1 Dorsal mesoderm cells under the ectoderm induce ectoderm cells above them to form the neural plate, a thickened region of ectoderm along the dorsal midline of the embryo (see photo above).
2 Center of neural plate sinks and edges elevate.
3 Center sinks further and edges move together.
Neural
crest
4 Edges fuse together, closing neural tube.
Ectoderm
Migrating
neural
crest cells
Neural
tube
5 Neural tube pinches free; ectoderm closes over tube. Neural crest cells migrate to many locations in the embryo to become numerous different cell types.
S. Black


A. Somites, derived from mesoderm
KEY
Ectoderm
Mesoderm
Ectoderm
Coelom
Notochord
Lateral mesoderm
Neural tube
Somites
B. 45-hour chick embryo
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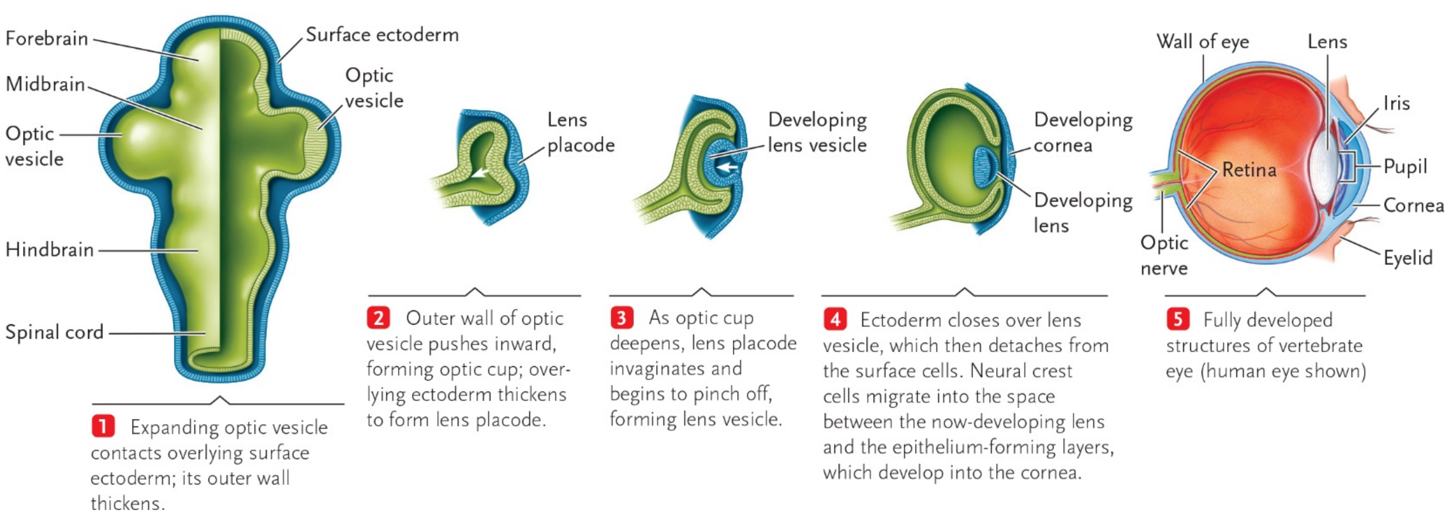
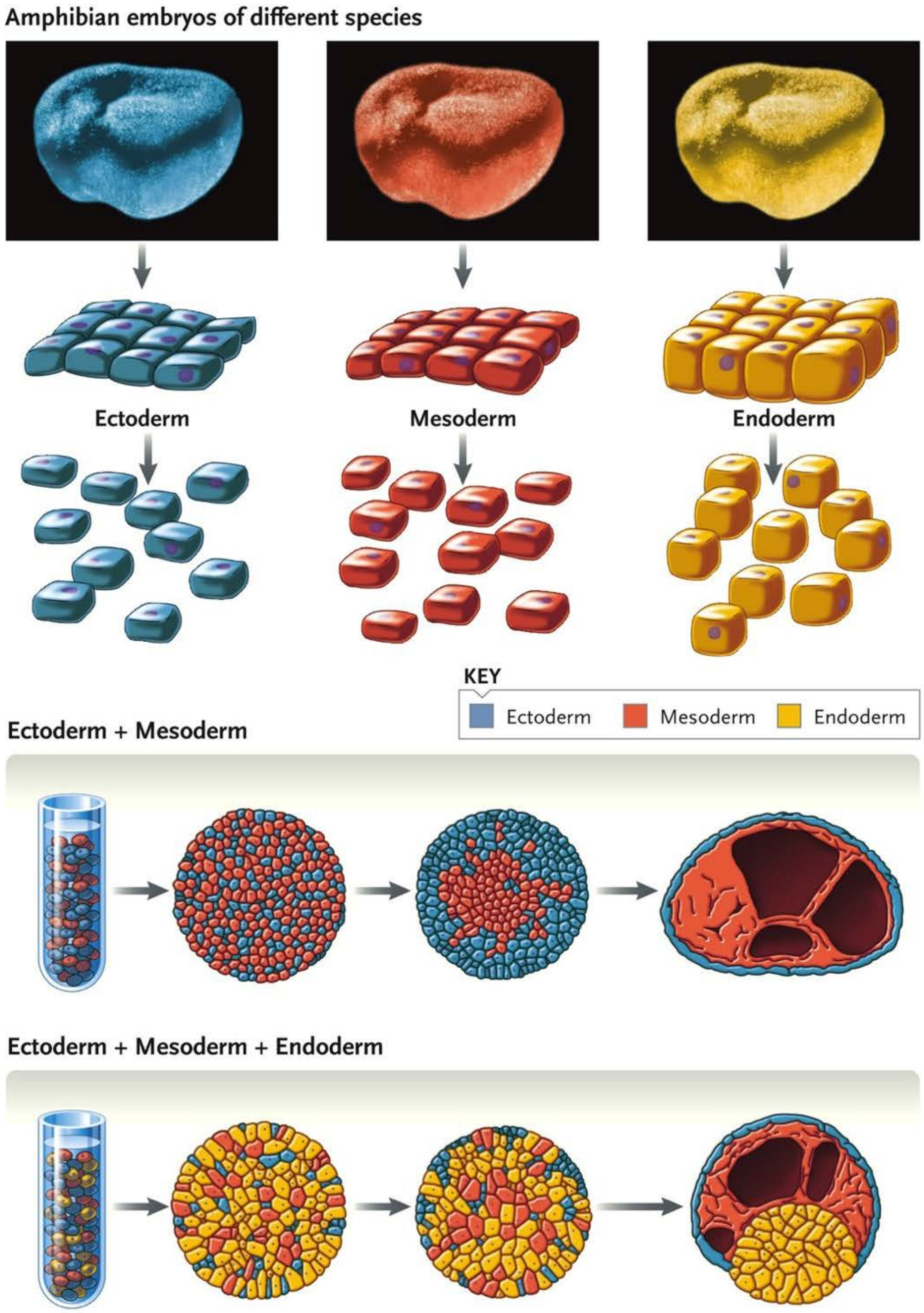

Forebrain
Midbrain
Optic vesicle
Hindbrain
Spinal cord
Surface ectoderm
Optic vesicle
Lens placode
Developing lens vesicle
Developing cornea
Developing lens
Wall of eye
Lens
Iris
Retina
Pupil
Cornea
Optic nerve
Eyelid
1 Expanding optic vesicle contacts overlying surface ectoderm; its outer wall thickens.
2 Outer wall of optic vesicle pushes inward, forming optic cup; overlying ectoderm thickens to form lens placode.
3 As optic cup deepens, lens placode invaginates and begins to pinch off, forming lens vesicle.
4 Ectoderm closes over lens vesicle, which then detaches from the surface cells. Neural crest cells migrate into the space between the now-developing lens and the epithelium-forming layers, which develop into the cornea.
5 Fully developed structures of vertebrate eye (human eye shown)



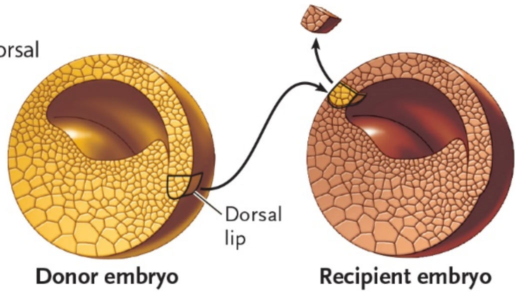
Source: P. L. Townes and J. Holtfreter. 1955. Directed movements and selective adhesion of embryonic amphibian cells. *Journal of Experimental Zoology* 128:53–120.

Spemann and Mangold's Experiment Demonstrating Induction in Embryos

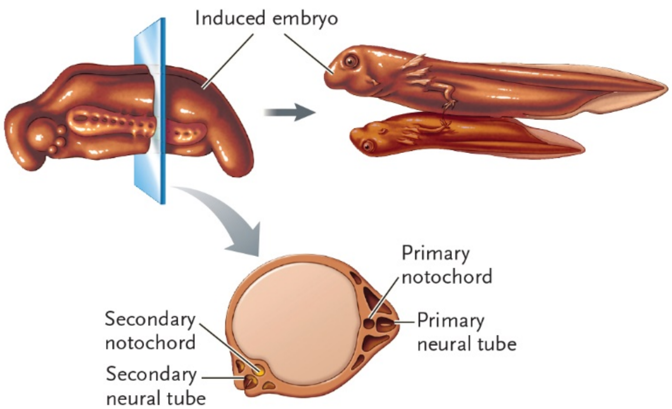
Question: Does induction occur in embryonic development?

Experiment: Hans Spemann and Hilde Mangold performed transplantation experiments with newt embryos.

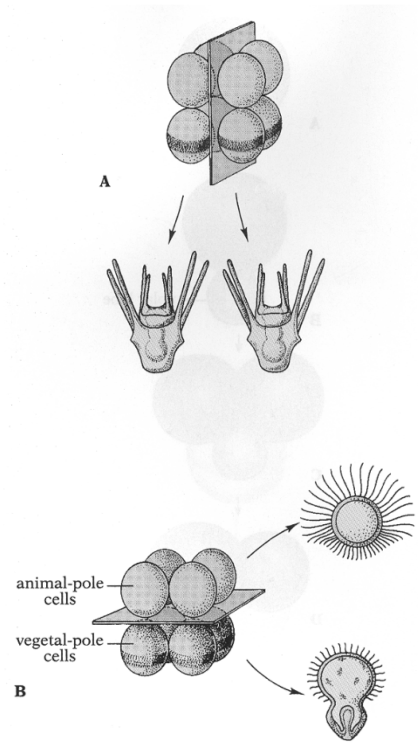
1. The researchers grafted the dorsal lip of the blastopore from one newt embryo onto a different position—the ventral side—of another embryo. The two embryos were from different newt species that differed in pigmentation, allowing the fate of the transplanted tissue to be followed easily during development.

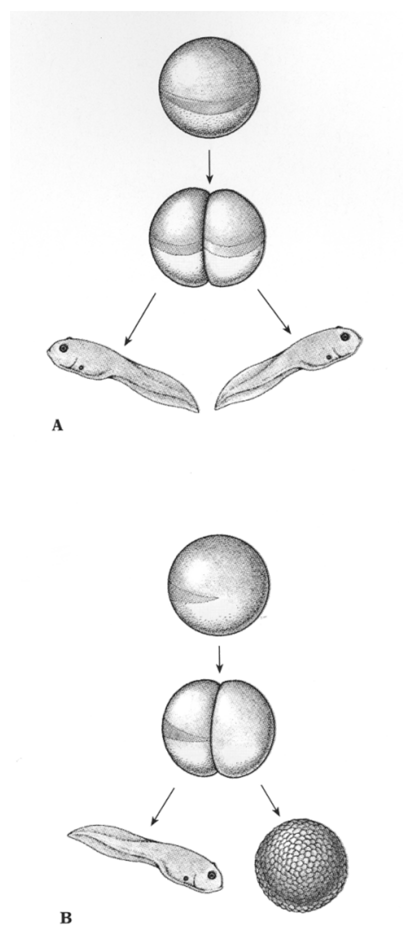


2. The embryo with the transplant was allowed to develop.



Result: At the ventral location on the recipient embryo where the dorsal lip of the blastopore was grafted, another embryo developed simultaneously with the recipient embryo. Eventually, two mature embryos were produced attached on their ventral surfaces.


A
animal-pole
cells
vegetal-pole
cells
B


A
B