

Overview: Diverse Forms, Common Challenges

- **Anatomy** is the study of the biological form of an organism.
- **Physiology** is the study of the biological functions an organism performs.
- The comparative study of animals reveals that *form and function are closely correlated*.

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How does a jackrabbit keep from overheating?



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Animal form and function are correlated at all levels of organization

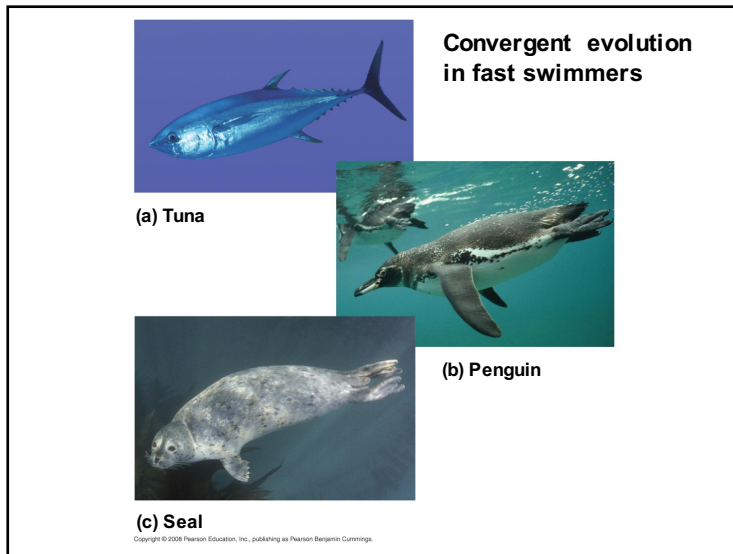
- *Size and shape affect the way an animal interacts with its environment.*
- Many different animal body plans have evolved and are determined by the genome.

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Physical Constraints on Animal Size and Shape

- The ability to perform certain actions depends on an animal's shape, size, and environment.
- *Evolutionary convergence reflects different species' adaptations to a similar environmental challenge.*
- Physical laws impose constraints on animal size and shape.

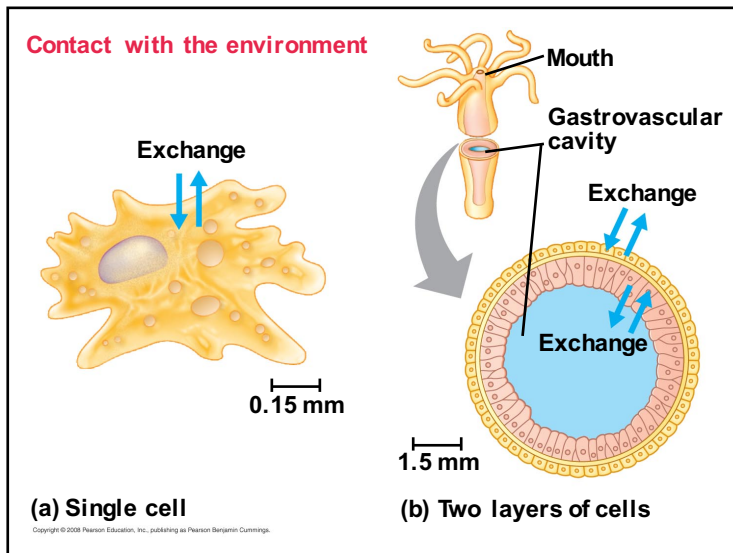
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Exchange with the Environment

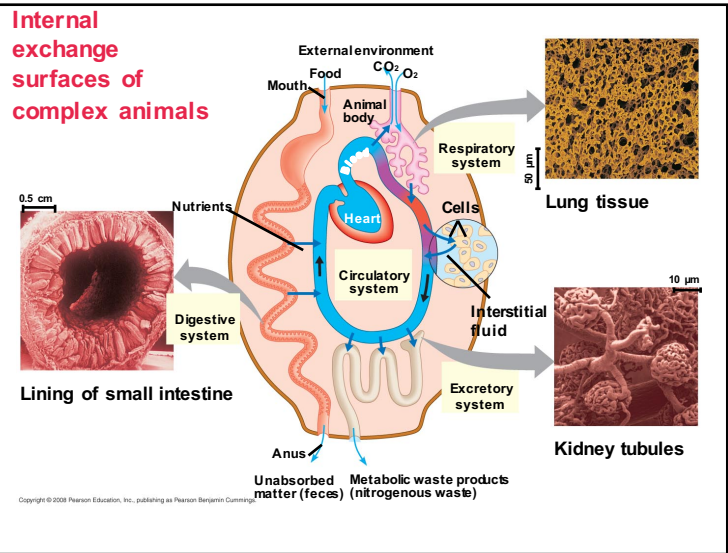
- An animal's size and shape directly affect how it exchanges energy and materials with its surroundings.
- *Exchange occurs as substances dissolved in the aqueous medium diffuse and are transported across the cells' plasma membranes.*
- A single-celled protist living in water has a sufficient surface area of plasma membrane to service its entire volume of cytoplasm.

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- Multicellular organisms with a sac body plan have body walls that are only two cells thick, facilitating diffusion of materials.
- *More complex organisms have highly folded internal surfaces for exchanging materials.*

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Hierarchical Organization of Body Plans

- In vertebrates, *the space between cells* is filled with **interstitial fluid**, which allows for the movement of material into and out of cells.
- A complex body plan helps an animal in a variable environment to maintain a relatively stable internal environment.
- Most animals are composed of specialized cells organized into **tissues** that have different functions.
- Tissues make up **organs**, which together make up **organ systems**.

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Organ Systems

Table 40.1: Organ Systems: Their Main Components and Functions in Mammals

Organ System	Main Components	Main Functions
Digestive	Mouth, pharynx, esophagus, stomach, intestines, liver, pancreas, anus	Food processing (ingestion, digestion, absorption, elimination)
Circulatory	Heart, blood vessels, blood	Internal distribution of materials
Respiratory	Lungs, trachea, other breathing tubes	Gas exchange (uptake of oxygen; disposal of carbon dioxide)
Immune and lymphatic	Bone marrow, lymph nodes, thymus, spleen, lymph vessels, white blood cells	Body defense (fighting infections and cancer)
Excretory	Kidneys, ureters, urinary bladder, urethra	Disposal of metabolic wastes; regulation of osmotic balance of blood
Endocrine	Pituitary, thyroid, pancreas, adrenal, and other hormone-secreting glands	Coordination of body activities (such as digestion and metabolism)
Reproductive	Ovaries or testes, and associated organs	Reproduction
Nervous	Brain, spinal cord, nerves, sensory organs	Coordination of body activities; detection of stimuli and formulation of responses to them
Integumentary	Skin and its derivatives (such as hair, claws, skin glands)	Protection against mechanical injury, infection, drying out; thermoregulation
Skeletal	Skeleton (bones, tendons, ligaments, cartilage)	Body support, protection of internal organs, movement
Muscular	Skeletal muscles	Locomotion and other movement

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Tissue Structure and Function

- Different tissues have different structures that are suited to their functions.
- *Tissues are classified into four main categories: epithelial, connective, muscle, and nervous.*

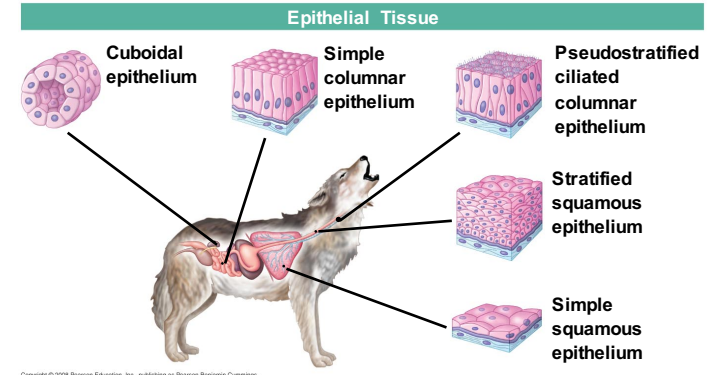
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Epithelial Tissue - Covering & Lining

- **Epithelial tissue** covers the outside of the body and lines the organs and cavities within the body.
- It contains cells that are closely joined.
- The shape of epithelial cells may be *cuboidal* (like dice), *columnar* (like bricks on end), or *squamous* (like floor tiles).

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Structure and function in animal tissues



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Connective Tissue

- **Connective tissue** mainly *binds and supports other tissues*.
- It contains sparsely packed cells scattered throughout an extracellular matrix.
- The matrix consists of fibers in a liquid, jellylike, or solid foundation.

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- There are three types of *connective tissue* fiber, all made of protein:
 - *Collagenous fibers* provide strength and flexibility.
 - *Elastic fibers* stretch and snap back to their original length.
 - *Reticular fibers* join connective tissue to adjacent tissues.

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Connective Tissue

In vertebrates, the fibers and foundation combine to form *six major types of connective tissue*:

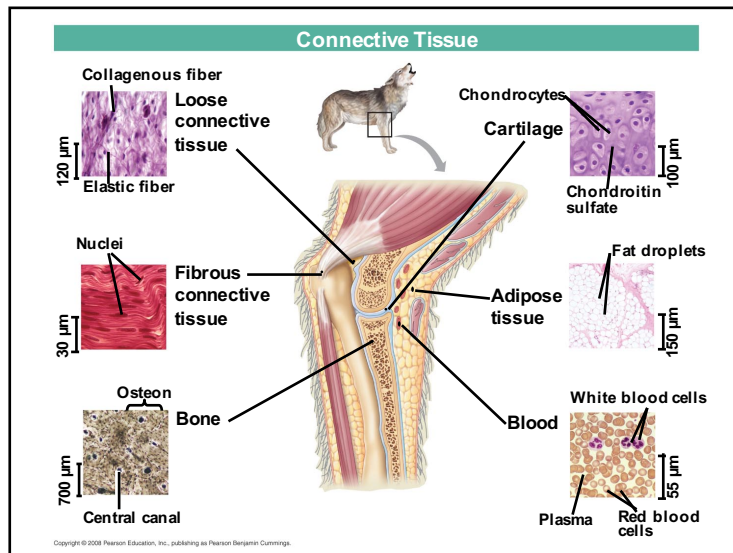
- **Loose connective tissue** binds epithelia to underlying tissues and holds organs in place.
- **Cartilage** is a strong and flexible support material.
- **Fibrous connective tissue** is found in **tendons**, which attach muscles to bones, and **ligaments**, which connect bones at joints.

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Connective Tissue

- **Adipose tissue** stores fat for insulation and fuel.
- **Blood** is composed of blood cells and cell fragments in blood plasma.
- **Bone** is mineralized and forms the skeleton.

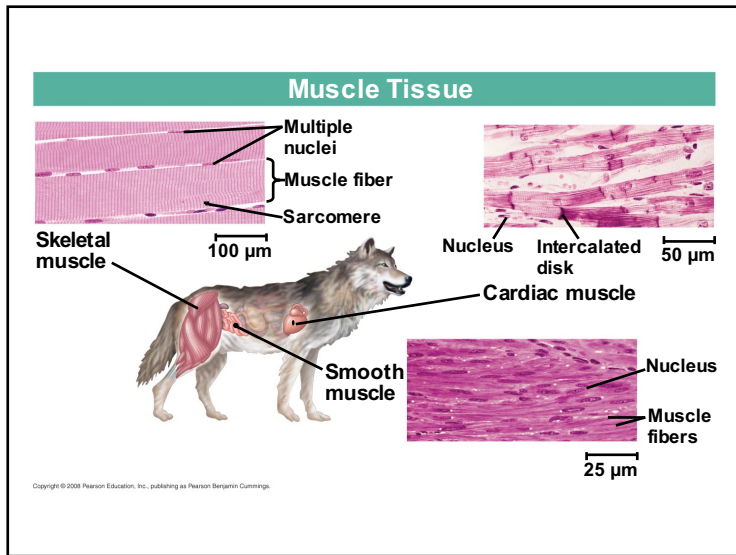
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Muscle Tissue

- **Muscle tissue** consists of long cells called muscle fibers, which contract in response to nerve signals.
- It is divided in the vertebrate body into three types:
 - **Skeletal muscle**, or striated muscle, is attached to bones and is responsible for voluntary movement.
 - **Smooth muscle** mainly lines internal organs and is responsible for involuntary body activities.
 - **Cardiac muscle** is responsible for contraction of the heart.

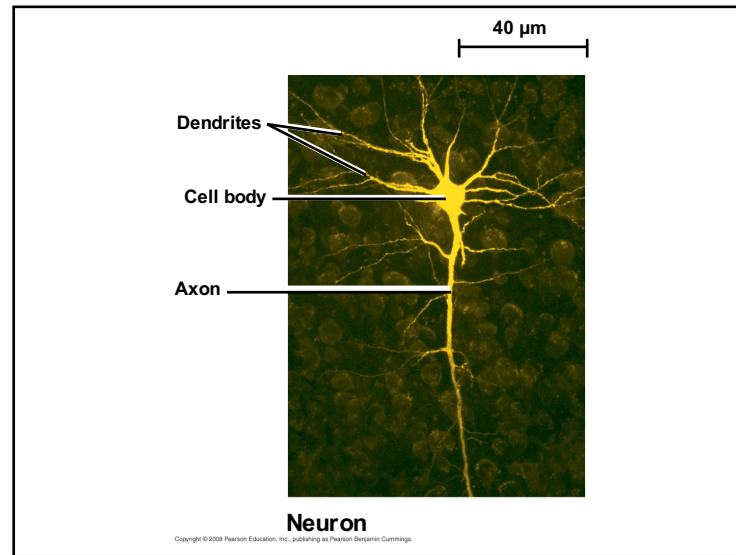
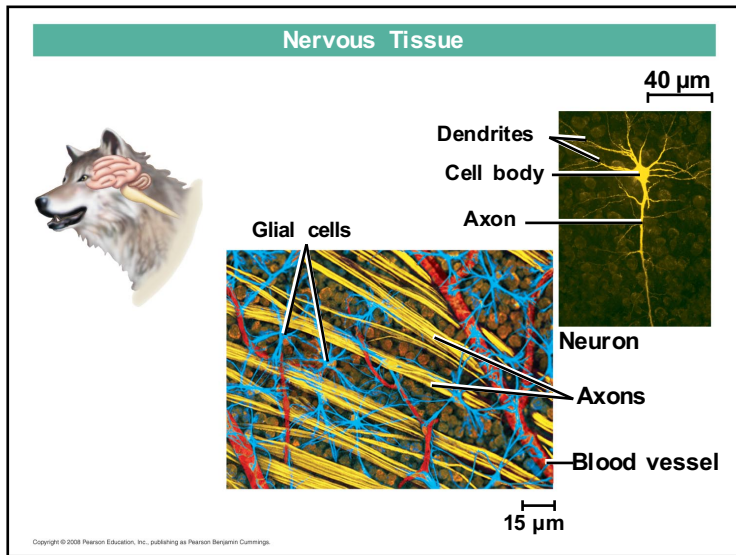
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Nervous Tissue

- **Nervous tissue** senses stimuli and transmits signals throughout the animal.
- Nervous tissue contains:
 - **Neurons**, or nerve cells, that transmit nerve impulses.
 - **Glial cells**, or **glia**, that help nourish, insulate, and replenish neurons.

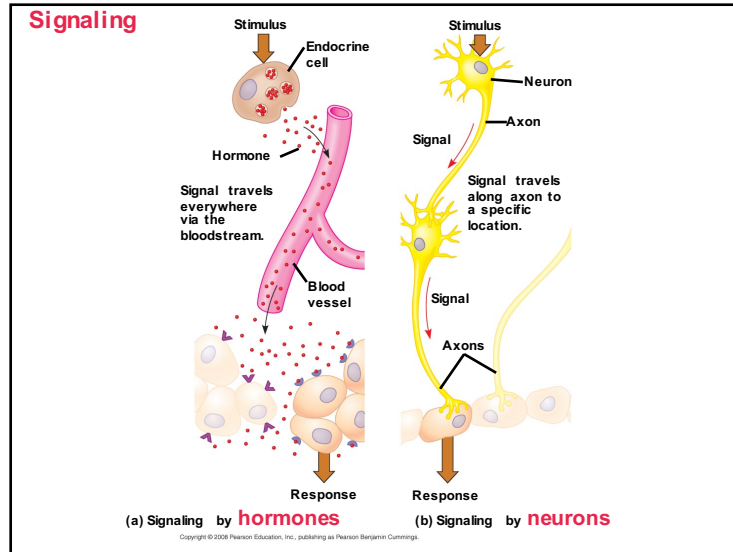
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Coordination and Control

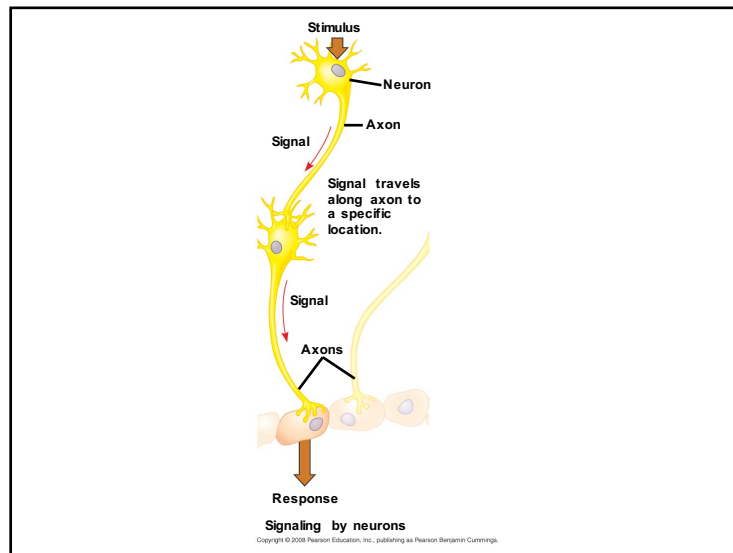
- Control and coordination within a body depend on the *endocrine system* and the *nervous system*.
- The endocrine system transmits *chemical signals* called *hormones* to receptive cells throughout the body via blood.
- A hormone may affect one or more regions throughout the body.
- Hormones are relatively slow acting, but can have long-lasting effects.

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- The nervous system transmits information between specific locations.
- The information conveyed depends on a signal's pathway, not the type of signal.
- Nerve signal transmission is very fast.
- *Nerve impulses can be received by neurons, muscle cells, and endocrine cells.*

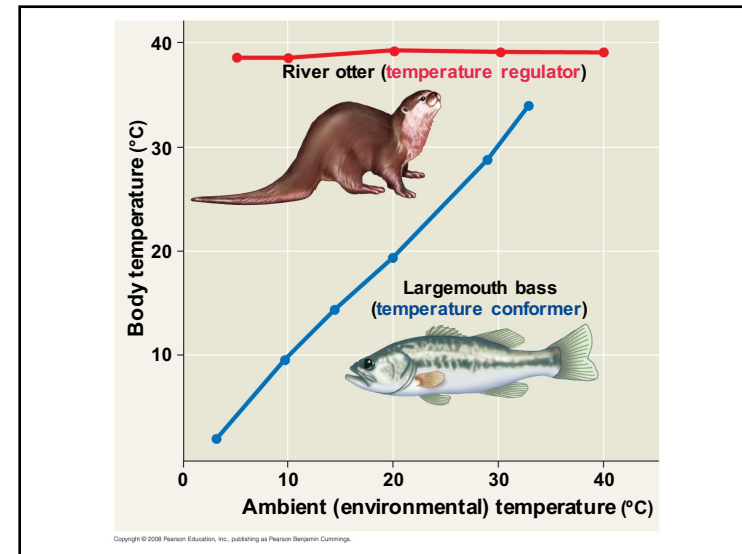
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Feedback control loops maintain the internal environment in many animals

- Animals manage their internal environment by regulating or conforming to the external environment.
- A **regulator** uses internal control mechanisms to moderate internal change in the face of external, environmental fluctuation.
- A **conformer** allows its internal condition to vary with certain external changes.

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Homeostasis

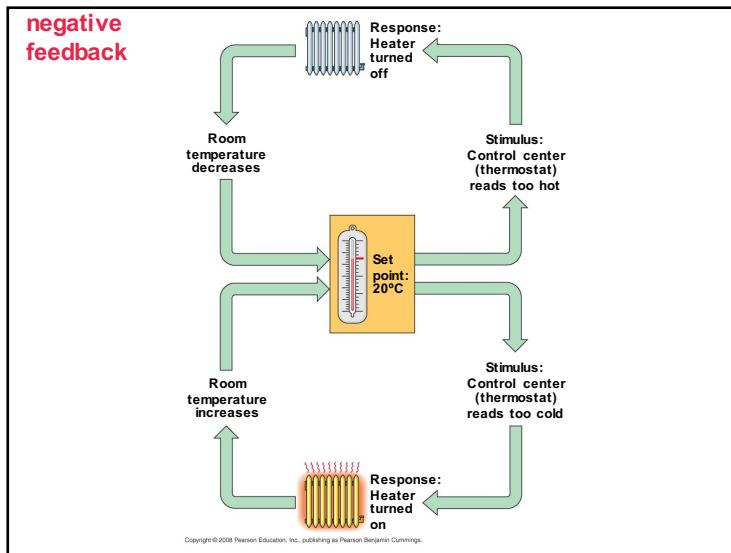
- Organisms use **homeostasis** to maintain a “steady state” or **internal balance** regardless of external environment.
- In humans, body temperature, blood pH, and glucose concentration are each maintained at a constant level.

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Mechanisms of Homeostasis

- Mechanisms of homeostasis **moderate changes in the internal environment**.
- For a given variable, fluctuations above or below a **set point** serve as a **stimulus**; these are detected by a **sensor** and trigger a **response**.
- The response returns the variable to the set point. **Negative Feedback acts to reverse a trend... To maintain the variable within a narrow range.**

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Feedback Loops in Homeostasis

- The *dynamic equilibrium of homeostasis* is maintained by **negative feedback**, which helps to return a variable to either a **normal range** or a set point.
- Most homeostatic control systems function by negative feedback, where buildup of the end product shuts the system off.
- **Positive feedback** loops occur in animals, but do not usually contribute to homeostasis. Instead, positive feedback *escalates a trend*.

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Alterations in Homeostasis

- Set points and normal ranges can change with age or show cyclic variation.
- Homeostasis can adjust to changes in external environment, a process called **acclimatization**.

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Homeostatic processes for thermoregulation involve form, function, and behavior

- **Thermoregulation** is the process by which animals maintain an internal temperature within a tolerable range.
- **Endothermic** animals **generate heat by metabolism**; birds and mammals are endotherms
- **Ectothermic** animals **gain heat from external sources**; ectotherms include most invertebrates, fishes, amphibians, and non-avian reptiles

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- In general, **ectotherms** tolerate greater variation in internal temperature, while **endotherms** are active at a greater range of external temperatures.
- *Endothermy is more energetically expensive than ectothermy.*

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(a) A walrus, an **endotherm**



(b) A lizard, an **ectotherm**

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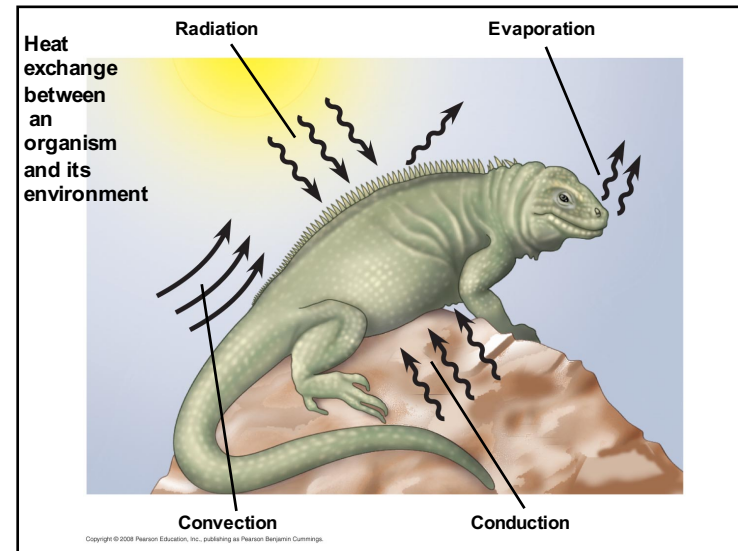
Variation in Body Temperature

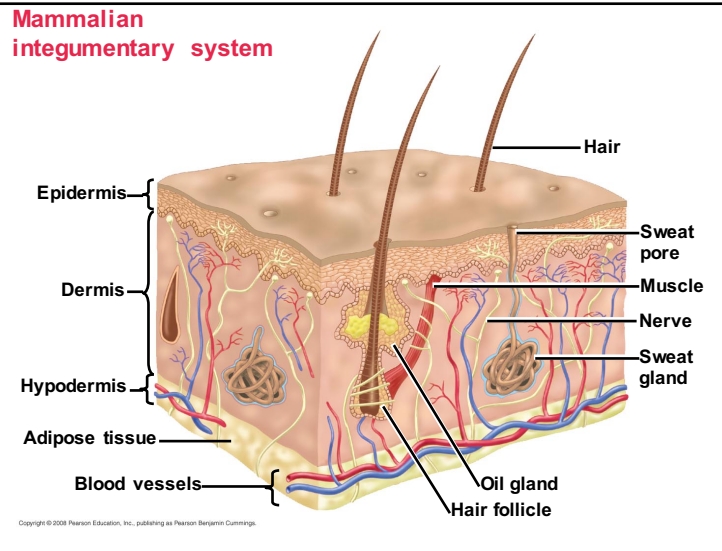
- The *body temperature* of a *poikilotherm* varies with its environment, while that of a *homeotherm* is relatively constant.

Balancing Heat Loss and Gain:

- Organisms exchange heat by four physical processes: conduction, convection, radiation, and evaporation.
- Heat regulation in mammals often involves the **integumentary system**: skin, hair, and nails.

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- Five general **adaptations** help animals **thermoregulate**:
 - Insulation
 - Circulatory adaptations
 - Cooling by evaporative heat loss
 - Behavioral responses
 - Adjusting metabolic heat production.

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Insulation

- Insulation is a major thermoregulatory adaptation in mammals and birds.
- Skin, feathers, fur, and blubber **reduce heat flow between an animal and its environment**.

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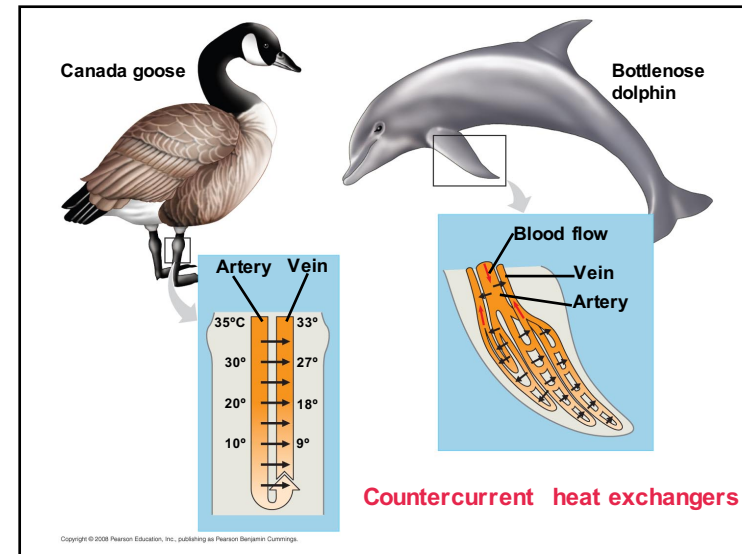
Circulatory Adaptations

- **Regulation of blood flow near the body surface significantly affects thermoregulation.**
- Many endotherms and some ectotherms can alter the amount of blood flowing between the body core and the skin.
- In **vasodilation**, blood flow in the skin increases, facilitating heat loss.
- In **vasoconstriction**, blood flow in the skin decreases, lowering heat loss.

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- The arrangement of blood vessels in many marine mammals and birds allows for **countercurrent exchange**.
- Countercurrent **heat exchangers transfer heat between fluids flowing in opposite directions**.
- Countercurrent heat exchangers are an important mechanism for reducing heat loss.

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Cooling by Evaporative Heat Loss

- Many types of animals lose heat through **evaporation of water in sweat = evaporative cooling**.
- Panting increases the cooling effect in birds and many mammals.
- Sweating or bathing moistens the skin, helping to cool an animal down.

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Behavioral Responses

- Both endotherms and ectotherms use behavioral responses to control body temperature.
- Some terrestrial invertebrates have postures that minimize or maximize absorption of solar heat.

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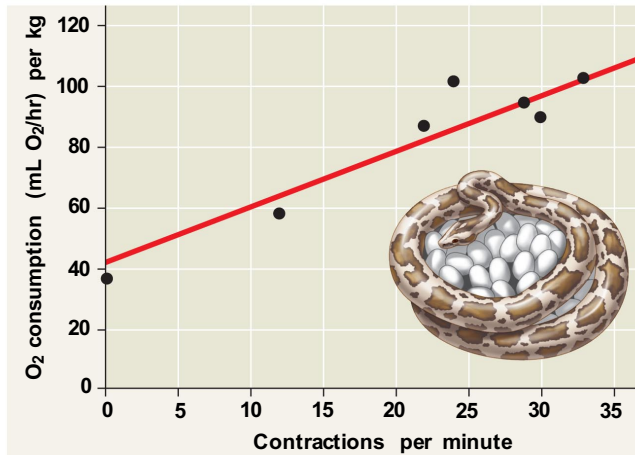
Adjusting Metabolic Heat Production

- Some animals can regulate body temperature by adjusting their rate of metabolic heat production.
- Heat production is increased by muscle activity such as moving or shivering.
- Some ectotherms can also shiver to increase body temperature.

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RESULTS

A Burmese python generates heat while incubating eggs

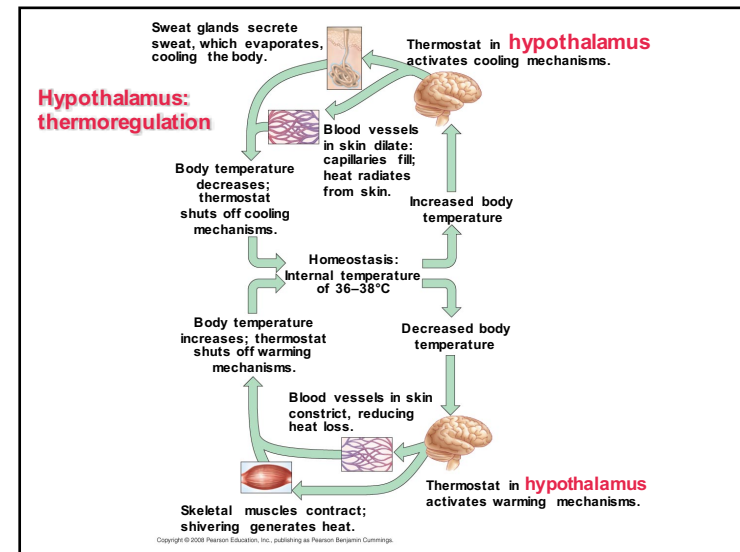


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Acclimatization in Thermoregulation

- Birds and mammals can vary their insulation to acclimatize to seasonal temperature changes.
- When temperatures are subzero, some ectotherms produce “antifreeze” compounds to prevent ice formation in their cells.
- **Thermoregulation is controlled by a region of the brain called the hypothalamus.** The hypothalamus triggers heat loss or heat generating mechanisms.
- Fever is the result of a change to the set point for a biological thermostat.

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Energy requirements are related to animal size, activity, and environment

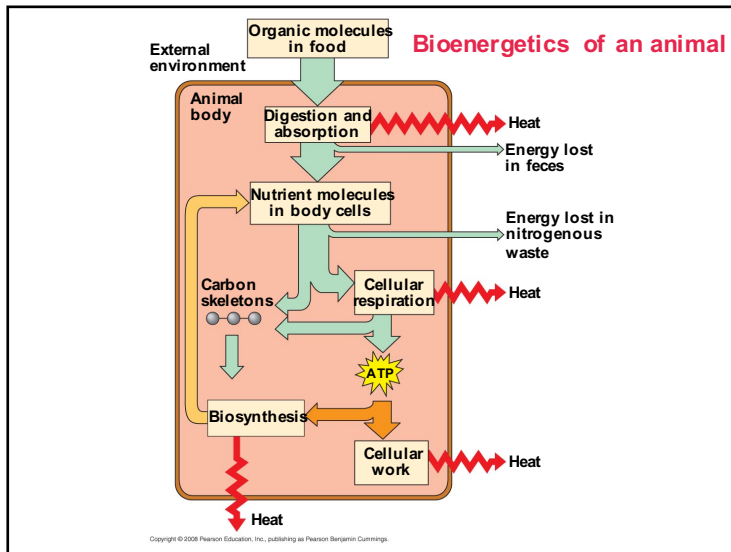
- **Bioenergetics** is the overall *flow and transformation of energy in an animal*.
- It determines how much food an animal needs and relates to an animal's size, activity, and environment.

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Energy Allocation and Use

- Animals harvest chemical energy from food.
- *Energy-containing molecules from food are usually used to make ATP, which powers cellular work.*
- After the needs of staying alive are met, remaining food molecules can be used in biosynthesis.
- *Biosynthesis includes body growth and repair, synthesis of storage material such as fat, and production of gametes.*

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Quantifying Energy Use

- **Metabolic rate** is the *amount of energy an animal uses in a unit of time*.
- One way to measure it is to determine the amount of oxygen consumed or carbon dioxide produced.

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Minimum Metabolic Rate and Thermoregulation

- **Basal metabolic rate (BMR)** is the metabolic rate of an endotherm at rest at a “comfortable” temperature.
- **Standard metabolic rate (SMR)** is the metabolic rate of an ectotherm at rest at a specific temperature.
- Both rates assume a nongrowing, fasting, and nonstressed animal.
- Ectotherms have much lower metabolic rates than endotherms of a comparable size.

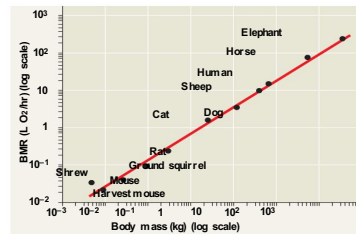
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Influences on Metabolic Rate

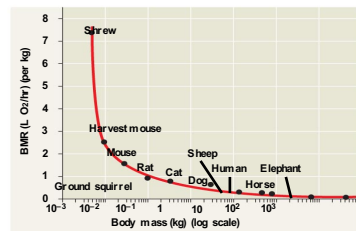
- Metabolic rates are affected by many factors besides whether an animal is an endotherm or ectotherm.
- Two of these factors are size and activity.
- **Metabolic rate is inversely related to body size** among similar animals.
- The higher metabolic rate of smaller animals leads to a higher oxygen delivery rate, breathing rate, heart rate, and greater (relative) blood volume, compared with a larger animal.

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Relationship of Metabolic Rate to Body Size



(a) Relationship of BMR to body size



(b) Relationship of BMR per kilogram of body mass to body size

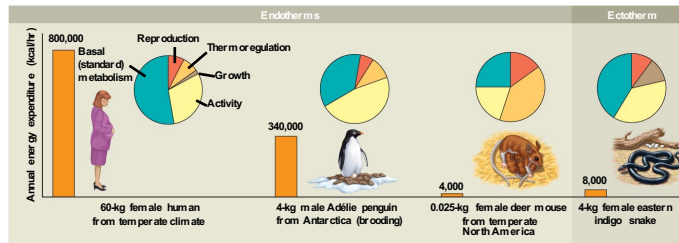
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Activity, Metabolic Rate, and Energy Budgets

- Activity greatly affects metabolic rate for endotherms and ectotherms.
- In general, **the maximum metabolic rate an animal can sustain is inversely related to the duration of the activity.**
- Different species use energy and materials in food in different ways, depending on their environment.
- Use of energy is partitioned to BMR (or SMR), activity, thermoregulation, growth, and reproduction.

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Energy budgets for four animals



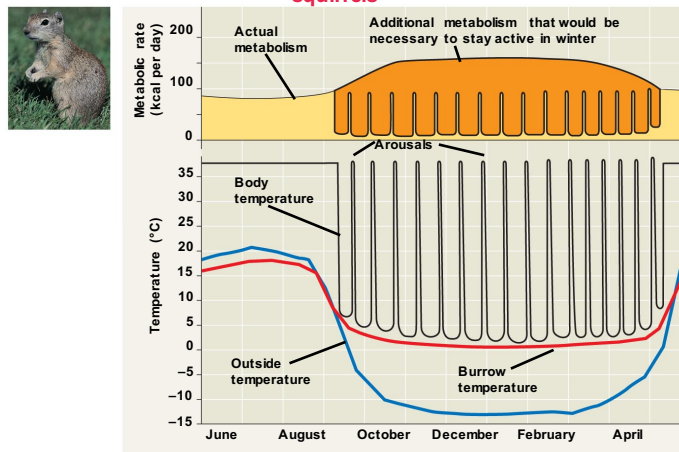
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Torpor and Energy Conservation

- **Torpor** is a physiological state in which *activity is low and metabolism decreases*.
- Torpor enables animals to save energy while avoiding difficult and dangerous conditions.
- **Hibernation** is *long-term torpor* that is an *adaptation to winter* cold and food scarcity.

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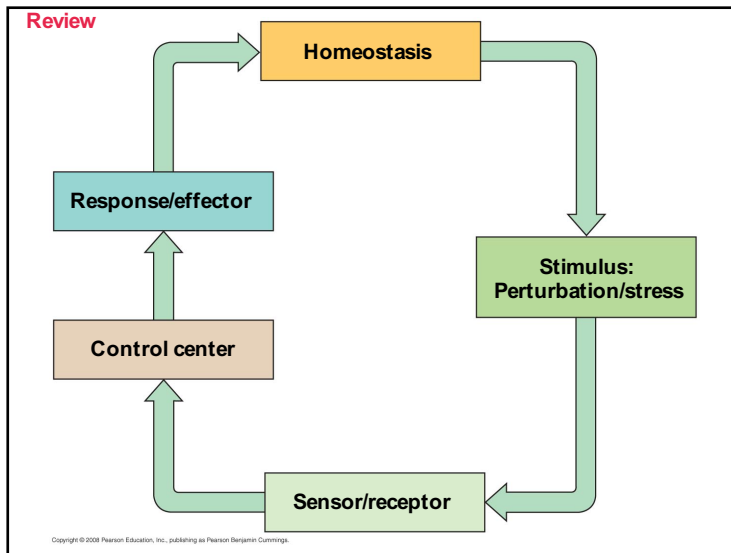
Body temperature and metabolism during hibernation in ground squirrels



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- **Estivation**, or *summer torpor*, enables animals to survive long periods of high temperatures and scarce water supplies.
- **Daily torpor** is exhibited by many small mammals and birds and seems adapted to feeding patterns.

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You should now be able to:

1. Distinguish among the following sets of terms: collagenous, elastic, and reticular fibers; regulator and conformer; positive and negative feedback; basal and standard metabolic rates; torpor, hibernation, estivation, and daily torpor.
 2. Relate structure with function and identify diagrams of the following animal tissues: epithelial, connective tissue (six types), muscle tissue (three types), and nervous tissue.
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3. Compare and contrast the nervous and endocrine systems.
 4. Define thermoregulation and explain how endotherms and ectotherms manage their heat budgets.
 5. Describe how a countercurrent heat exchanger may function to retain heat within an animal body.
 6. Define bioenergetics and biosynthesis.
 7. Define metabolic rate and explain how it can be determined for animals.
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