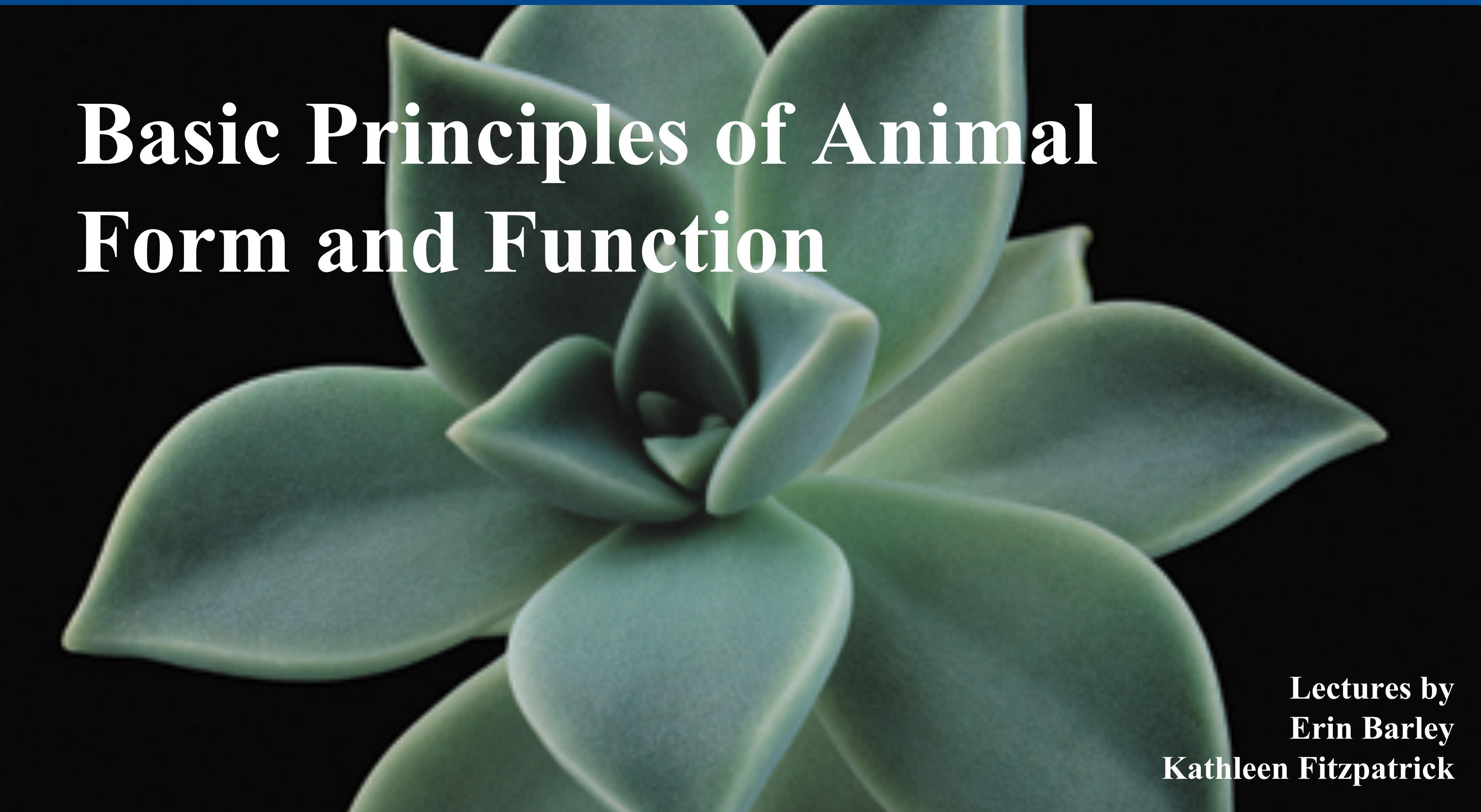
**LECTURE PRESENTATIONS**
For CAMPBELL BIOLOGY, NINTH EDITION
Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson



# Basic Principles of Animal Form and Function

**Lectures by**
**Erin Barley**
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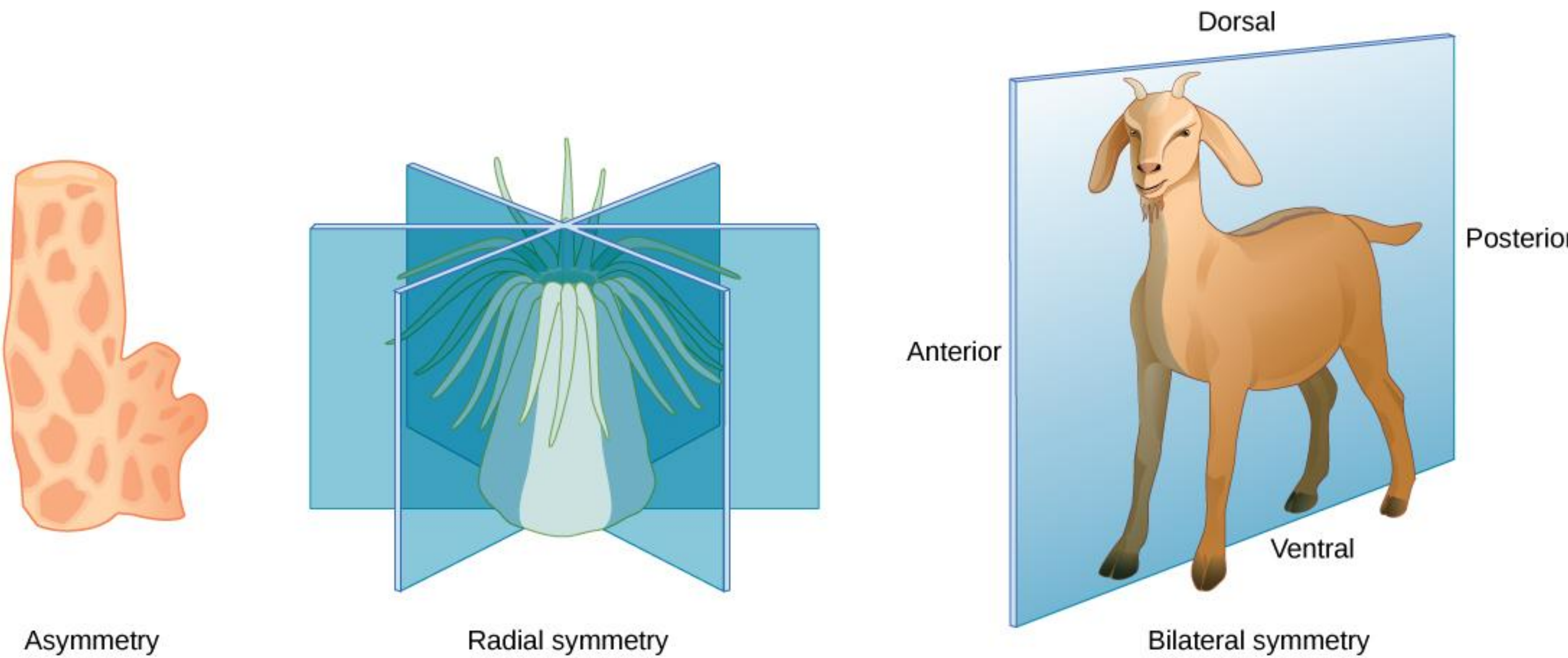
# Animals vary in form and function.

- From a sponge to a worm to a goat, an organism has a distinct body plan that limits its size and shape.
- Animals' bodies are also designed to interact with their environments, whether in the deep sea, a rainforest canopy, or the desert.
- Therefore, a large amount of information about the structure of an organism's body (anatomy) and the function of its cells, tissues and organs (physiology) can be learned by studying that organism's environment.

# Animal body plans follow set patterns related to symmetry.



# Different Symmetry

- ***Asymmetrical*** animals are animals with no pattern or symmetry; an example of an asymmetrical animal is a sponge.
- **Radial symmetry**: when an animal has an up-and-down orientation: any plane cut along its longitudinal axis through the organism produces equal halves, but not a definite right or left side.
- This plan is found mostly in aquatic animals, especially organisms that attach themselves to a base, like a rock or a boat, and extract their food from the surrounding water as it flows around the organism.

# Different Symmetry

- **Bilateral symmetry** is illustrated in the same figure by a goat. The goat also has an upper and lower component to it, but a plane cut from front to back separates the animal into definite right and left sides.
- Additional terms used when describing positions in the body are anterior (front), posterior (rear), dorsal (toward the back), and ventral (toward the stomach).
- Bilateral symmetry is found in both land-based and aquatic animals; it enables a high level of mobility.

# Animal Bioenergetics

- All animals must obtain their energy from food they ingest or absorb.
- These nutrients are converted to adenosine triphosphate (ATP) for short-term storage and use by all cells.
- Some animals store energy for slightly longer times as glycogen, and others store energy for much longer times in the form of triglycerides housed in specialized adipose tissues. No energy system is one hundred percent efficient, and an animal's metabolism produces waste energy in the form of heat.

# Metabolic rate

- The amount of energy expended by an animal over a specific time is called its metabolic rate.
- The rate is measured variously in joules, calories, or kilocalories (1000 calories).
- Carbohydrates and proteins contain about 4.5 to 5 kcal/g, and fat contains about 9 kcal/g.
- Metabolic rate is estimated as the **basal metabolic rate (BMR)** in endothermic animals at rest and as the **standard metabolic rate (SMR)** in ectotherms.
- Human males have a BMR of 1600 to 1800 kcal/day, and human females have a BMR of 1300 to 1500 kcal/day.
- Even with insulation, endothermal animals require extensive amounts of energy to maintain a constant body temperature. An ectotherm such as an alligator has an SMR of 60 kcal/day.

# Animal Bioenergetics

- If an animal can conserve that heat and maintain a relatively constant body temperature, it is classified as a warm-blooded animal and called an **endotherm**.
- The insulation used to conserve the body heat comes in the forms of fur, fat, or feathers.

- The absence of insulation in **ectothermic** animals increases their dependence on the environment for body heat.

# Energy Requirements Related to Body Size

| Species |  |  |
|---|---|---|
| Mass | 35 g | 4,500,000 g |
| Metabolic rate | 890 mm$^3$ $0_2$/g body mass/hr | 75 mm$^3$ $0_2$/g body mass/hr |

- Smaller endothermic animals have a greater surface area for their mass than larger ones. Therefore, smaller animals lose heat at a faster rate than larger animals and require more energy to maintain a constant internal temperature. This results in a smaller endothermic animal having a higher BMR, per body weight, than a larger endothermic animal.[9]

# 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

Figure 40.1

- The ears of the jackrabbit (*Lepus alleni*) in **Figure 40.1** are thin and remarkably large. They provide this hare with an acute sense of hearing, a primary defense against predators. The ears also help the jackrabbit shed excess heat. Blood flowing through each ear's network of vessels transfers heat to the surrounding air. However, when the air is warmer than the jackrabbit, blood passing through the ears could absorb heat, raising body temperature to a dangerous level. How, then, does a big-eared jackrabbit survive in the midday desert heat? To answer this question, we need to look more closely at the biological form, or **anatomy**, of the animal.

  Over the course of its life, a jackrabbit faces the same fundamental challenges as any other animal, whether hydra, hawk, or human. All animals must obtain oxygen and nutrients, fight off infection, and produce offspring. Given that they share these and other basic requirements, why do species vary so enormously in makeup, complexity, organization, and appearance? The answer is adaptation: Natural selection favors those variations in a population that increase relative fitness (see Chapter 23). The solutions to the challenges of survival vary among environments and species, but they frequently result in a close match of form to function. Because form and function are correlated, examining anatomy often provides clues to **physiology**—biological function. In the case of the jackrabbit, researchers noted that its large, pink-tinged ears turn pale when the air temperature exceeds 40°C (104°F), the normal temperature of the jackrabbit's body. The color change reflects a temporary narrowing of blood vessels in response to a hot environment. With their blood supply reduced, the ears can absorb heat without overheating the rest of the body. When the air cools, blood flow increases, and the large ears again help release excess heat.

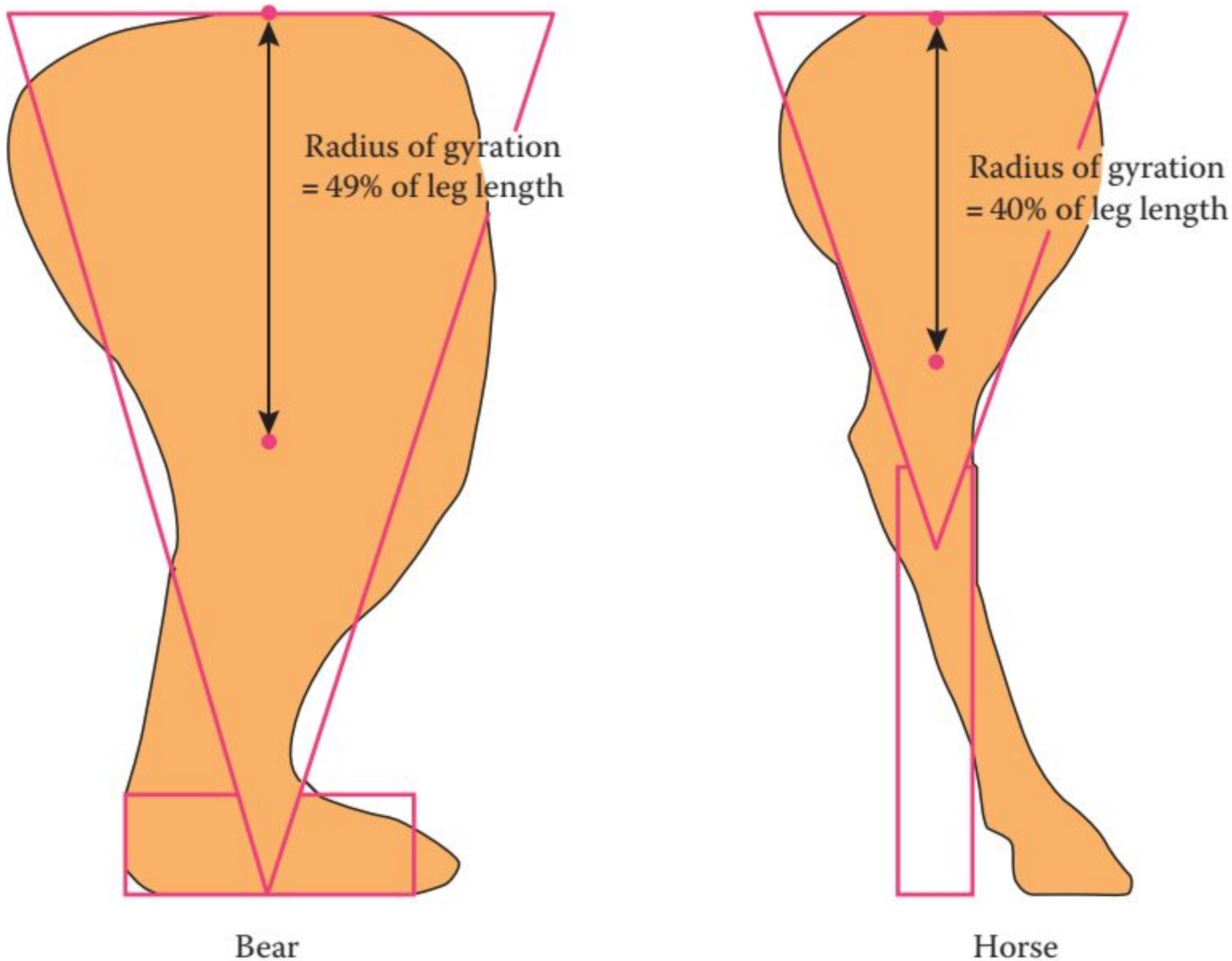



**FIGURE 5.1.1** The weight distribution of the hind leg of a horse is compared to the weight distribution of a bear. The horse's weight is much higher on the leg, reducing its inertia (given here by the radius of gyration) and allowing faster acceleration and deceleration in running. (From Hildebrand, M., *Am. Sci.*, 75, 594, 1987. With permission.)

Horses are built for speed (Figure 5.1.1). Their legs are elongated relative to their body size, but not too far as to cause undue interference between forelegs and hind legs (as in giraffes). Muscle attachment points are closer to the joints than in other animals, so that a small muscular contraction causes a faster movement of the end of the limbs (Hildebrand, 1987). Ligaments of the hind limb act as elastic bands to store energy upon impact and release it during movement of the leg. Leg bones are as light as possible and still have enough strength to sustain forces incurred during galloping and jumping. The weight of muscles is minimized because the structures of the joints lock the legs into movements in a plane; muscles and tendons are not needed to strengthen the joints in a transverse direction. Everything about the form of a horse's leg is related to its function of generating running speed.

Form and function: They are enough related that function can often be inferred from the form of a part of a living being.

# Concept 40.1: 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

# Evolution of Animal Size and Shape

- Physical laws constrain strength, diffusion, movement, and heat exchange
- As animals increase in size, their skeletons must be proportionately larger to support their mass
- Evolutionary convergence reflects different species' adaptations to a similar environmental challenge

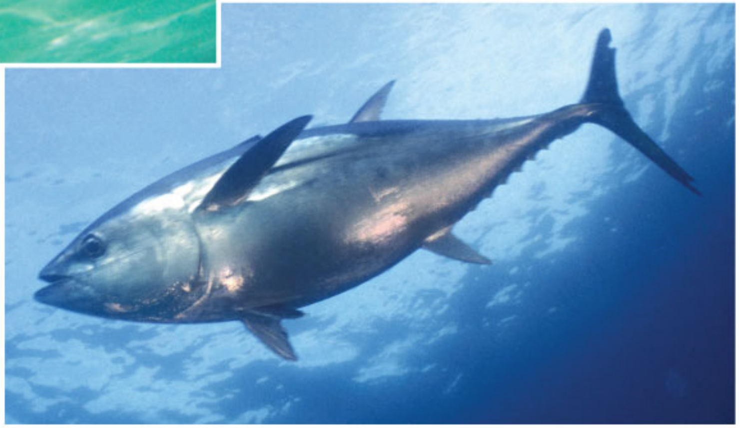
Video: Shark Eating Seal

Video: Galápagos Sea Lion

Figure 40.2

▲ Seal

▲ Penguin



▲ Tun
a

Figure 40.2a

**Seal**

Figure 40.2b

▲ **Penguin**

Figure 40.2c

▲ **Tuna**

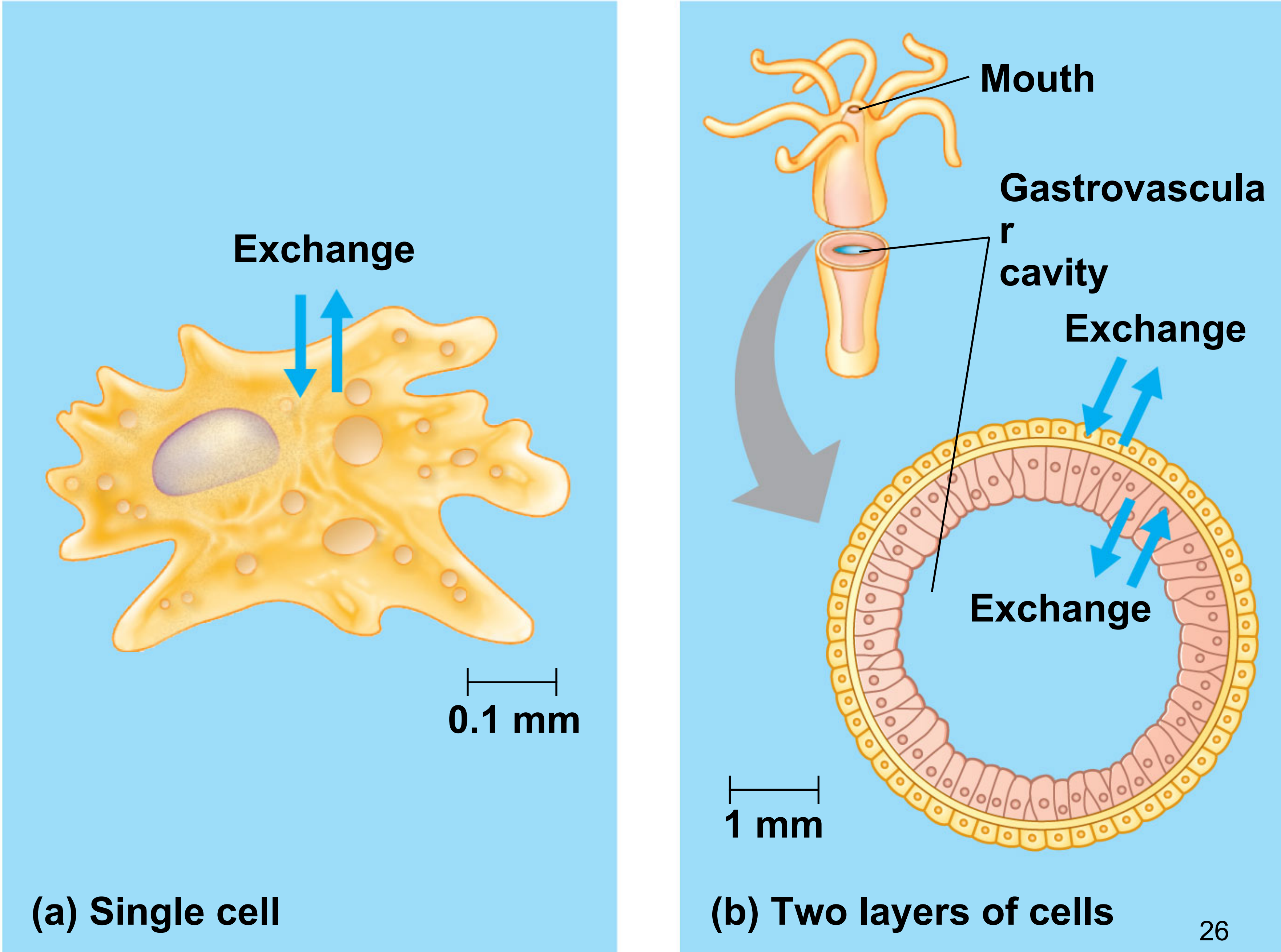
# Exchange with the Environment

- Materials such as nutrients, waste products, and gases must be exchanged across the cell membranes of animal cells
- Rate of exchange is proportional to a cell’s surface area while amount of exchange material is proportional to a cell’s volume

Video: Hydra Eating Daphnia

- A single-celled protist living in water has a sufficient surface area of plasma membrane to service its entire volume of cytoplasm
- Multicellular organisms with a saclike body plan have body walls that are only two cells thick, facilitating diffusion of materials

Figure 40.3




(a) Single cell

(b) Two layers of cells

- In flat animals such as tapeworms, the distance between cells and the environment is minimized
- More complex organisms have highly folded internal surfaces for exchanging materials

Figure 40.4

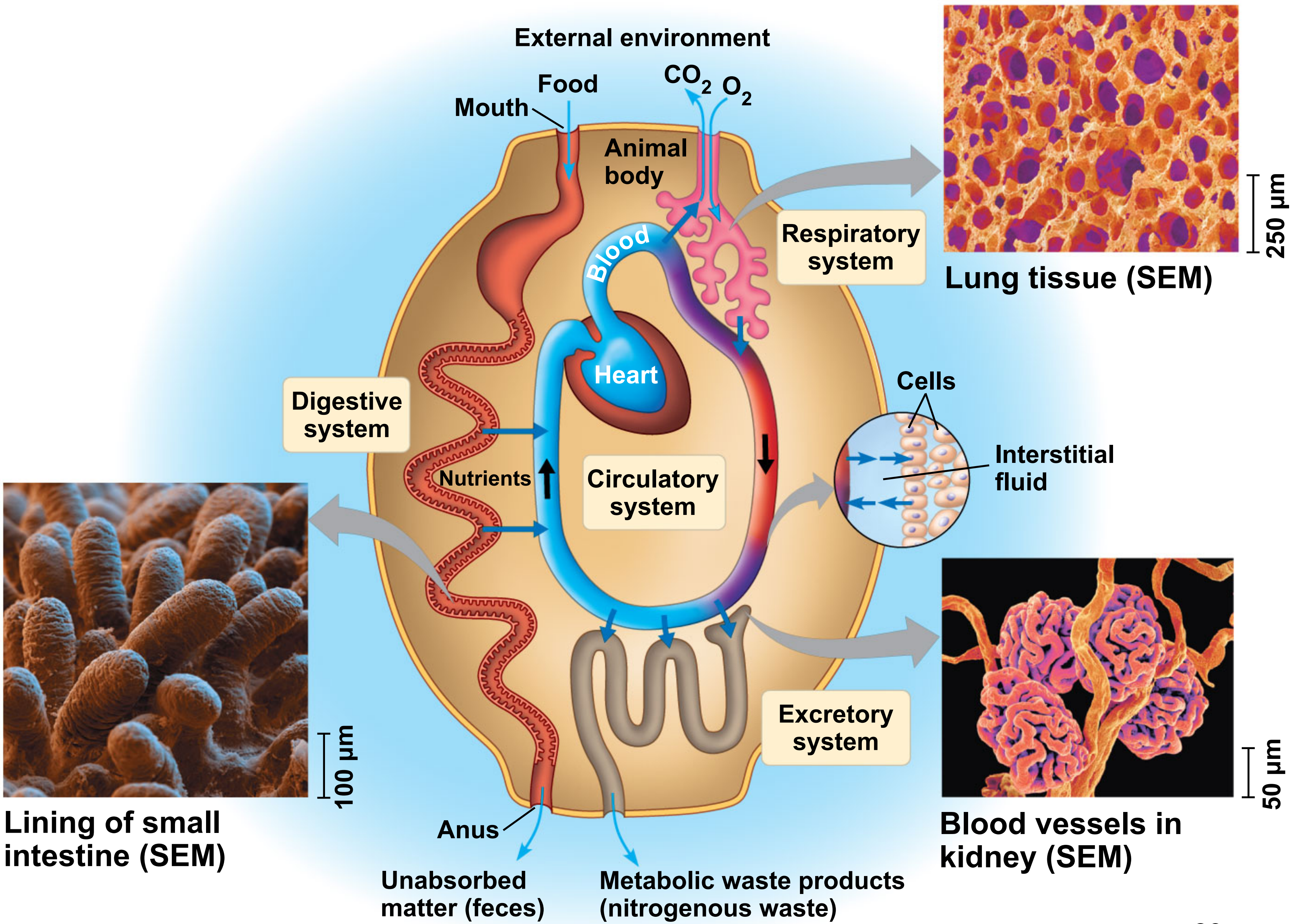
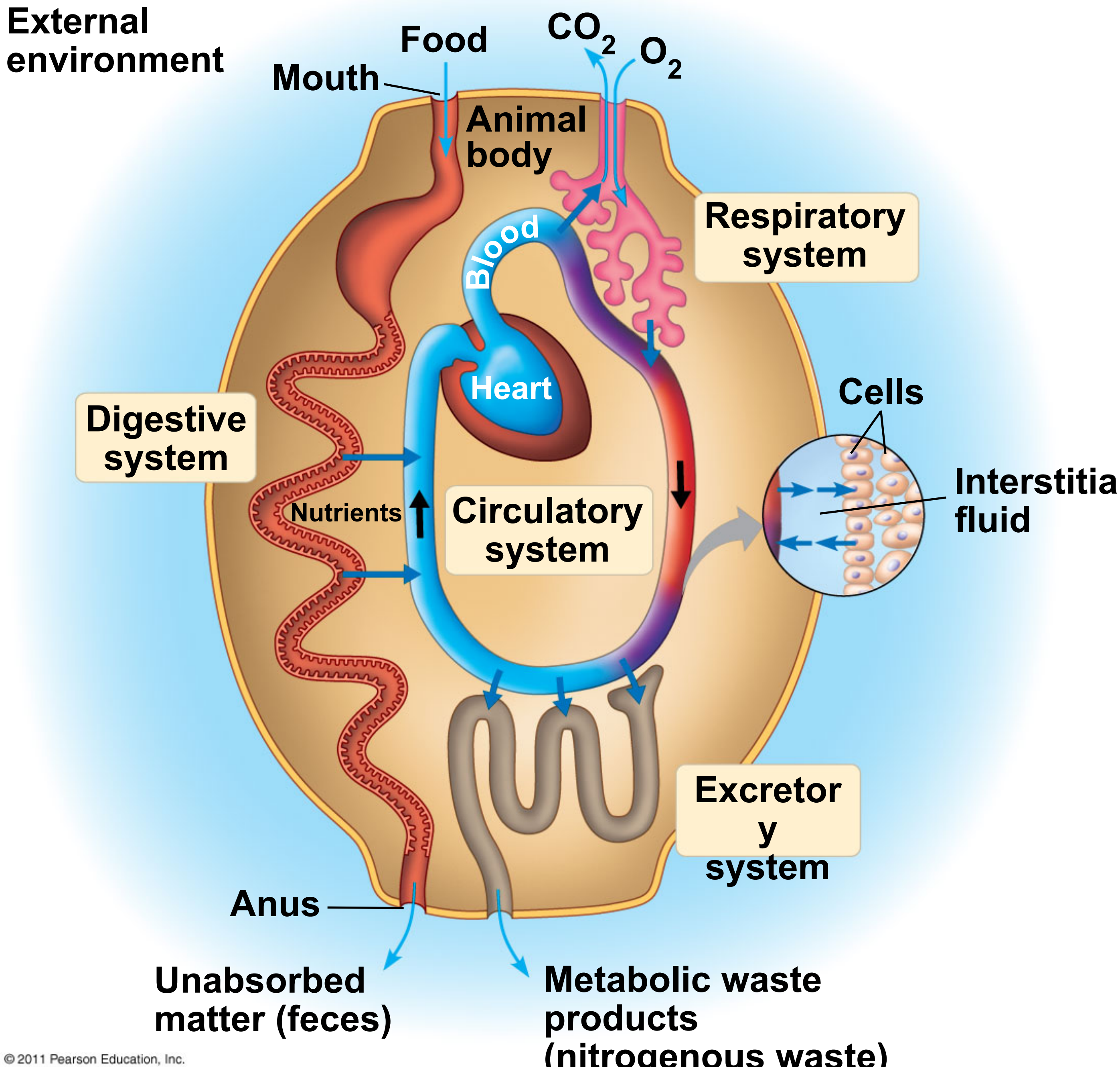

External environment
Food
Mouth
$CO_2$
$O_2$
Animal body
Blood
Heart
Respiratory system
Lung tissue (SEM)
250 µm
Cells
Interstitial fluid
Digestive system
Nutrients
Circulatory system
Lining of small intestine (SEM)
100 µm
Excretory system
Blood vessels in kidney (SEM)
50 µm
Anus
Unabsorbed matter (feces)
Metabolic waste products (nitrogenous waste)

Figure 40.4a



External environment
Food
Mouth
$CO_2$
$O_2$
Animal body
Blood
Respiratory system
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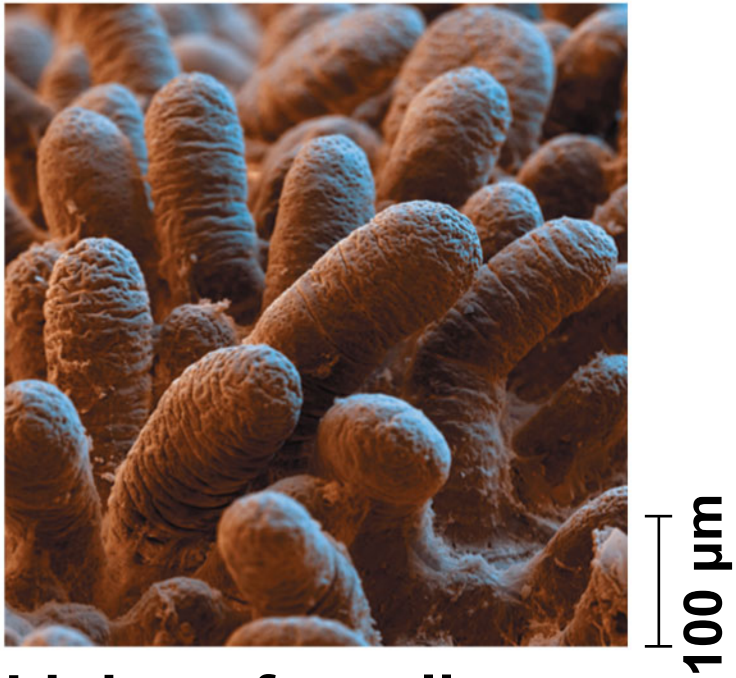
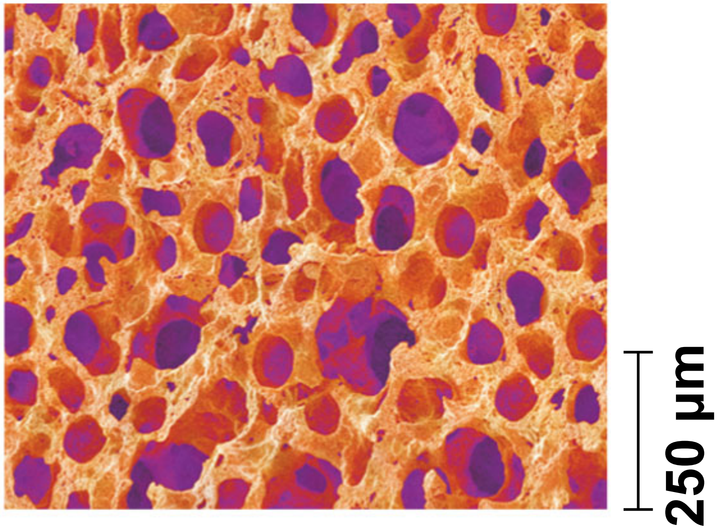
Digestive system
Interstitial fluid
Nutrients
Circulatory system
Excretor y system
Anus
Unabsorbed matter (feces)
Metabolic waste products (nitrogenous waste)




**Lining of small intestine (SEM)**

Figure 40.4c




**Lung tissue (SEM)**

Figure 40.4d


**Blood vessels in kidney (SEM)**

- 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 living in a variable environment to maintain a relatively stable internal environment

# Hierarchical Organization of Body Plans

- Most animals are composed of specialized cells organized into **tissues** that have different functions
- Tissues make up **organs**, which together make up **organ systems**
- Some organs, such as the pancreas, belong to more than one organ system

Table 40.1

**Table 40.1 Organ Systems 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, dehydration; thermoregulation |
| Skeletal | Skeleton (bones, tendons, ligaments, cartilage) | Body support, protection of internal organs, movement |
| Muscular | Skeletal muscles | Locomotion and other movement |

## Exploring Structure and Function in Animal Tissues

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

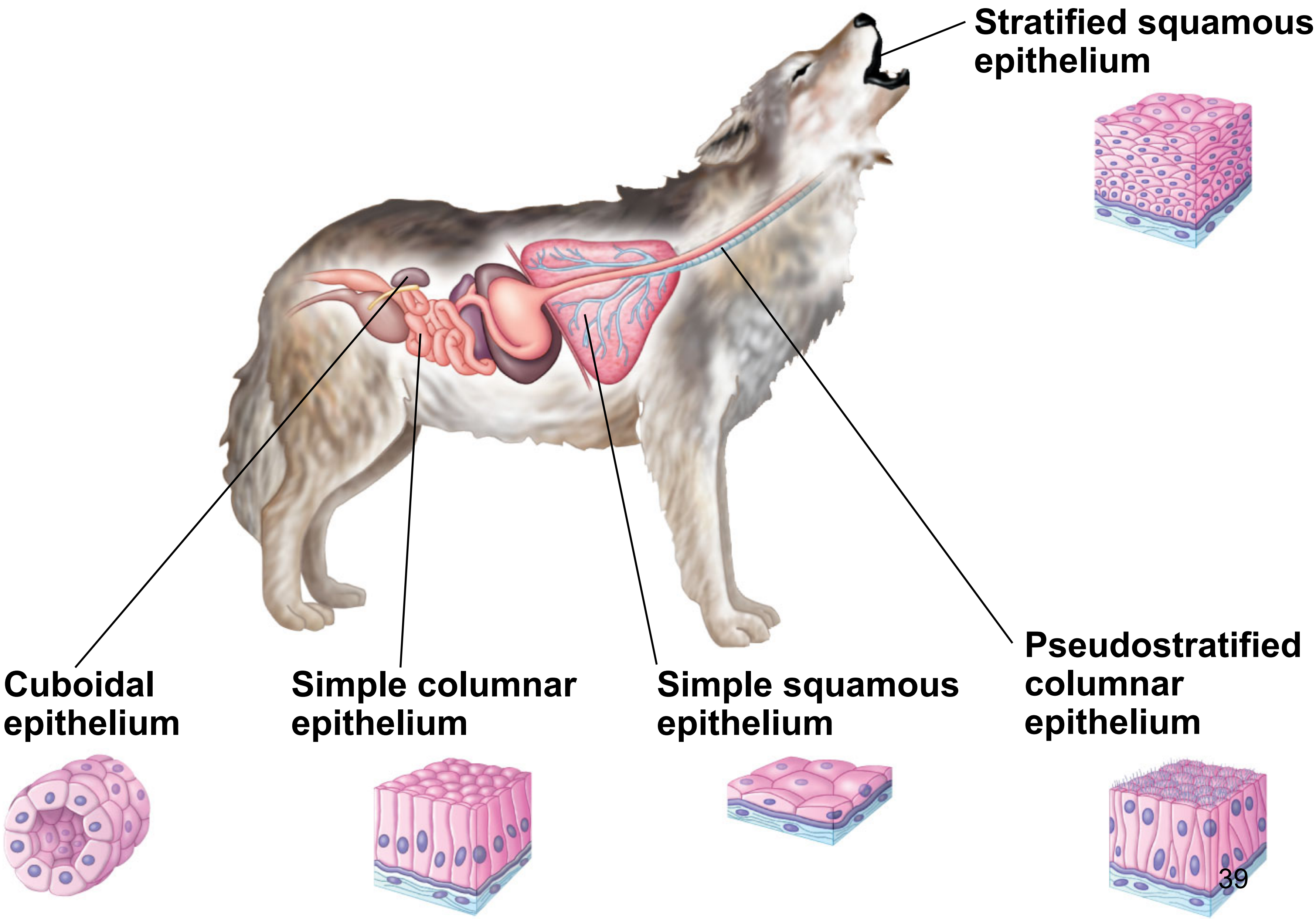
## Epithelial Tissue

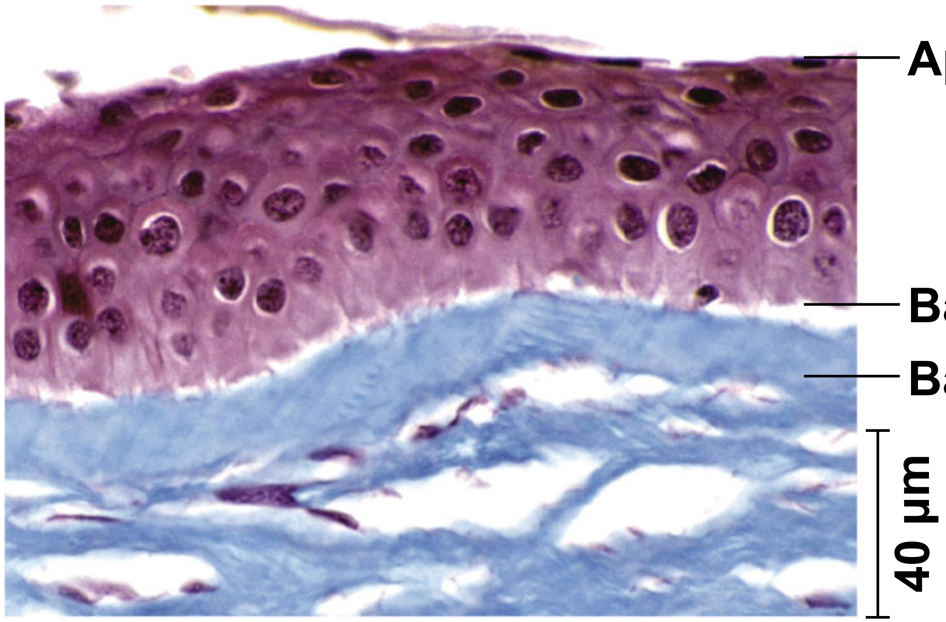
- **Epithelial tissue** covers the outside of the body and lines the organs and cavities within the body
- It contains cells that are closely joined
- The shape of epithelial cells may be cuboidal (like dice), columnar (like bricks on end), or squamous (like floor tiles)

- The arrangement of epithelial cells may be simple (single cell layer), stratified (multiple tiers of cells), or pseudostratified (a single layer of cells of varying length)

Figure 40.5aa

# Epithelial Tissue






Polarity of epithelia

## 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

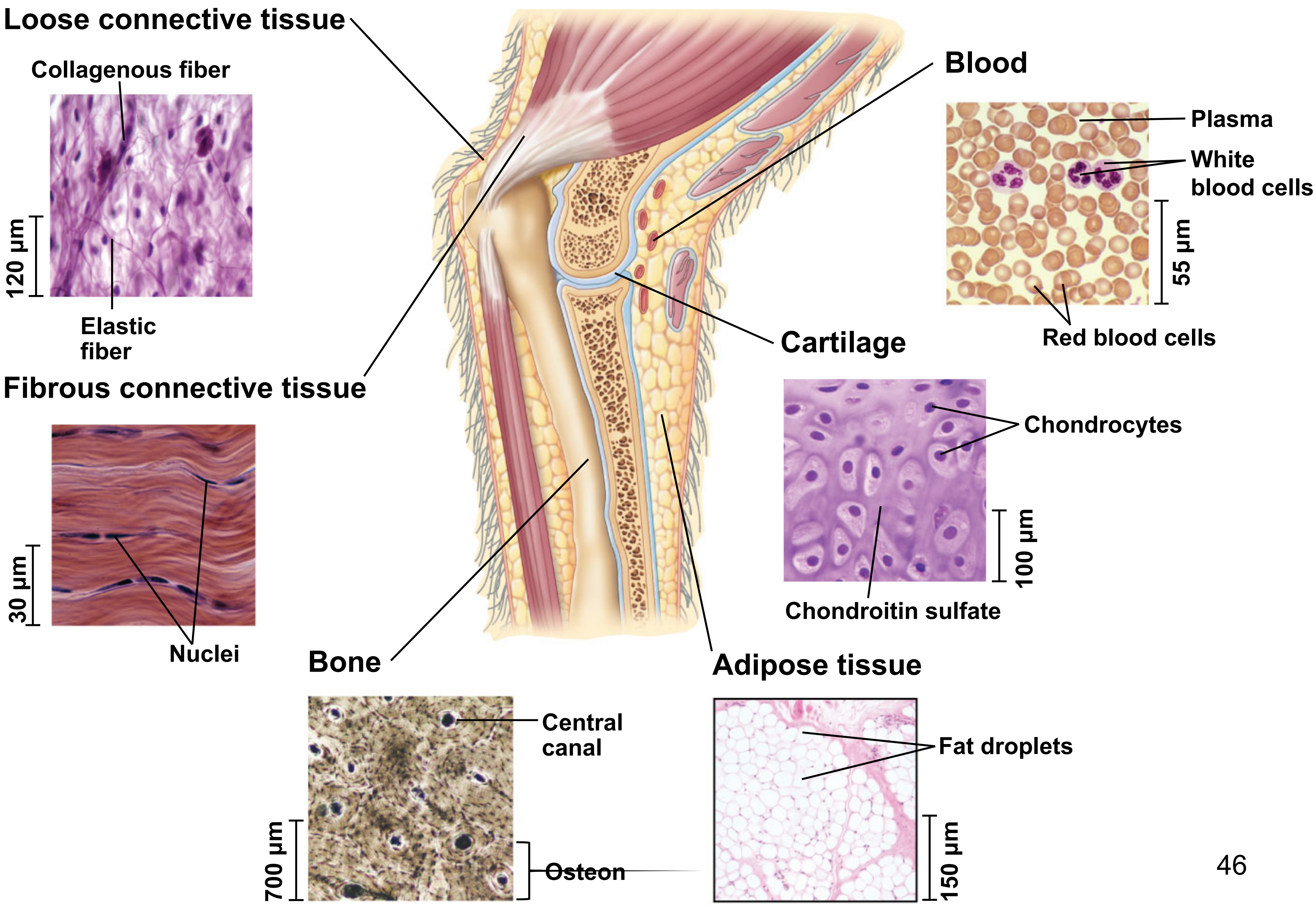
- There are three types of connective tissue fiber, all made of protein:
  - Collagenous fibers provide strength and flexibility
  - Elastic fibers stretch and snap back to their original length
  - Reticular fibers join connective tissue to adjacent tissues

- Connective tissue contains cells, including
  - **Fibroblasts** that secrete the protein of extracellular fibers
  - **Macrophages** that are involved in the immune system

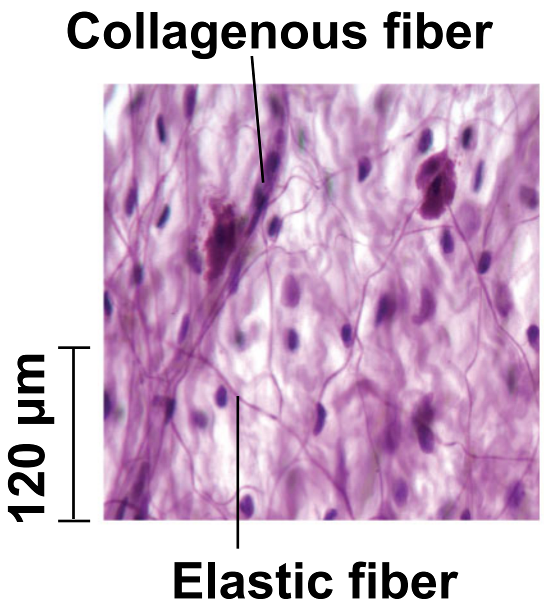
- In vertebrates, the fibers and foundation combine to form six major types of connective tissue:
  - Loose connective tissue binds epithelia to underlying tissues and holds organs in place
  - **Cartilage** is a strong and flexible support material
  - Fibrous connective tissue is found in **tendons**, which attach muscles to bones, and **ligaments**, which connect bones at joints

- **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

# Connective Tissue



# Loose connective tissue



## Fibrous connective tissue

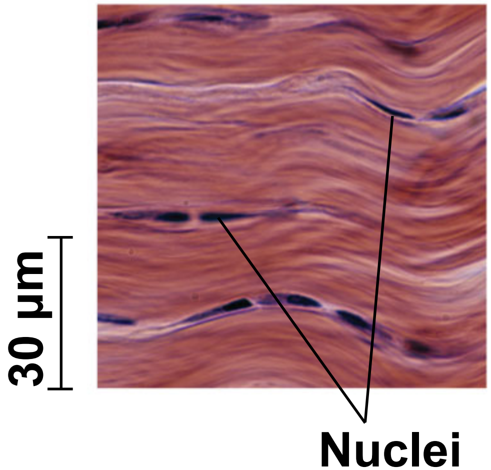
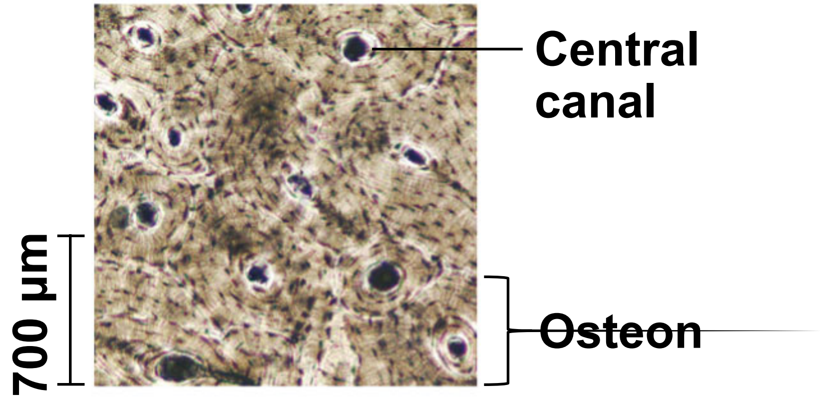
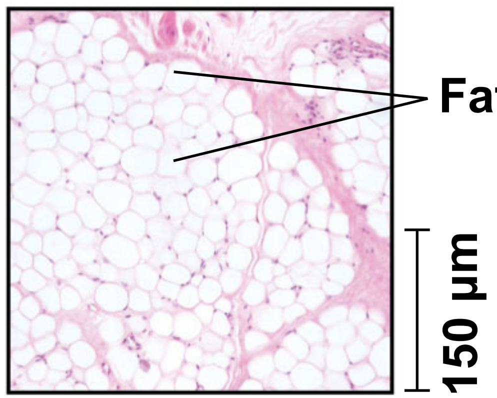


Figure 40.5bd

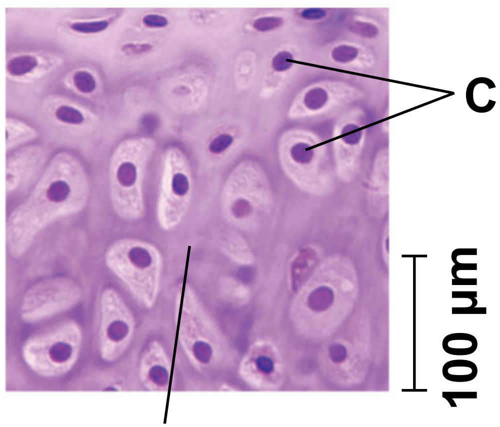
## Bone



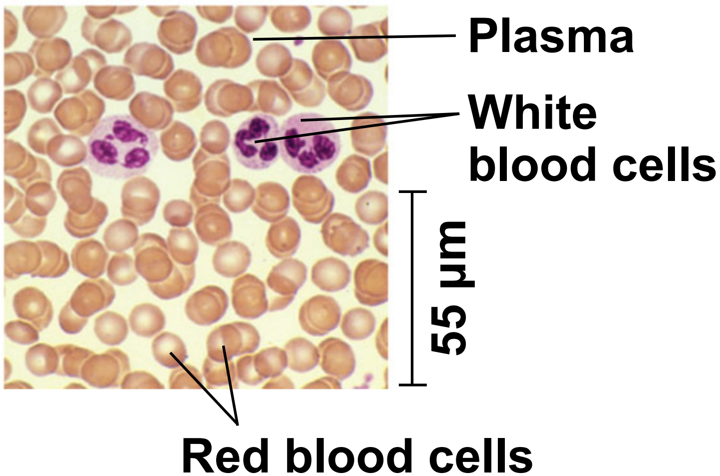
## Adipose tissue



# Cartilage



# Blood

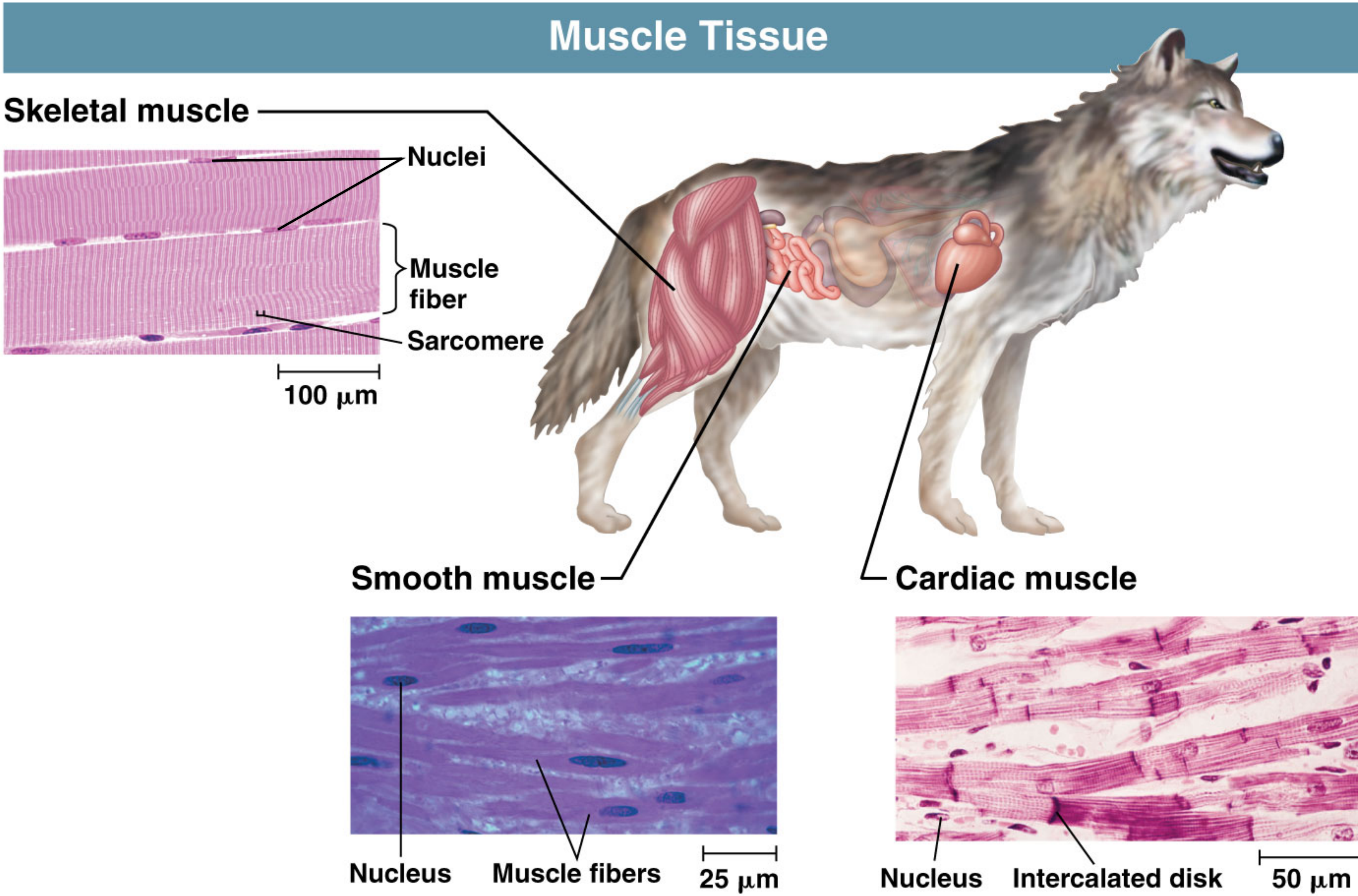


## Muscle Tissue

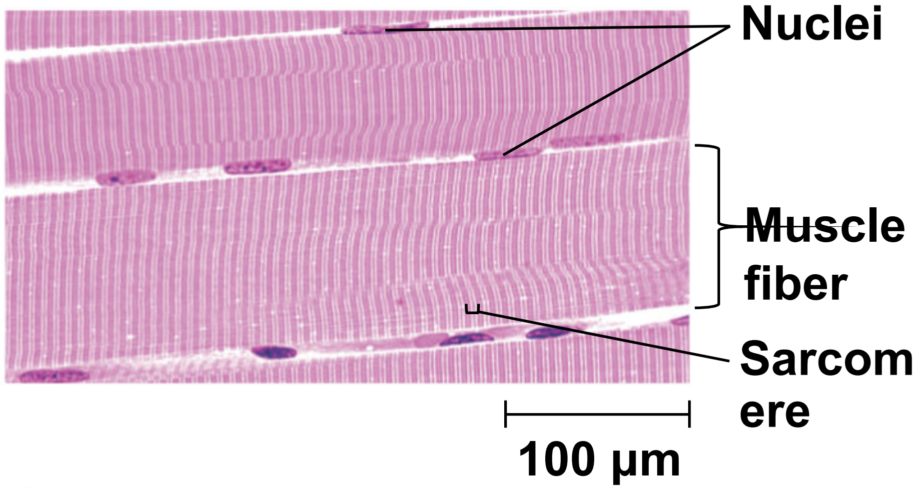
- **Muscle tissue** consists of long cells called muscle fibers, which contract in response to nerve signals

- It is divided in the vertebrate body into three types:
  - **Skeletal muscle**, or striated muscle, is responsible for voluntary movement
  - **Smooth muscle** is responsible for involuntary body activities
  - **Cardiac muscle** is responsible for contraction of the heart

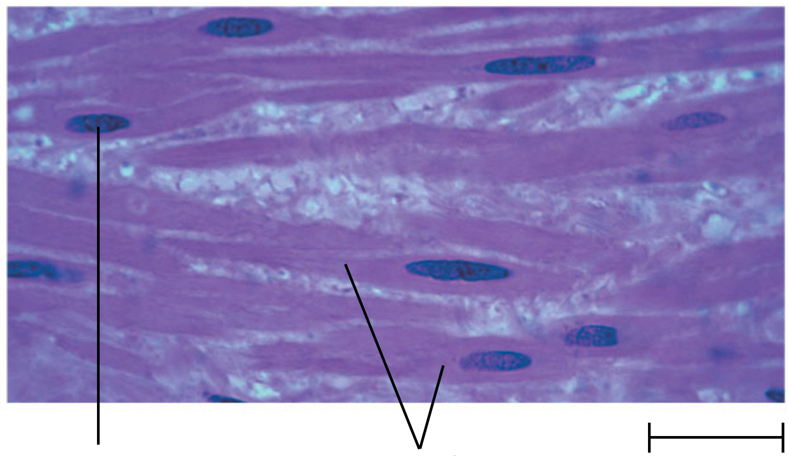
Figure 40.5ca



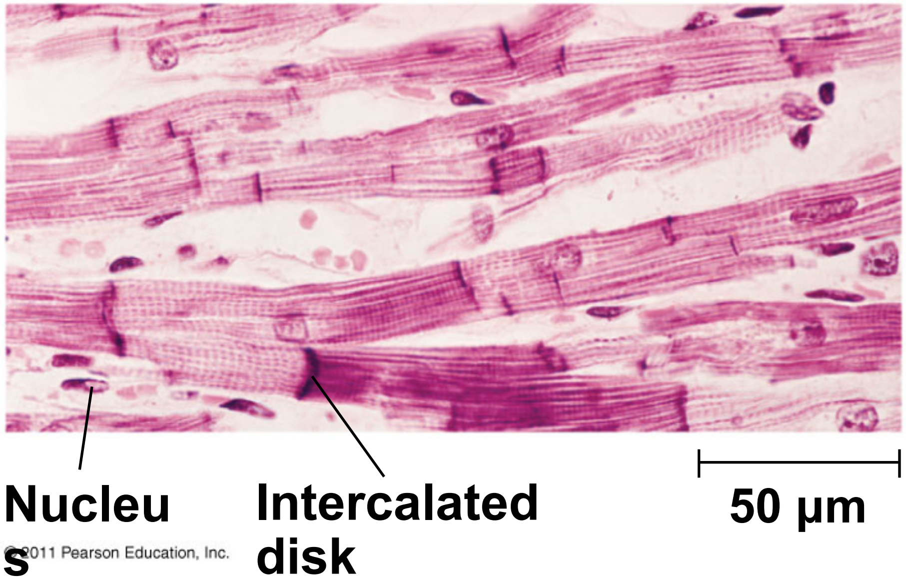
## Skeletal muscle



## Smooth muscle



# Cardiac muscle

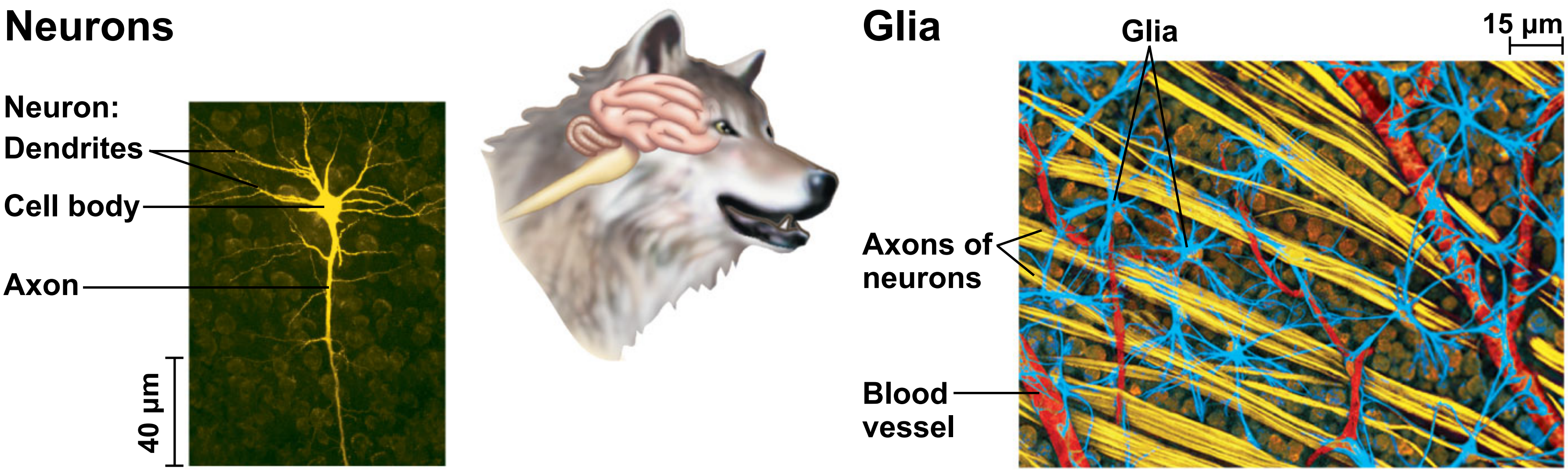


## Nervous Tissue

- **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

Figure 40.5da

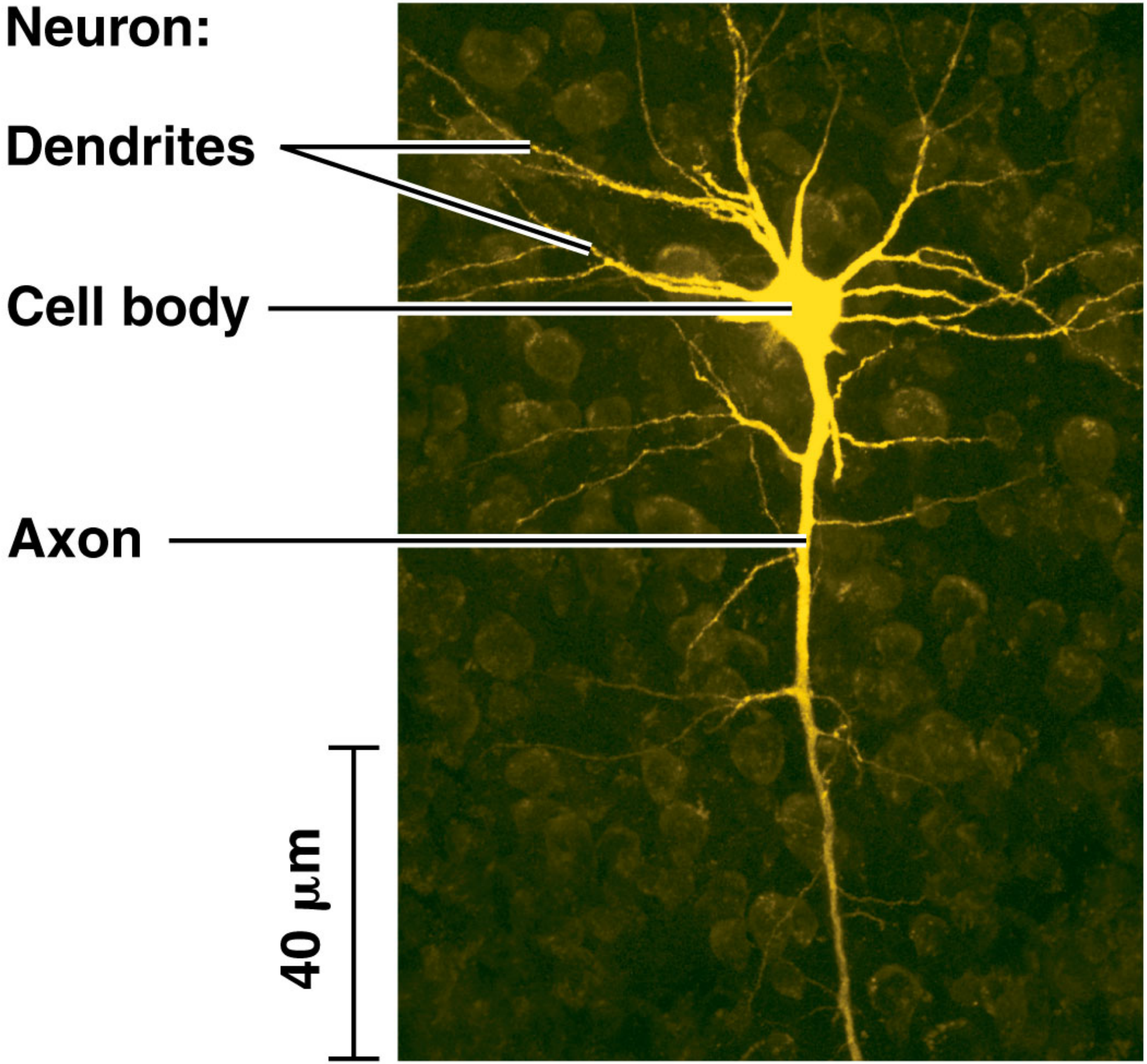
# Nervous Tissue



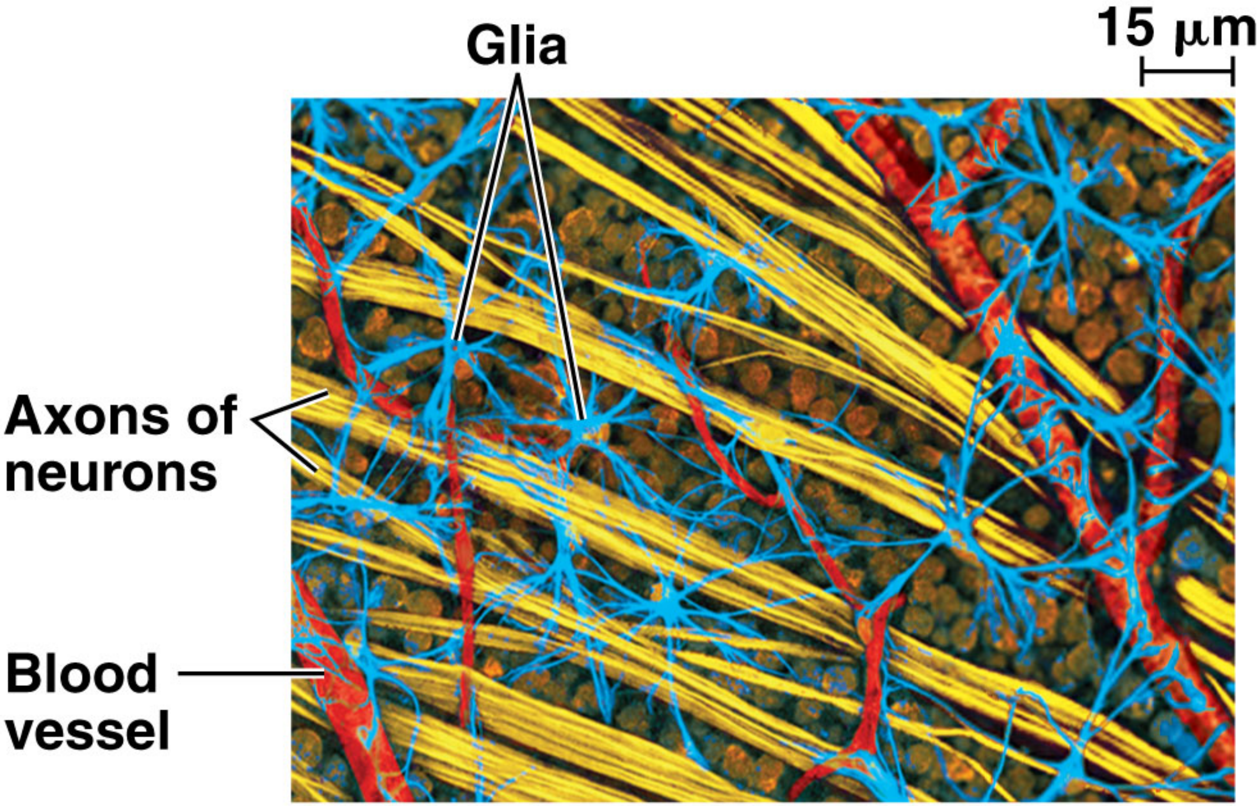

(Fluorescent LM)

(Confocal LM)

Figure 40.5db




(Fluorescent LM)




(Confocal LM)

# 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

Figure 40.6

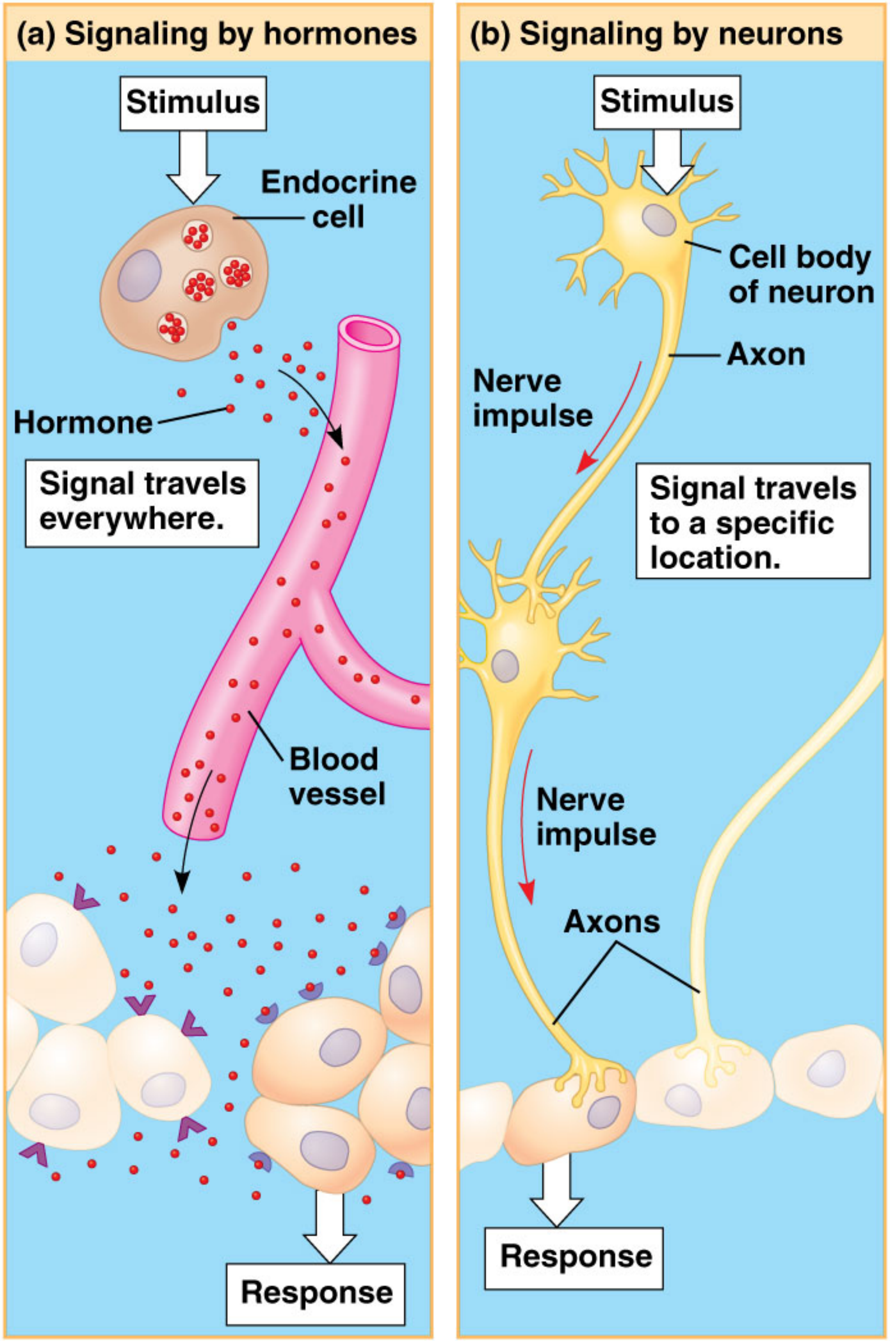
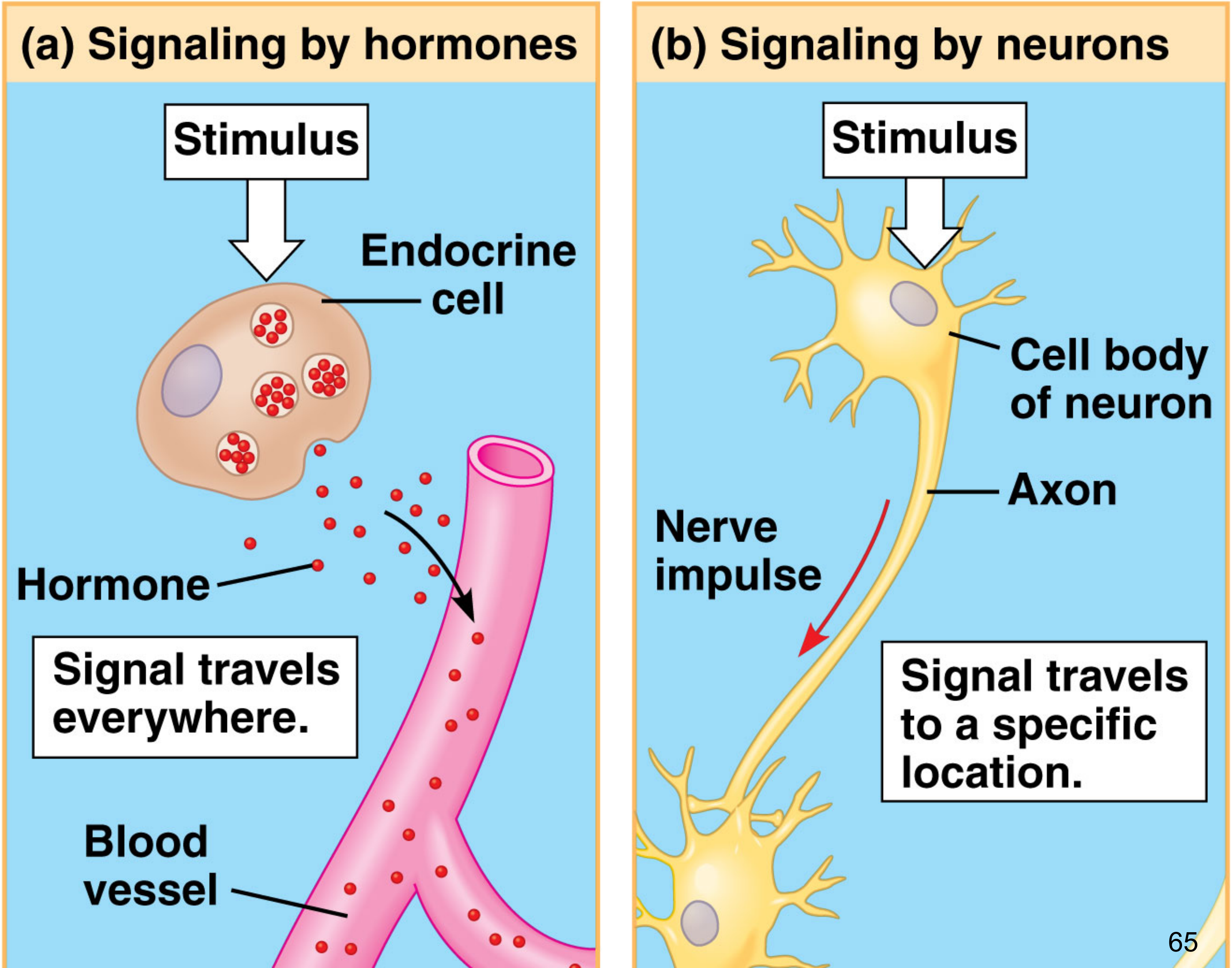
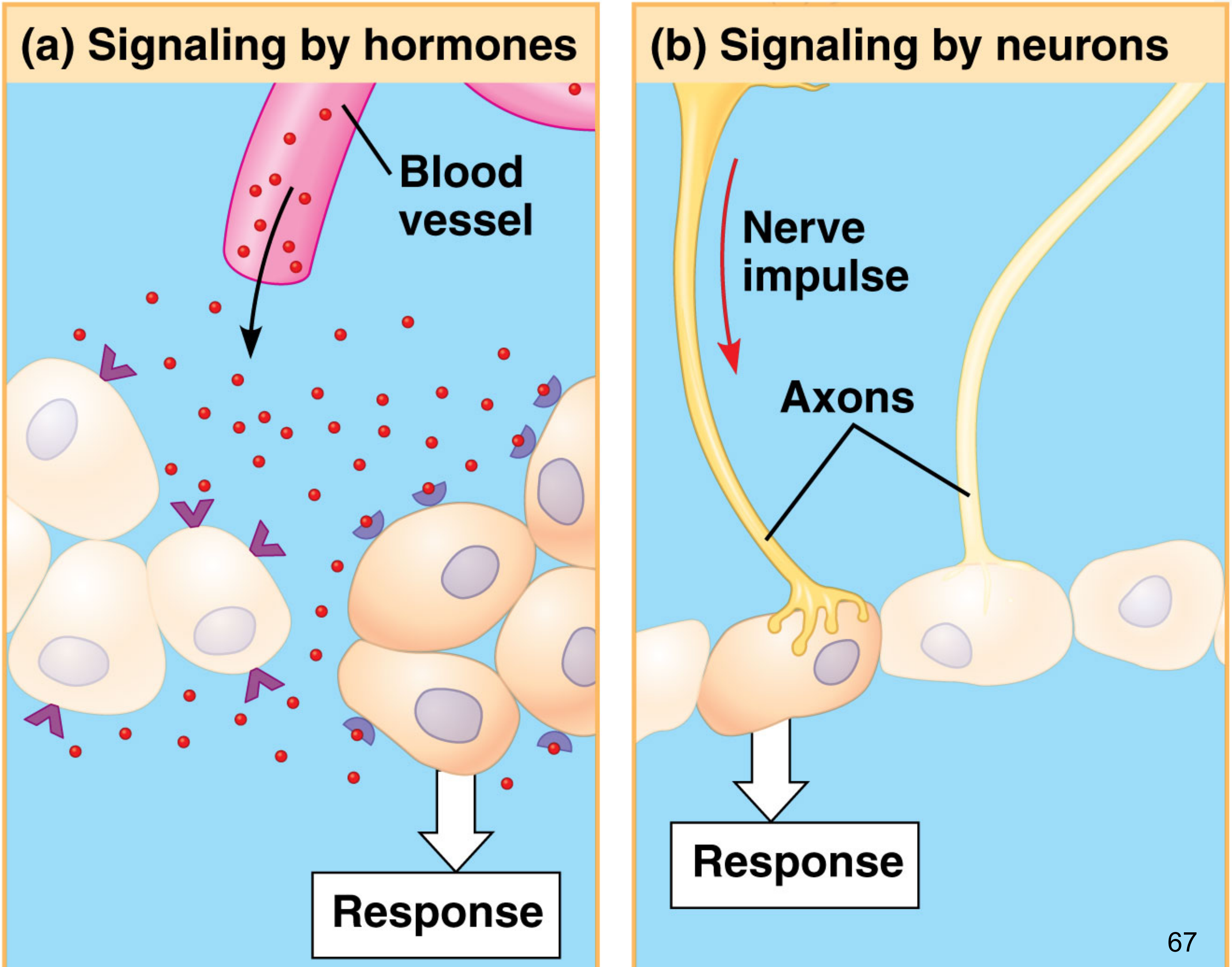

(a) Signaling by hormones
Stimulus
Endocrine cell
Hormone
Signal travels everywhere.
Blood vessel
Response
(b) Signaling by neurons
Stimulus
Cell body of neuron
Axon
Nerve impulse
Signal travels to a specific location.
Nerve impulse
Axons
Response

Figure 40.6a


(a) Signaling by hormones
Stimulus
Endocrine cell
Hormone
Signal travels everywhere.
Blood vessel
(b) Signaling by neurons
Stimulus
Cell body of neuron
Axon
Nerve impulse
Signal travels to a specific location.

- 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, endocrine cells, and exocrine cells

Figure 40.6b



(a) Signaling by hormones
Blood vessel
Response
(b) Signaling by neurons
Nerve impulse
Axons
Response

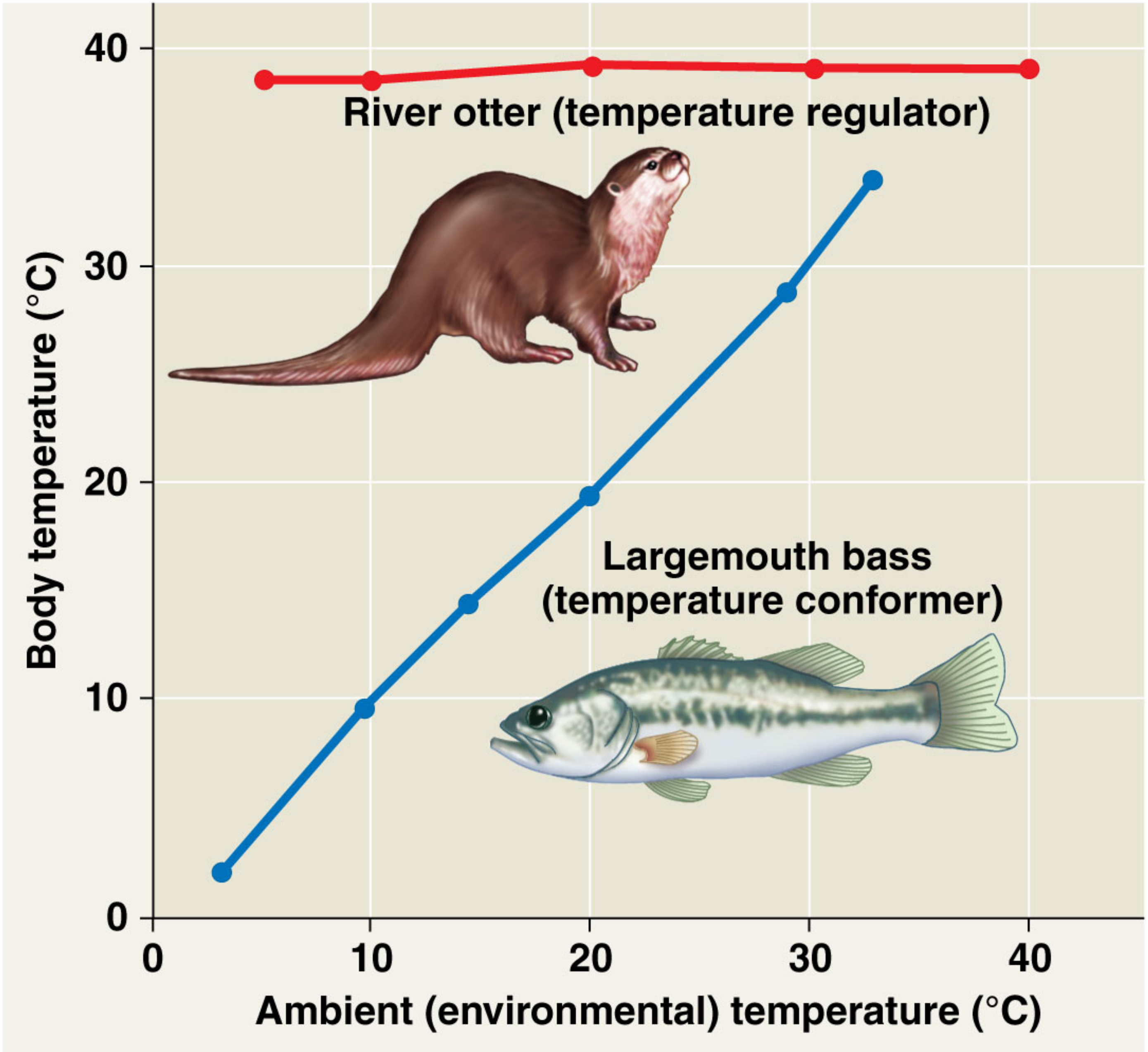
# Concept 40.2: Feedback control maintains the internal environment in many animals

- Animals manage their internal environment by regulating or conforming to the external environment

# Regulating and Conforming

- 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
- Animals may regulate some environmental variables while conforming to others

Figure 40.7



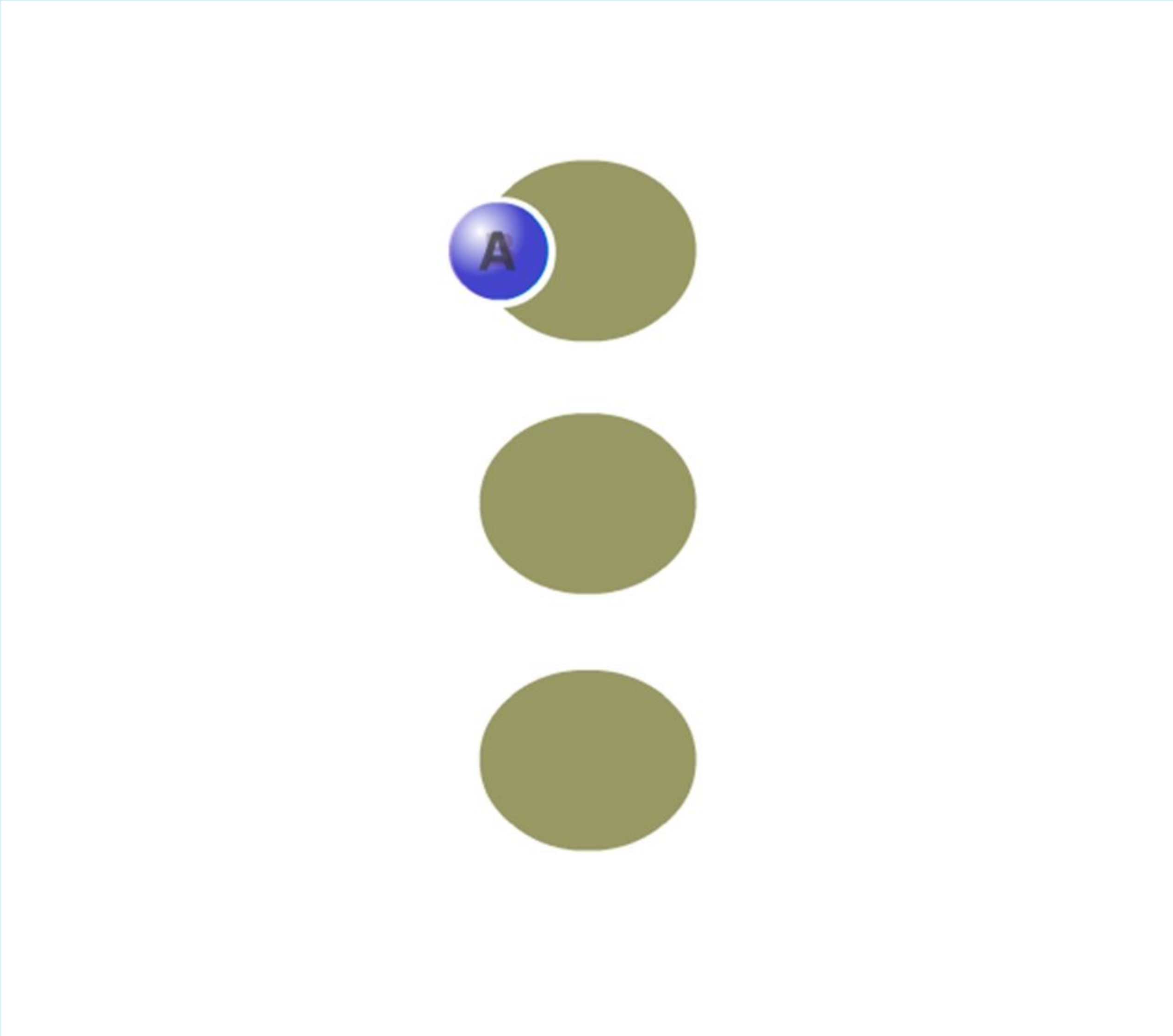
River otter (temperature regulator)
Largemouth bass
(temperature conformer)
Body temperature (°C)
Ambient (environmental) temperature (°C)
0
10
20
30
40
0
10
20
30
40

# Homeostasis

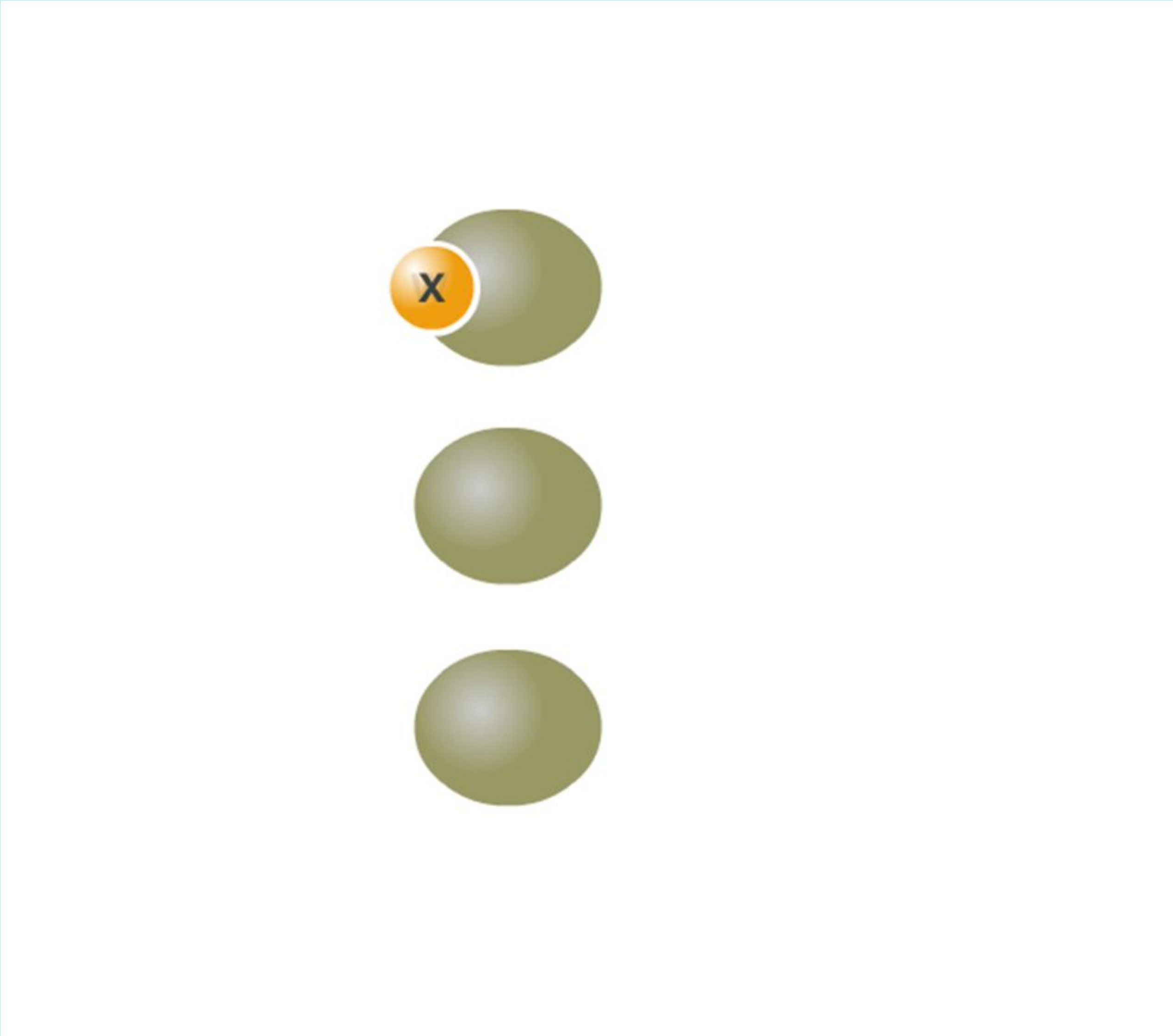
- Organisms use **homeostasis** to maintain a "steady state" or internal balance regardless of external environment
- In humans, body temperature, blood pH, and glucose concentration are each maintained at a constant level

# *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

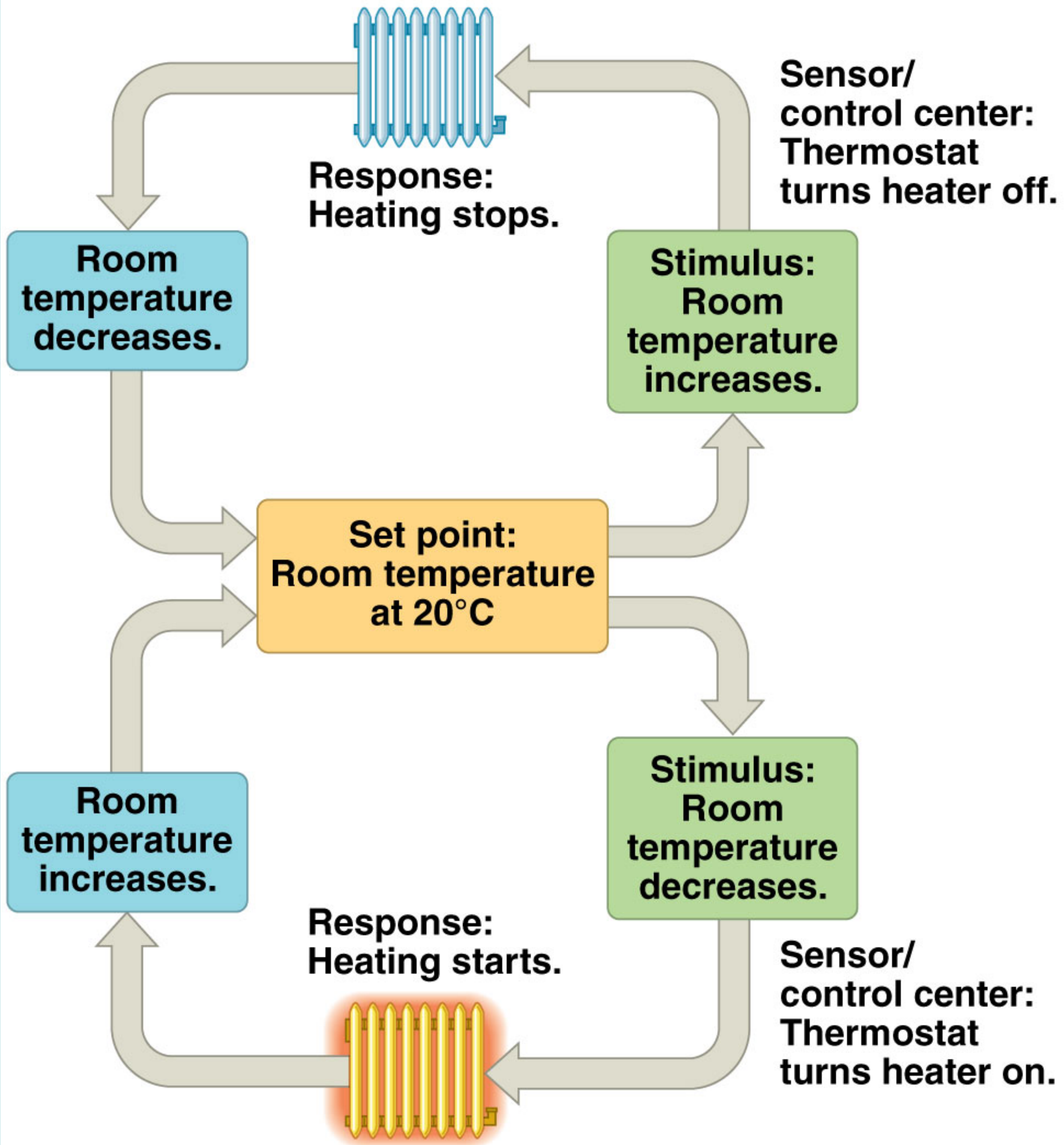



Animation: Negative Feedback
Right-click slide / select "Play"




Animation: Positive Feedback
Right-click slide / select “Play”

Figure 40.8


Sensor/
control center:
Thermostat
turns heater off.
Response:
Heating stops.
Room
temperature
decreases.
Stimulus:
Room
temperature
increases.
Set point:
Room temperature
at 20°C
Room
temperature
increases.
Stimulus:
Room
temperature
decreases.
Response:
Heating starts.
Sensor/
control center:
Thermostat
turns heater on.

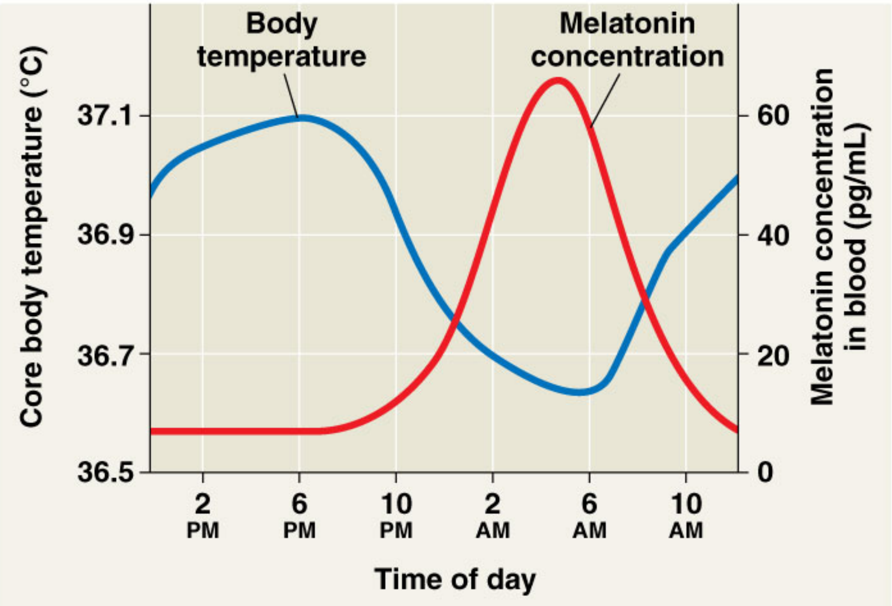
# *Feedback Control in Homeostasis*

- The dynamic equilibrium of homeostasis is maintained by **negative feedback,** which helps to return a variable to a normal range
- Most homeostatic control systems function by negative feedback, where buildup of the end product shuts the system off
- **Positive feedback** amplifies a stimulus and does not usually contribute to homeostasis in animals

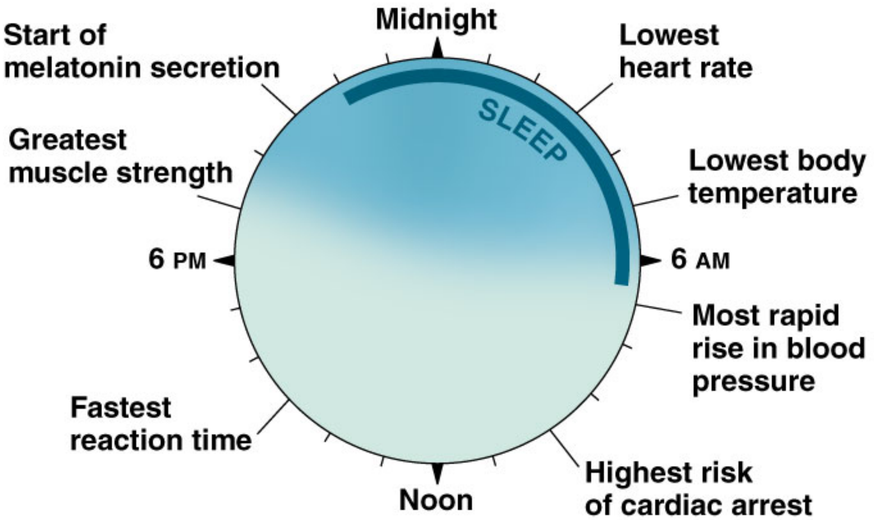
# *Alterations in Homeostasis*

- Set points and normal ranges can change with age or show cyclic variation
- In animals and plants, a **circadian rhythm** governs physiological changes that occur roughly every 24 hours

Figure 40.9

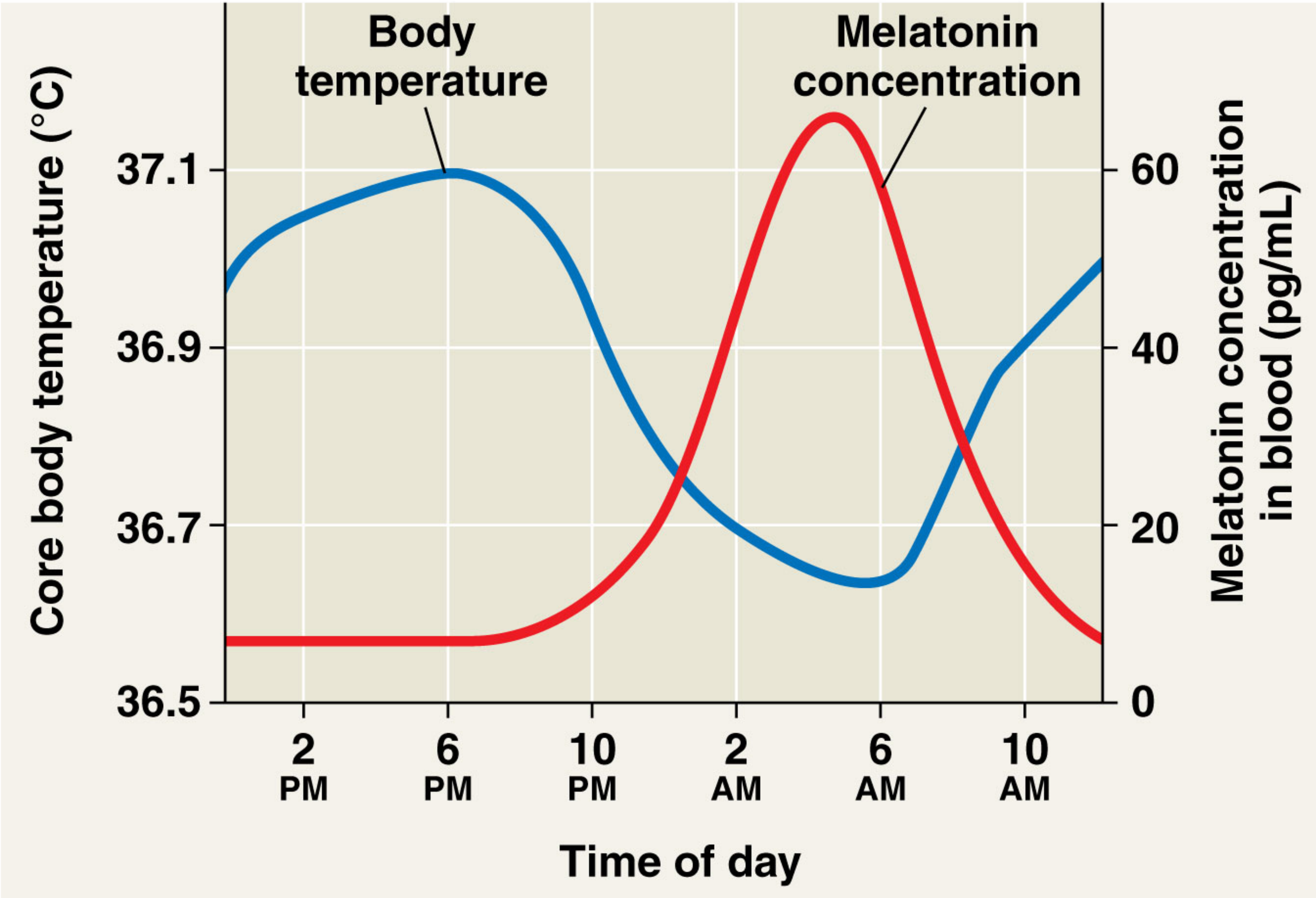



(a) Variation in core body temperature and melatonin concentration in blood

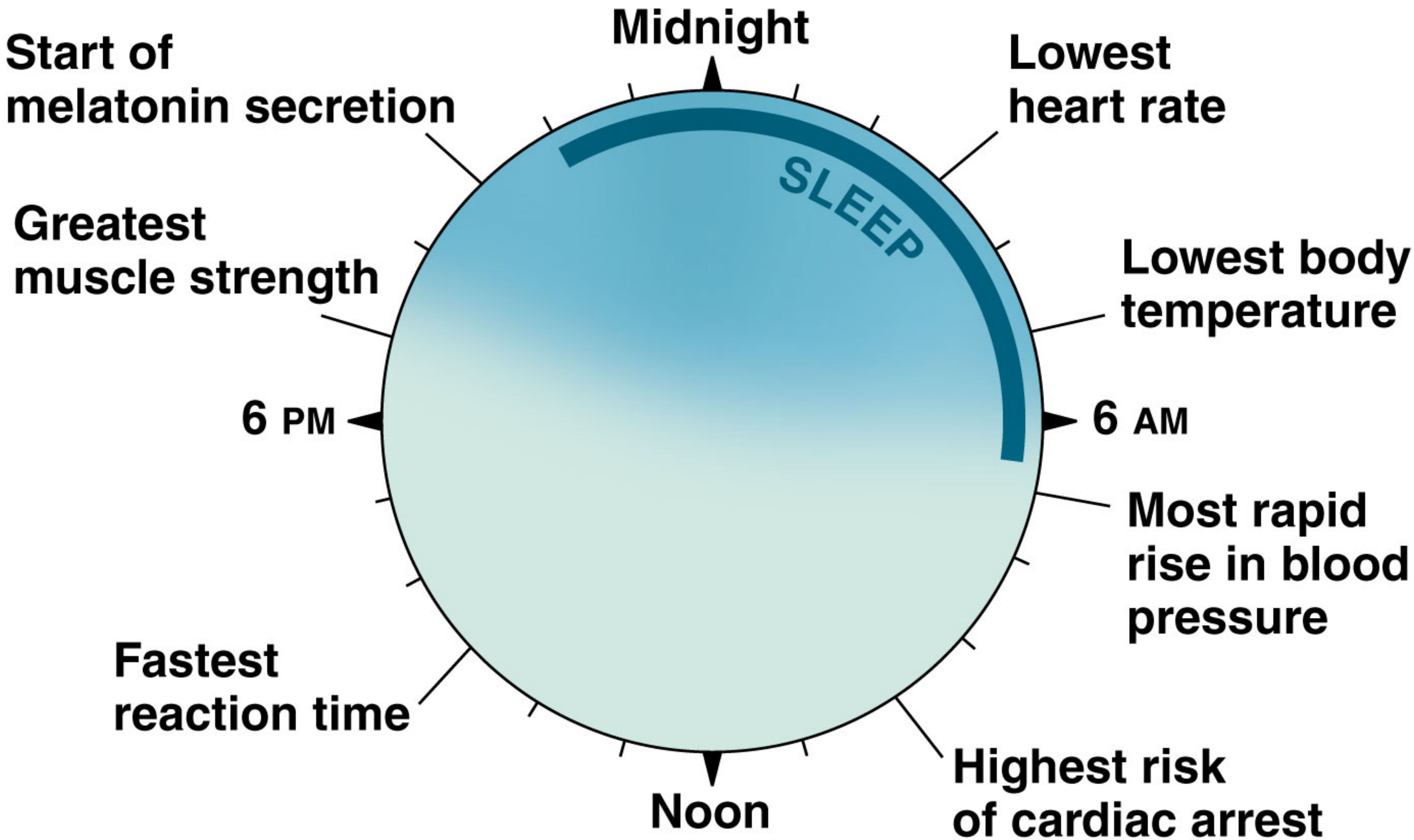



(b) The human circadian clock

Figure 40.9a




**(a) Variation in core body temperature and melatonin concentration in blood**




(b) The human circadian clock

- Homeostasis can adjust to changes in external environment, a process called **acclimatization**

# Concept 40.3: Homeostatic processes for thermoregulation involve form, function, and behavior

- **Thermoregulation** is the process by which animals maintain an internal temperature within a tolerable range

# Endothermy and Ectothermy

- **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 nonavian reptiles

- 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

Figure 40.10

(a) A walrus, an endotherm

(b) A lizard, an ectotherm

Figure 40.10a

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

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

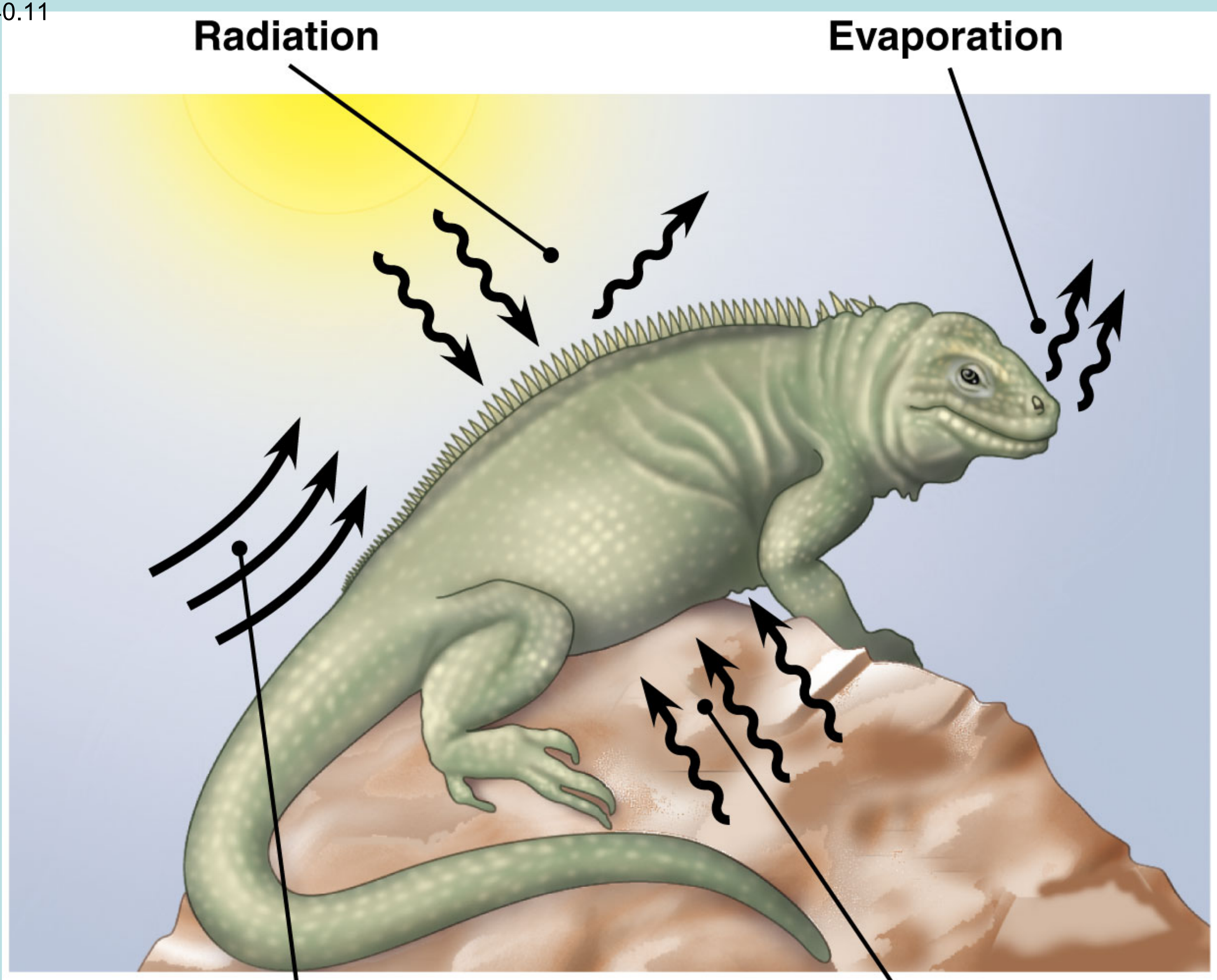
# Variation in Body Temperature

- The body temperature of a poikilotherm varies with its environment
- The body temperature of a homeotherm is relatively constant
- The relationship between heat source and body temperature is not fixed (that is, not all poikilotherms are ectotherms)

# Balancing Heat Loss and Gain

- Organisms exchange heat by four physical processes: radiation, evaporation, convection, and conduction

Figure 40.11



- Heat regulation in mammals often involves the **integumentary system**: skin, hair, and nails
- Five adaptations help animals thermoregulate:
  - Insulation
  - Circulatory adaptations
  - Cooling by evaporative heat loss
  - Behavioral responses
  - Adjusting metabolic heat production

# *Insulation*

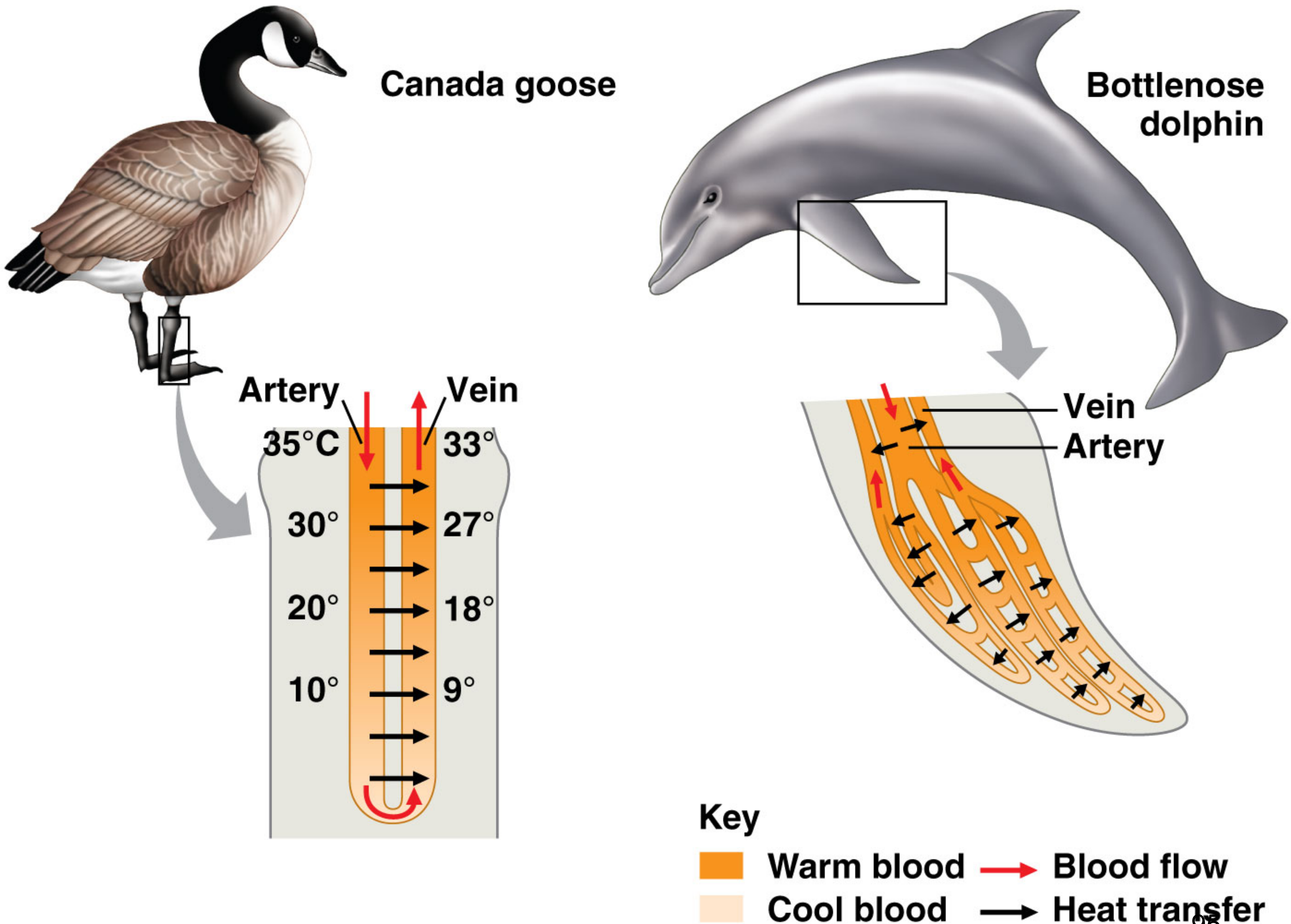
- Insulation is a major thermoregulatory adaptation in mammals and birds
- Skin, feathers, fur, and blubber reduce heat flow between an animal and its environment
- Insulation is especially important in marine mammals such as whales and walruses

# *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

- 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 and reduce heat loss

Figure 40.12


Canada goose
Artery
Vein
35°C
33°
30°
27°
20°
18°
10°
9°
Bottlenose dolphin
Vein
Artery
Key
Warm blood
Cool blood
Blood flow
Heat transfer

- Some bony fishes and sharks also use countercurrent heat exchanges
- Many endothermic insects have countercurrent heat exchangers that help maintain a high temperature in the thorax

# *Cooling by Evaporative Heat Loss*

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

# *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

Figure 40.13

# *Adjusting Metabolic Heat Production*

- Thermogenesis is the adjustment of metabolic heat production to maintain body temperature
- Thermogenesis is increased by muscle activity such as moving or shivering
- Nonshivering thermogenesis takes place when hormones cause mitochondria to increase their metabolic activity
- Some ectotherms can also shiver to increase body temperature

Figure 40.14

# EXPERIMENT

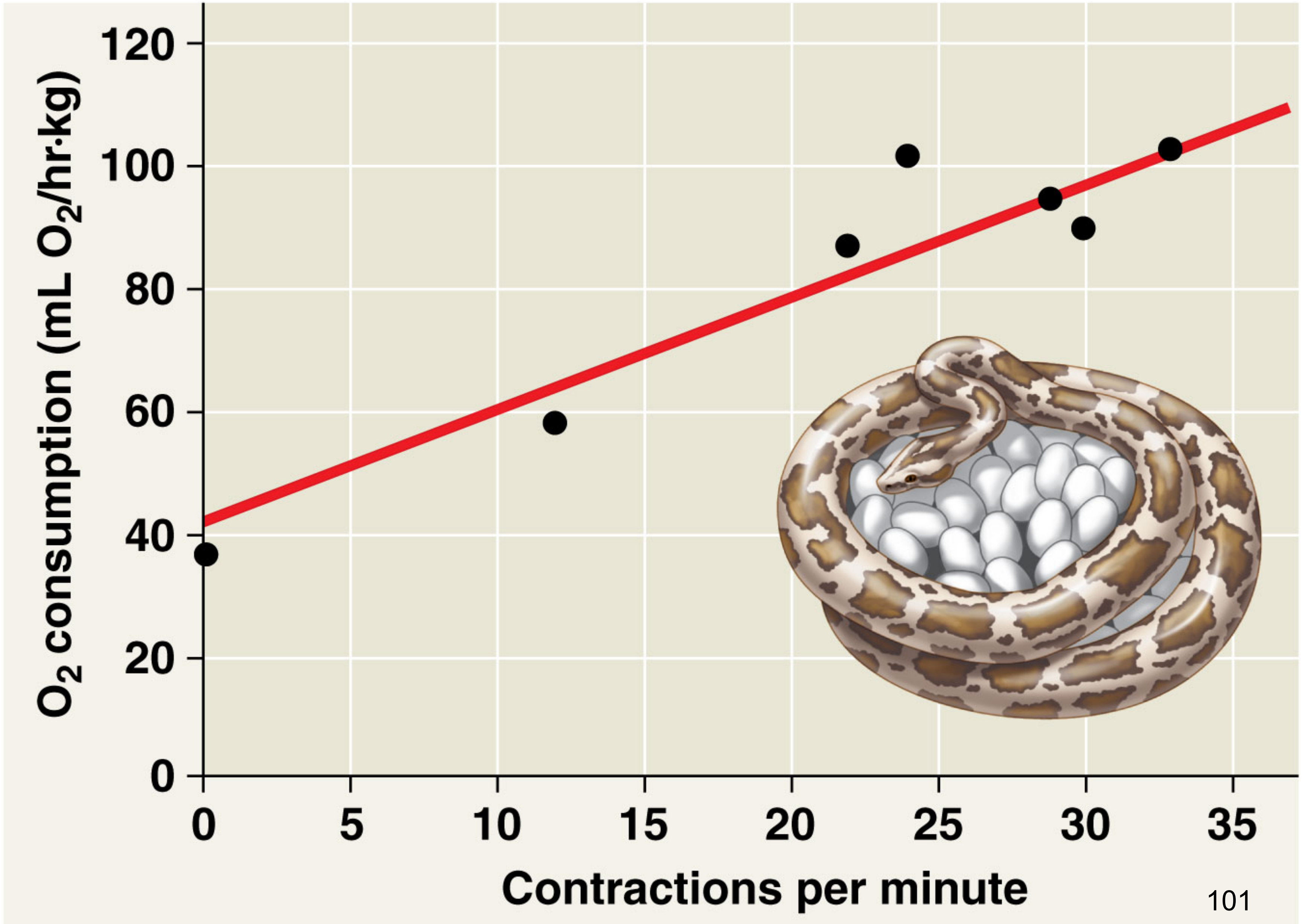
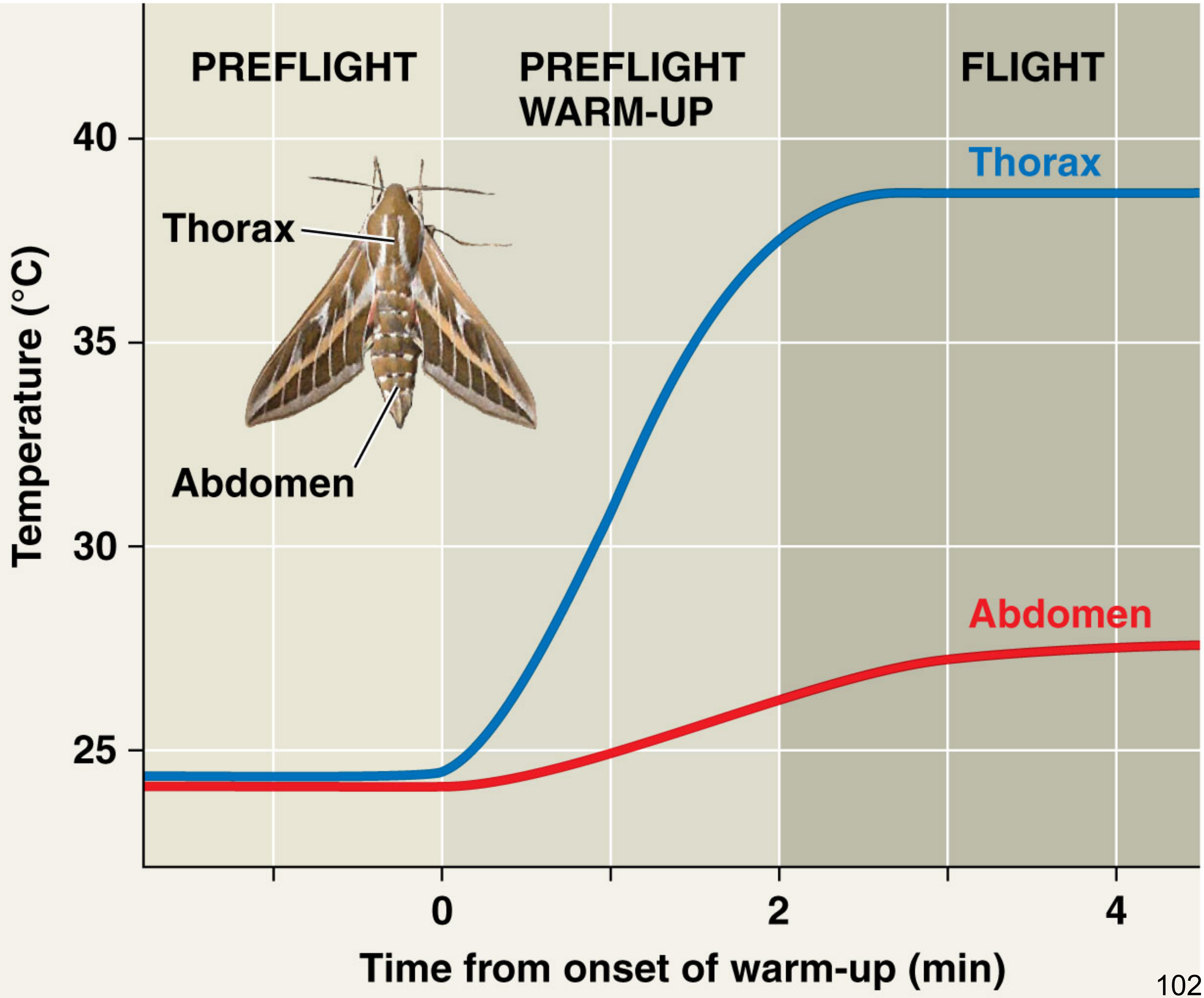


Figure 40.15



PREFLIGHT
PREFLIGHT WARM-UP
FLIGHT
Thorax
Abdomen
Thorax
Abdomen
Temperature (°C)
40
35
30
25
0
2
4
Time from onset of warm-up (min)

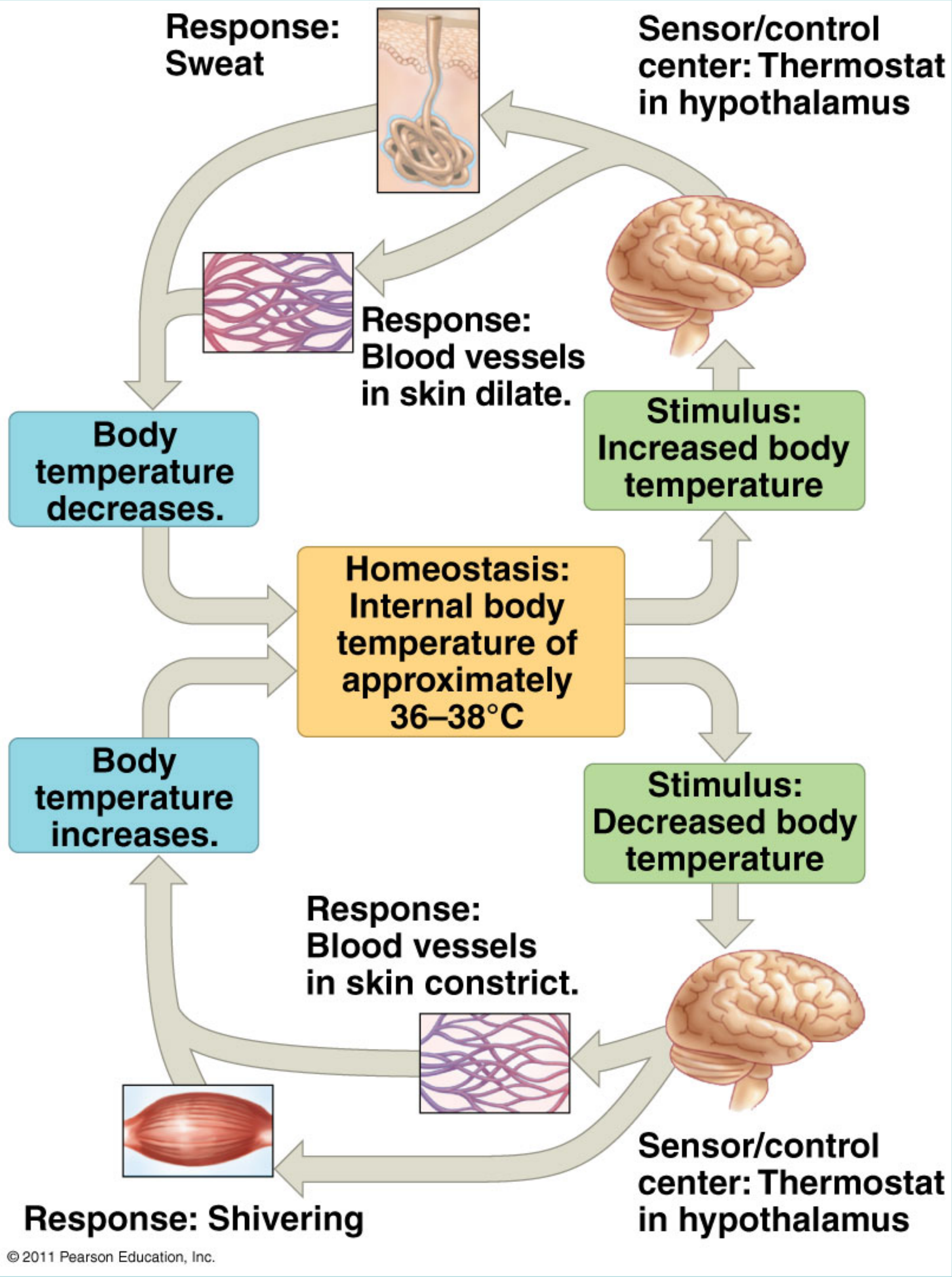
# Acclimatization in Thermoregulation

- 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

# Physiological Thermostats and Fever

- 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

Figure 40.16


Response: Sweat
Sensor/control center: Thermostat in hypothalamus
Response: Blood vessels in skin dilate.
Body temperature decreases.
Stimulus: Increased body temperature
Homeostasis: Internal body temperature of approximately 36–38°C
Body temperature increases.
Stimulus: Decreased body temperature
Response: Blood vessels in skin constrict.
Response: Shivering
Sensor/control center: Thermostat in hypothalamus
© 2011 Pearson Education, Inc.

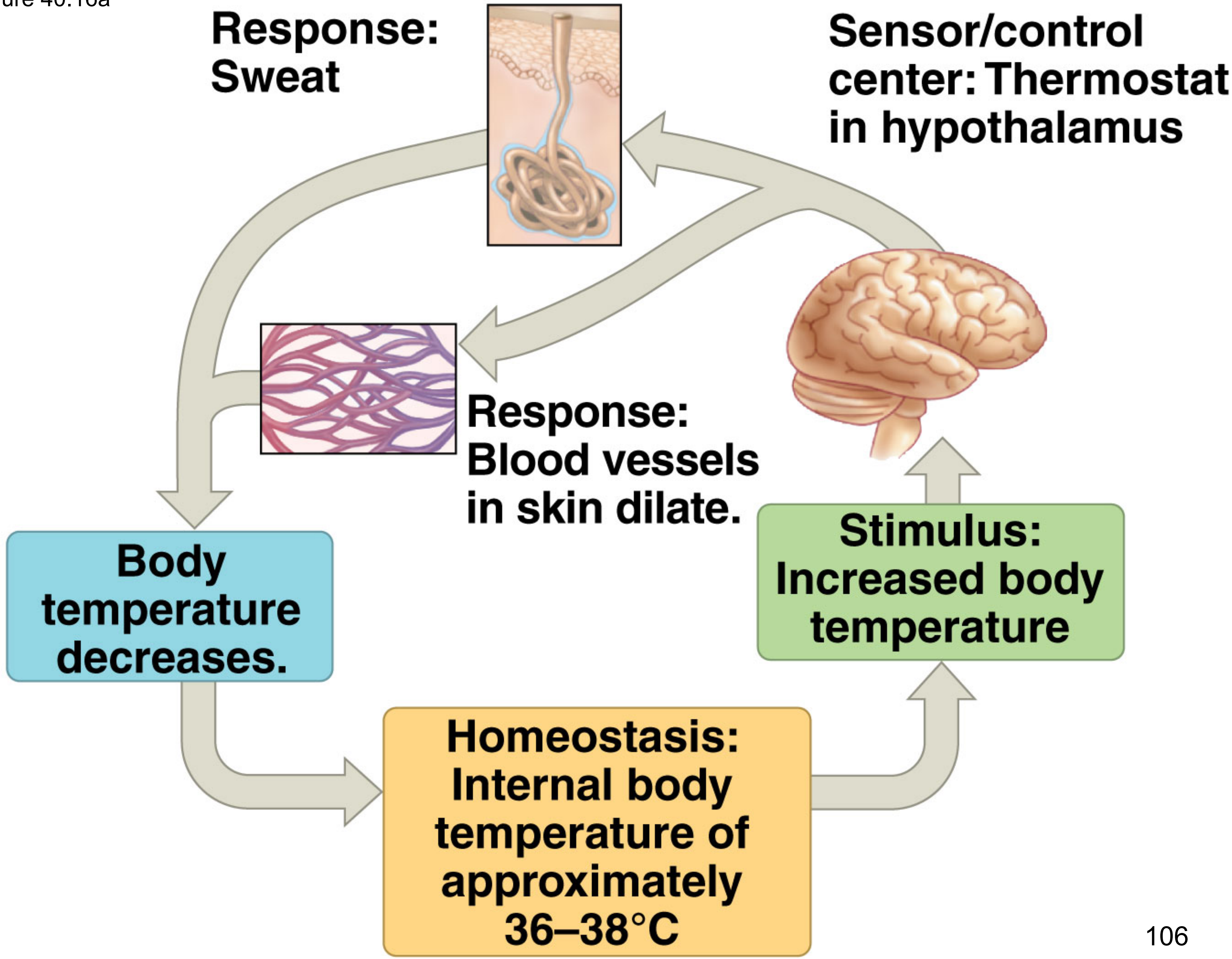
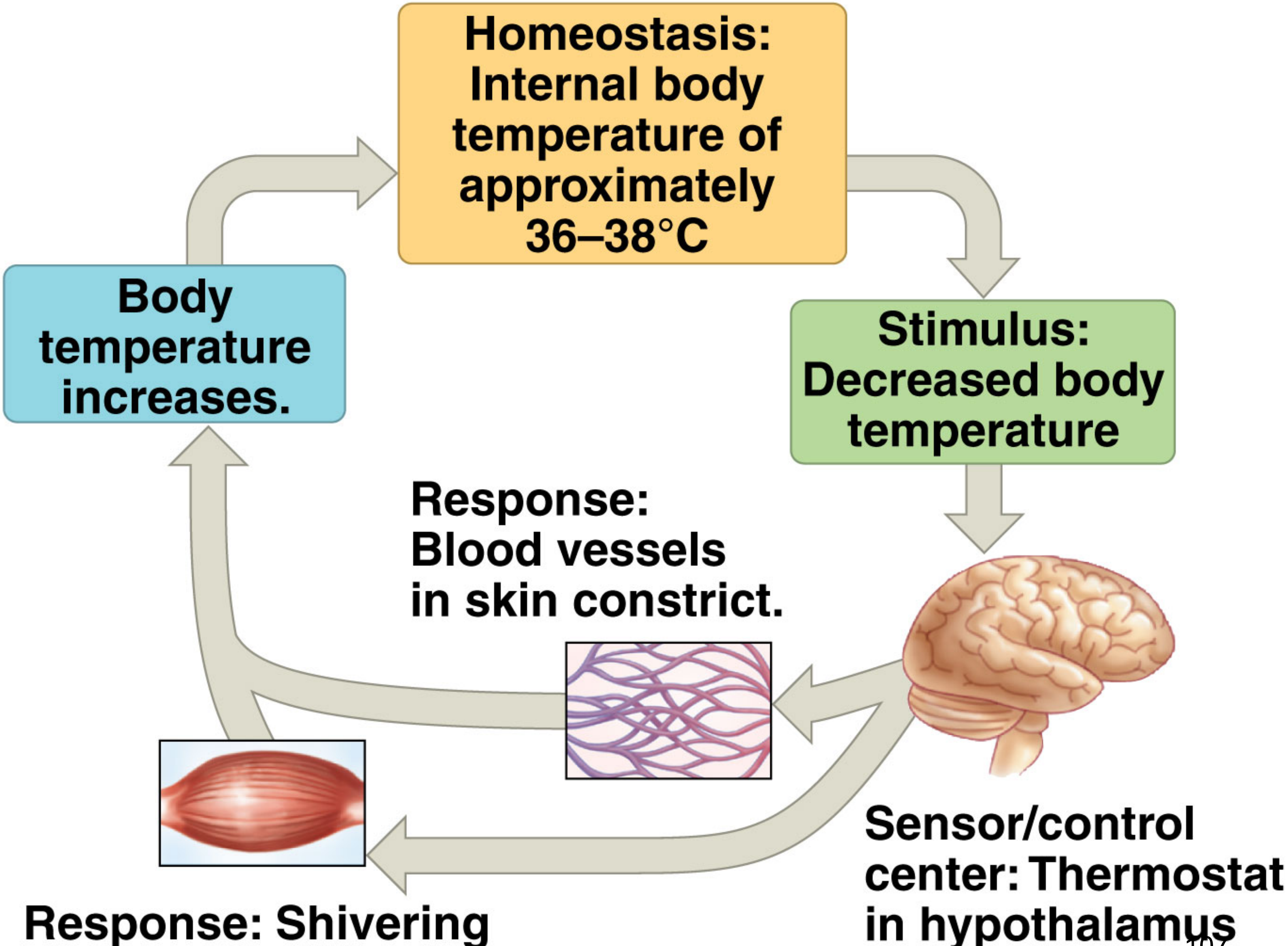

Response:
Sweat
Sensor/control
center: Thermostat
in hypothalamus
Response:
Blood vessels
in skin dilate.
Body
temperature
decreases.
Stimulus:
Increased body
temperature
Homeostasis:
Internal body
temperature of
approximately
36–38°C

Figure 40.16b



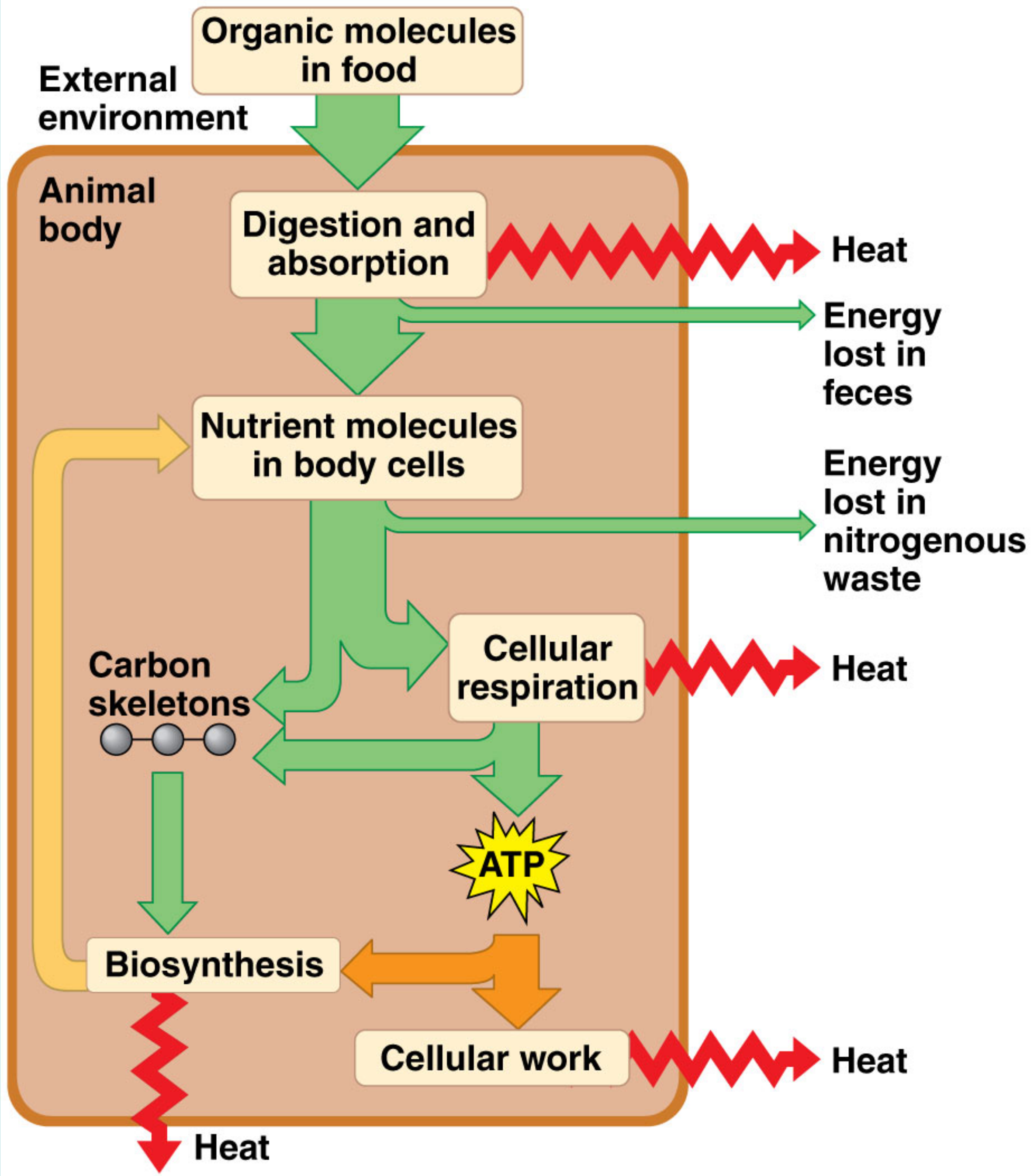
# Concept 40.4: Energy requirements are related to animal size, activity, and environment

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

# 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

Figure 40.17

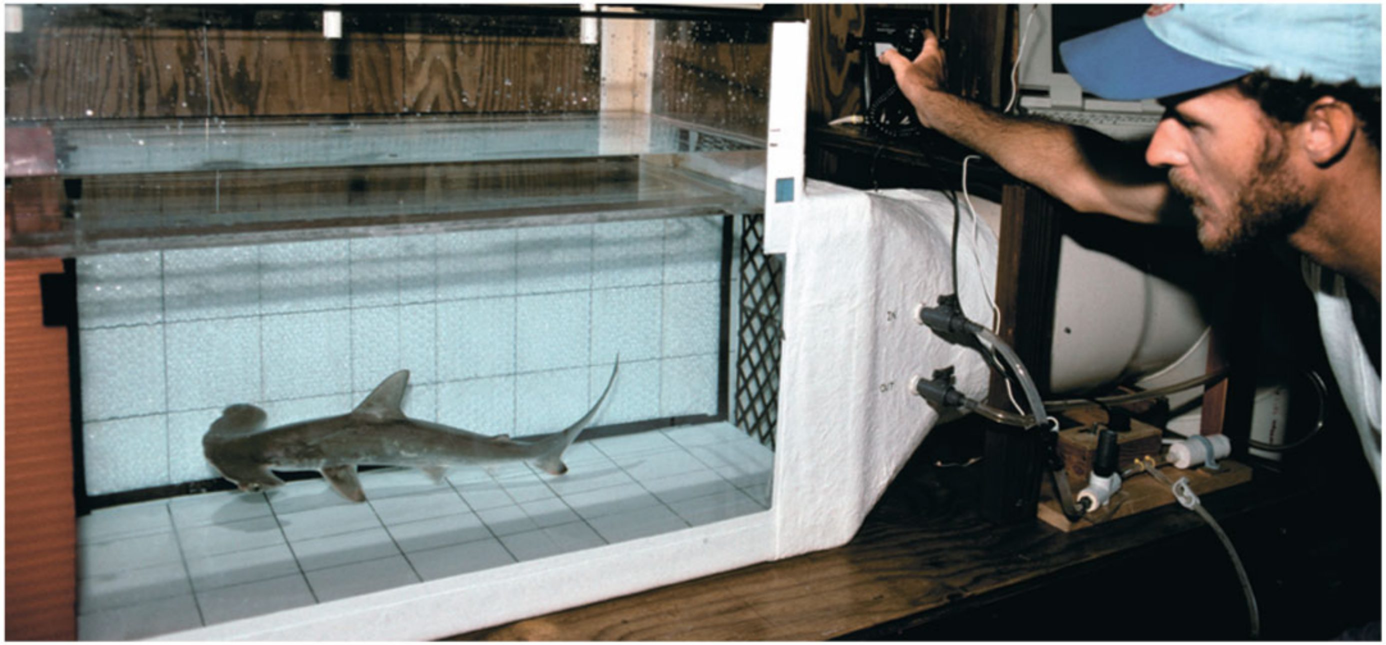


Organic molecules in food
External environment
Animal body
Digestion and absorption
Heat
Energy lost in feces
Nutrient molecules in body cells
Energy lost in nitrogenous waste
Carbon skeletons
Cellular respiration
Heat
ATP
Biosynthesis
Cellular work
Heat
Heat

# Quantifying Energy Use

- **Metabolic rate** is the amount of energy an animal uses in a unit of time
- Metabolic rate can be determined by
  - An animal's heat loss
  - The amount of oxygen consumed or carbon dioxide produced

Figure 40.18



# 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

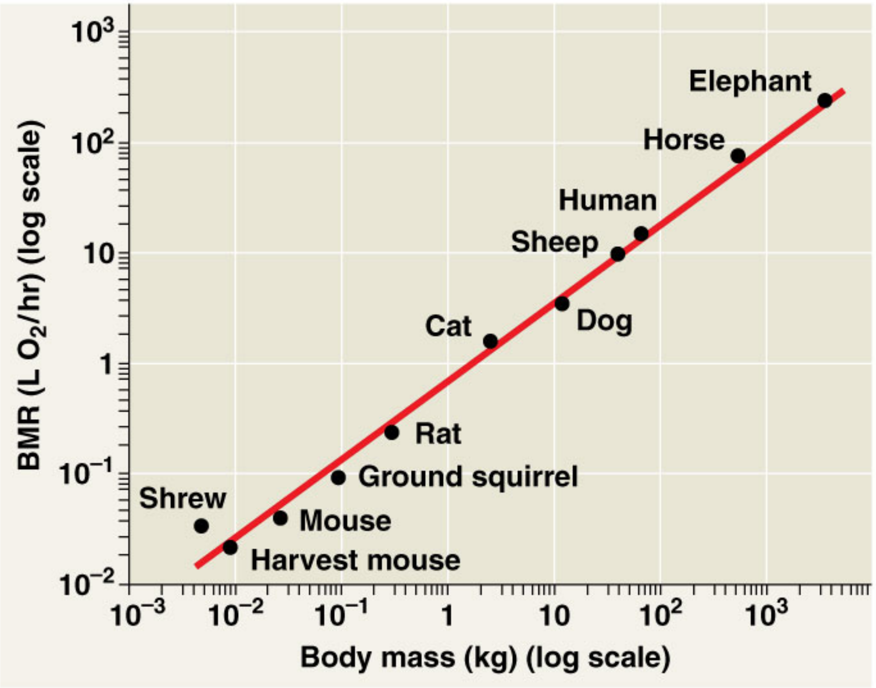
# Influences on Metabolic Rate

- Metabolic rates are affected by many factors besides whether an animal is an endotherm or ectotherm
- Two of these factors are size and activity

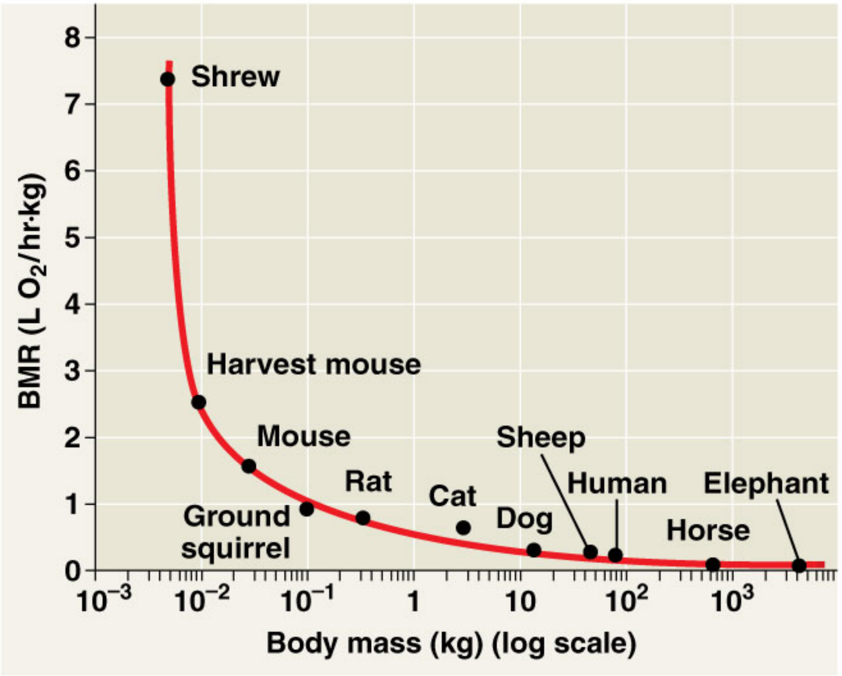
# *Size and Metabolic Rate*

- Metabolic rate is proportional to body mass to the power of three quarters ($m^{3/4}$)
- Smaller animals have higher metabolic rates per gram than larger 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

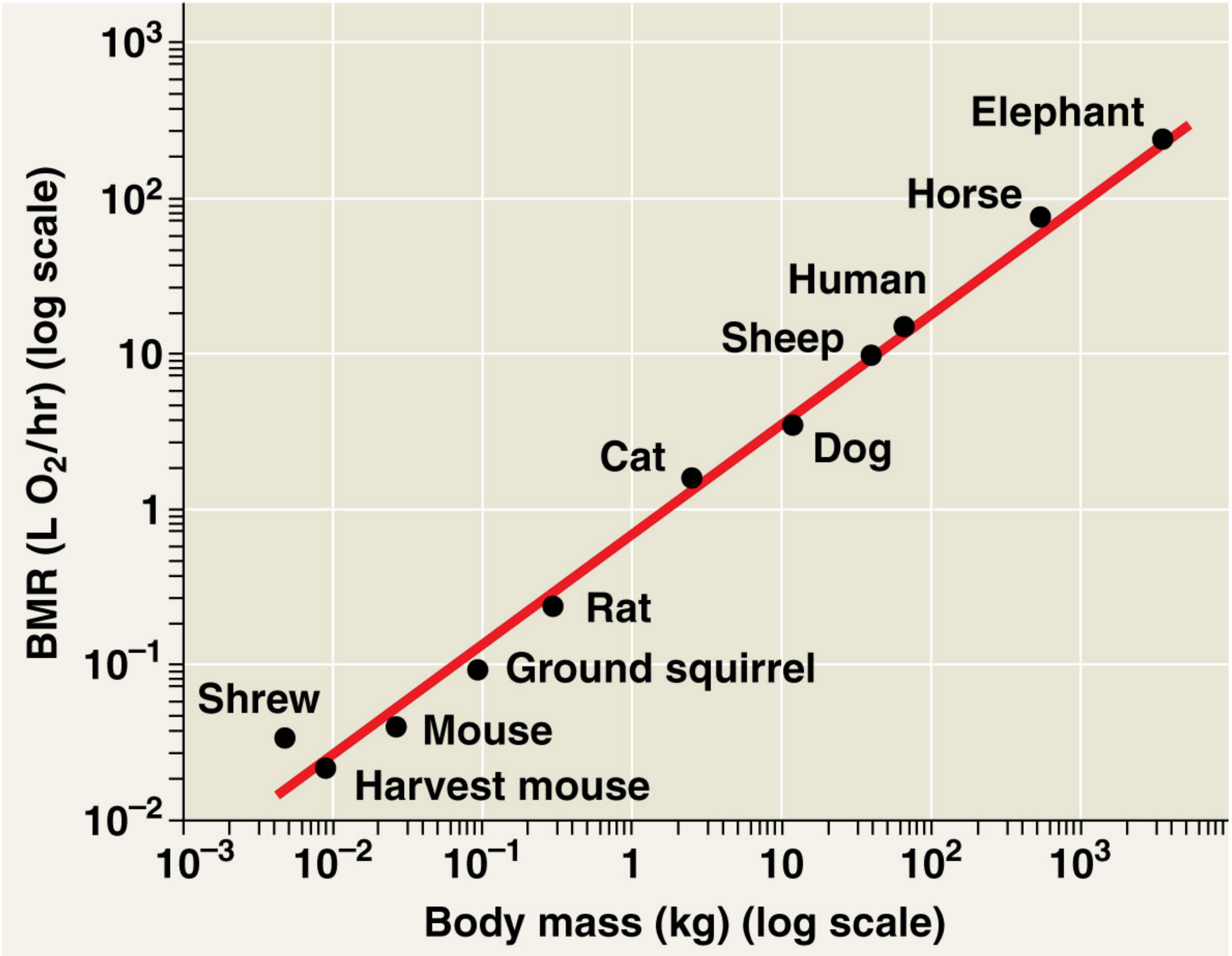
Figure 40.19




(a) Relationship of basal metabolic rate (BMR) to body size for various mammals

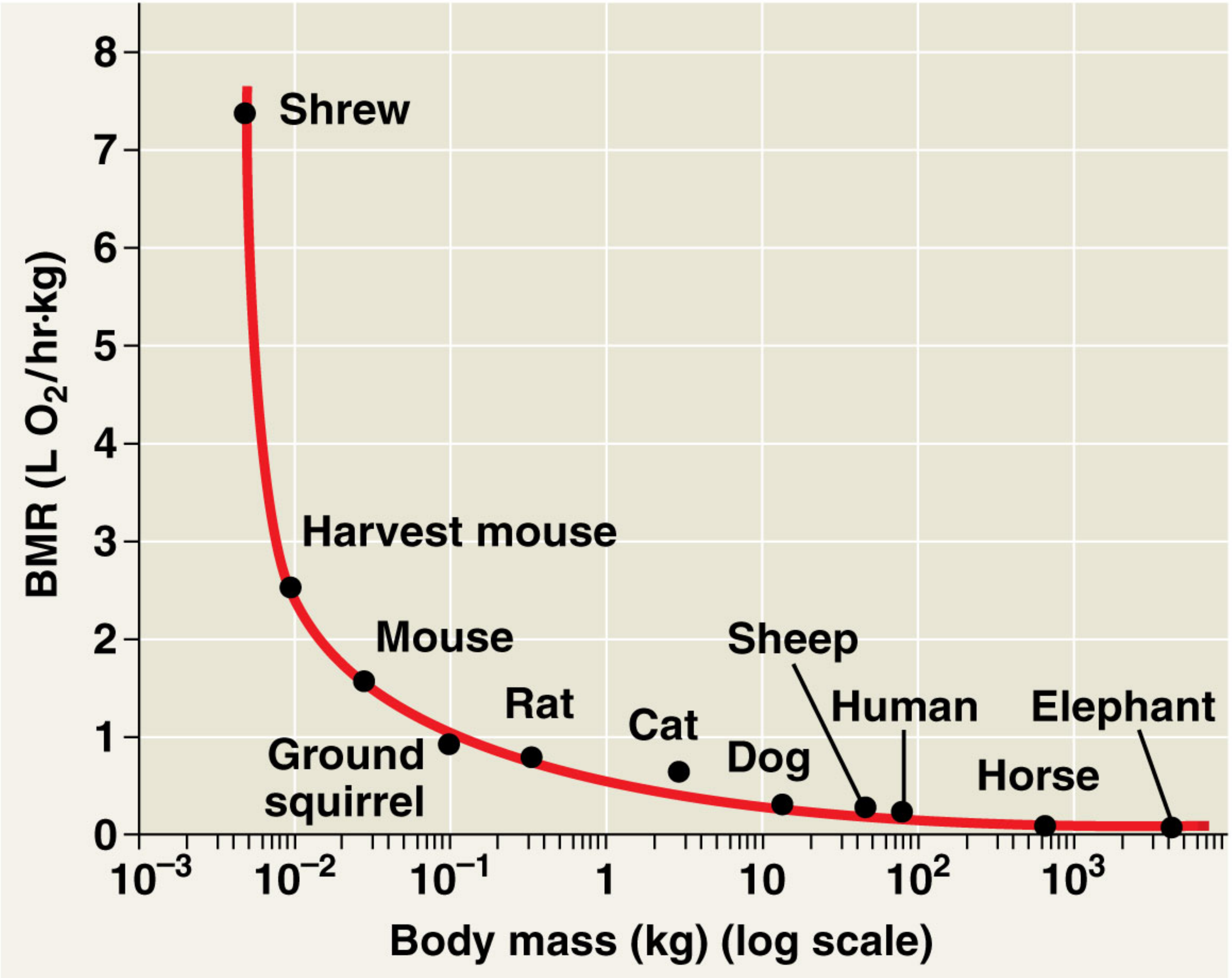



(b) Relationship of BMR per kilogram of body mass to body size




**(a) Relationship of basal metabolic rate (BMR) to body size for various mammals**

Figure 40.19b




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

# *Activity and Metabolic Rate*

- 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

# Energy Budgets

- 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

Figure 40.20

# ENERGY BUDGETS:
Size, energy strategy, and environment have a great influence on how the total annual energy expenditure is distributed among energetic needs.

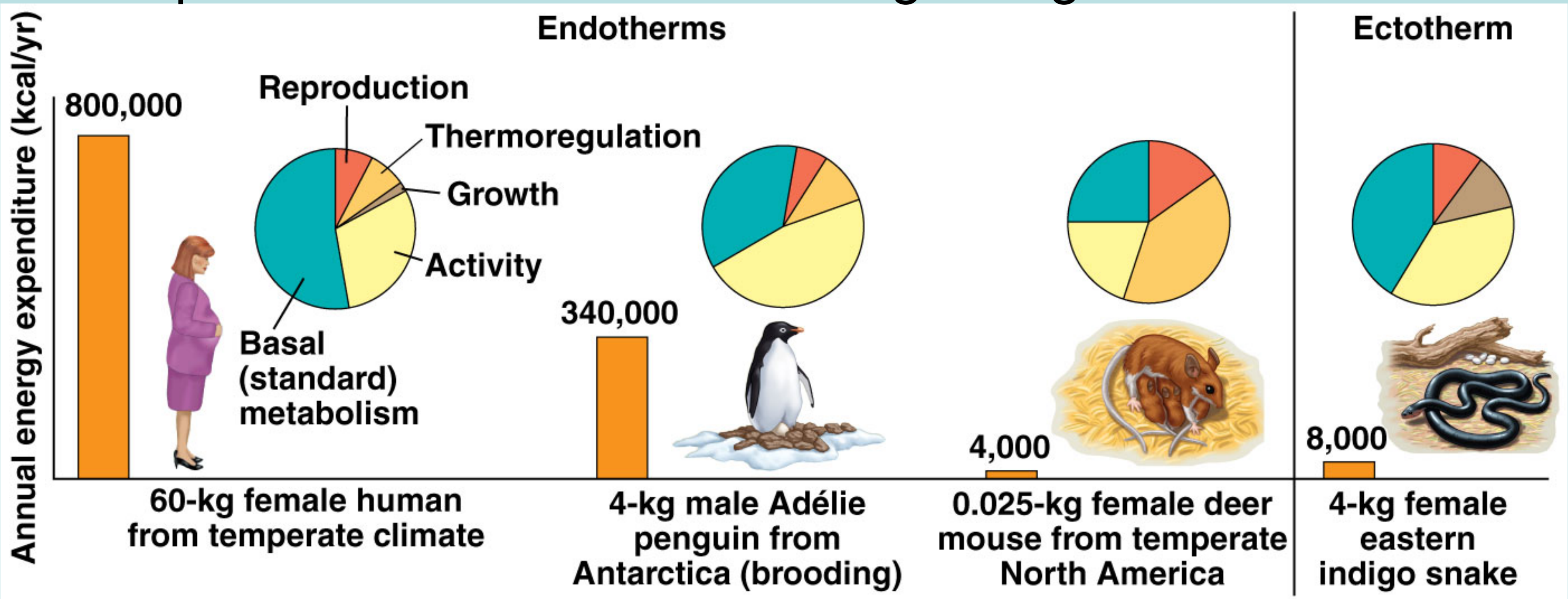


Figure 40.20a

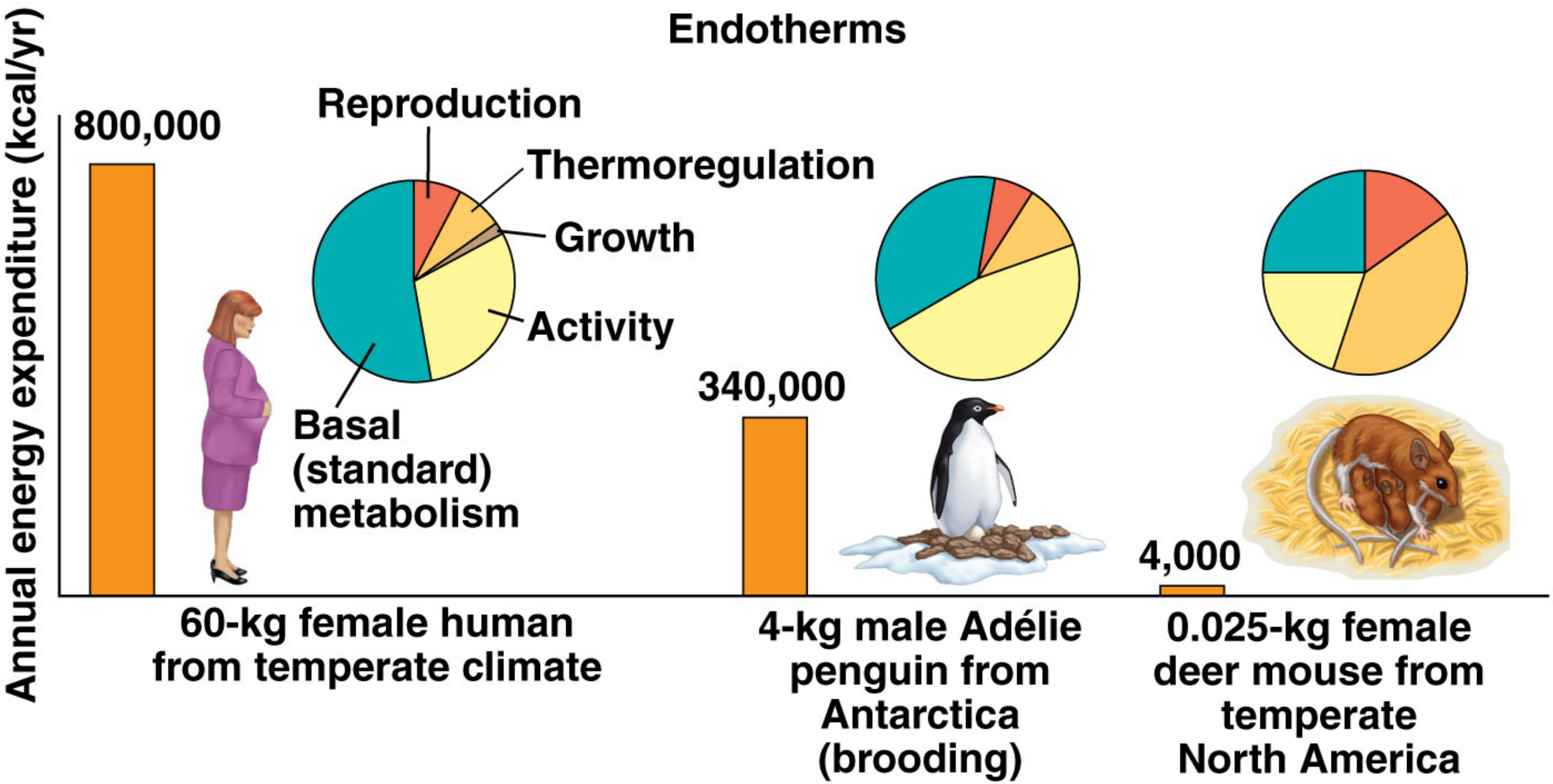
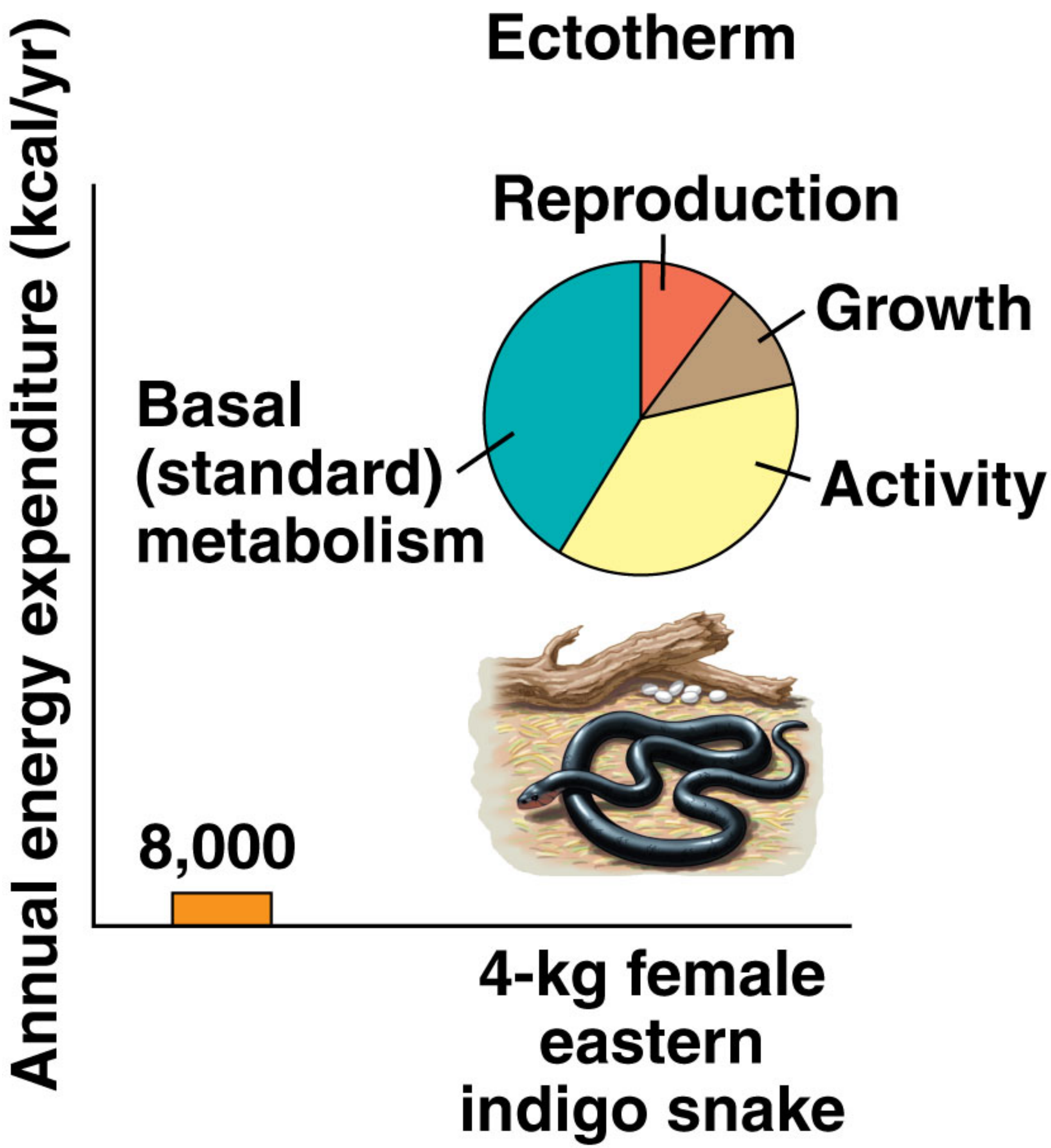


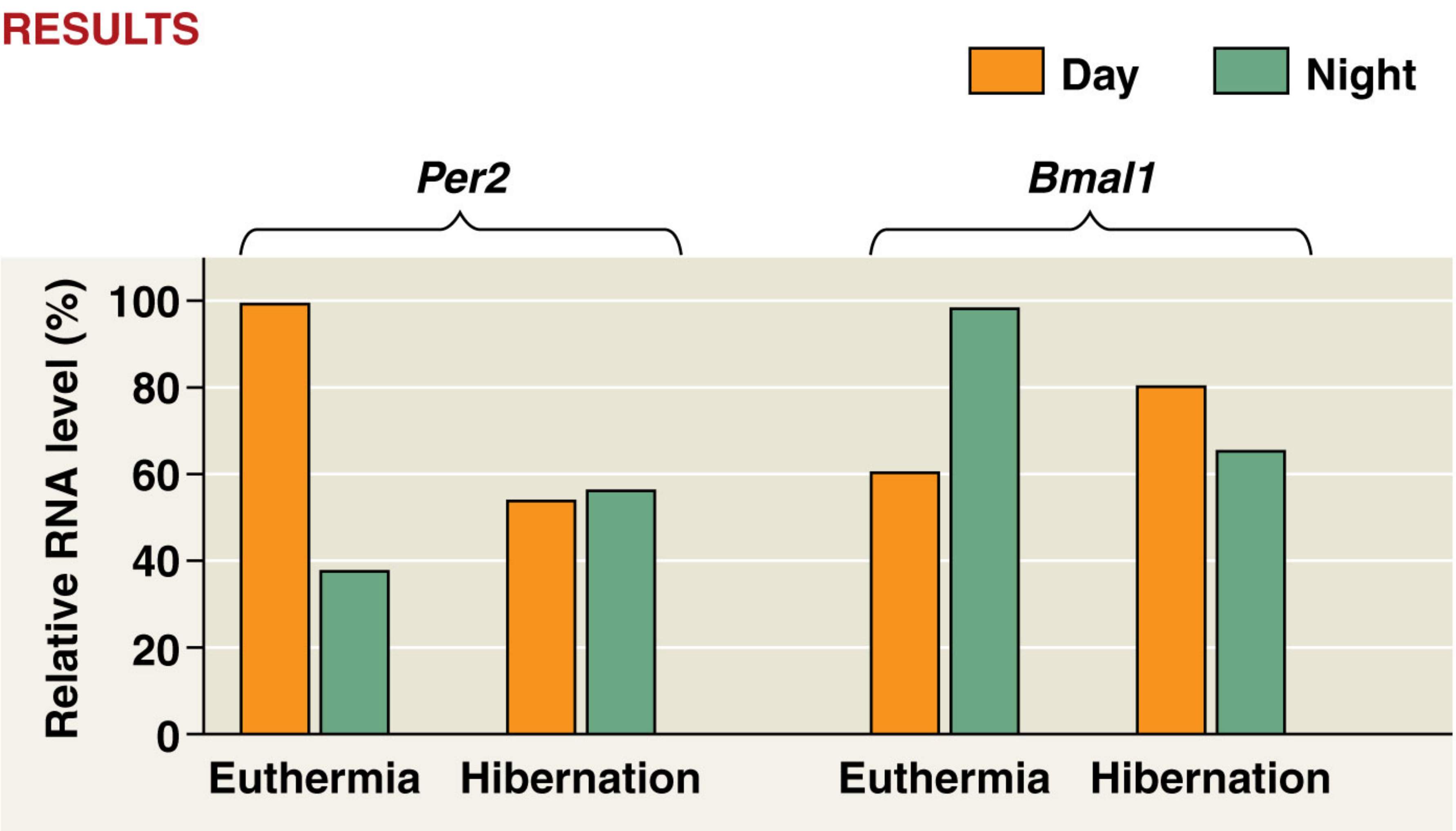
Figure 40.20b



# 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

Figure 40.21


RESULTS
Day
Night
Per2
Bmal1
Relative RNA level (%)
100
80
60
40
20
0
Euthermia
Hibernation
Euthermia
Hibernation

- Summer torpor, called estivation, enables animals to survive long periods of high temperatures and scarce water
- Daily torpor is exhibited by many small mammals and birds and seems adapted to feeding patterns

Figure 40.UN01

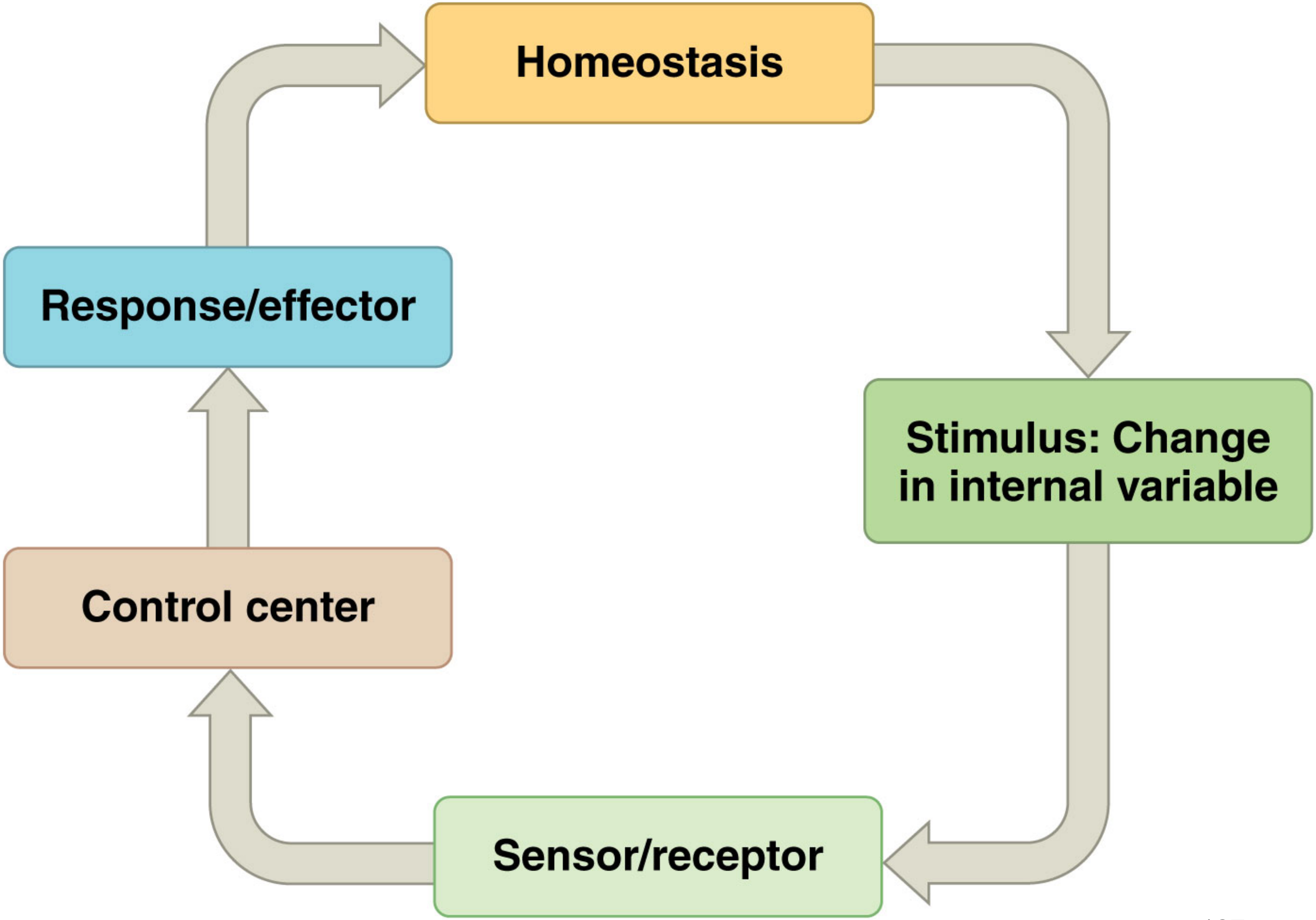


Figure 40.UN02