# BIOL 1202
# General Biology II Lecture

## CHAPTER 40
## *Basic Principles of Animal Form and Function*

**Dr. Adam Hrincevich**

# CH 40 Learning Objectives

1. Identify the levels of organization within the animal body, and use examples to show how structure and function are related at each level.
2. Distinguish how negative feedback and positive feedback mechanisms regulate internal conditions.
3. Use examples to demonstrate how endotherms and ectotherms regulate body temperature.
4. Relate the energy requirements and metabolic rate of animals to their size, activity, and environment.

I would suggest completing the crossword puzzle to help you understand the terminology and correlate how the terms relate to topics covered in this chapter.

# Concept 40.1: Animal form and function are correlated at all levels of organization

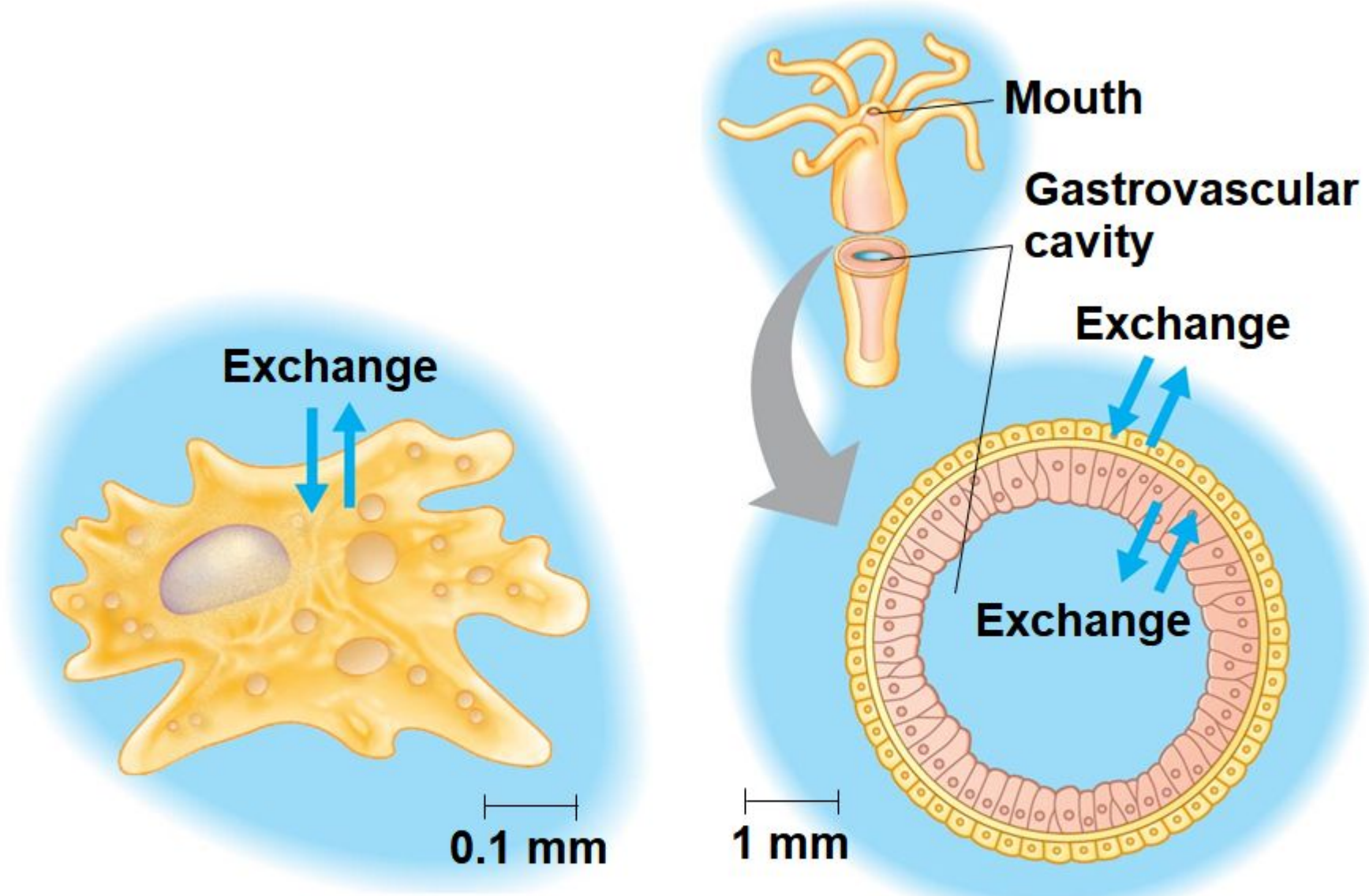
- **Anatomy** is the biological form of an organism
- **Physiology** is the biological functions an organism performs
- The comparative study of animals reveals that form and function are closely correlated
- Size and shape affect the way an animal interacts with its environment
- The body plan of an animal is programmed by the genome, itself the product of millions of years of evolution

# Evolution of Animal Size and Shape

- Physical laws govern strength, diffusion, movement, and heat exchange
- Properties of water limit possible shapes for fast swimming animals
- Convergent evolution often results in similar adaptations of diverse organisms facing the same challenge
- As animals increase in size, thicker skeletons are required for support

# Exchange with the Environment

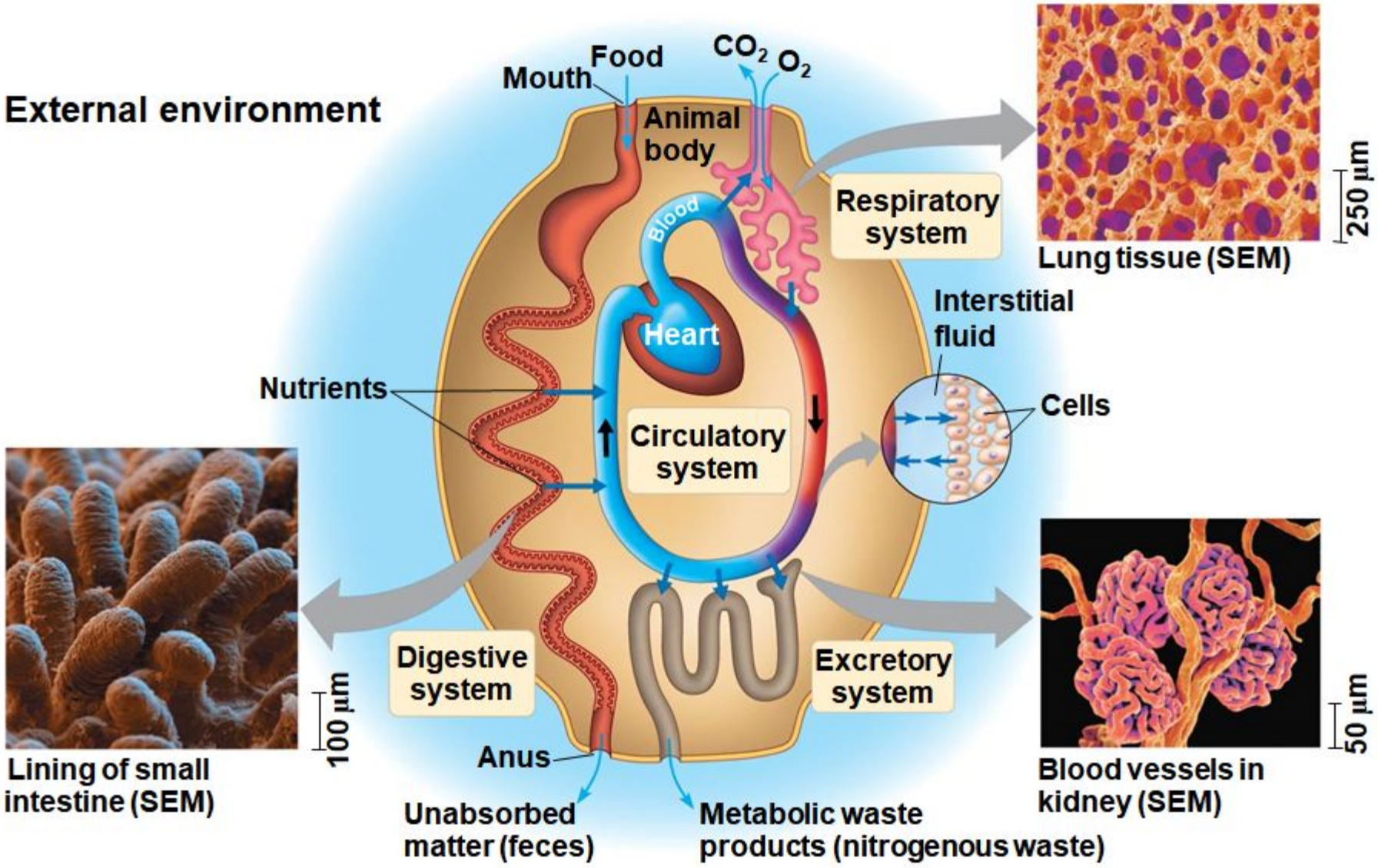
- Materials such as nutrients, waste products, and gases must be exchanged across the membranes of animal cells
- Rate of exchange is proportional to a cell's surface area, while amount of exchange material is proportional to a cell's volume
- A single-celled organism living in water has sufficient surface area to carry out all necessary exchange
- Multicellular organisms with a saclike body plan have body walls that are only two cells thick, facilitating diffusion of materials




(a) An amoeba, a single-celled organism

(b) A hydra, an animal with two layers of cells

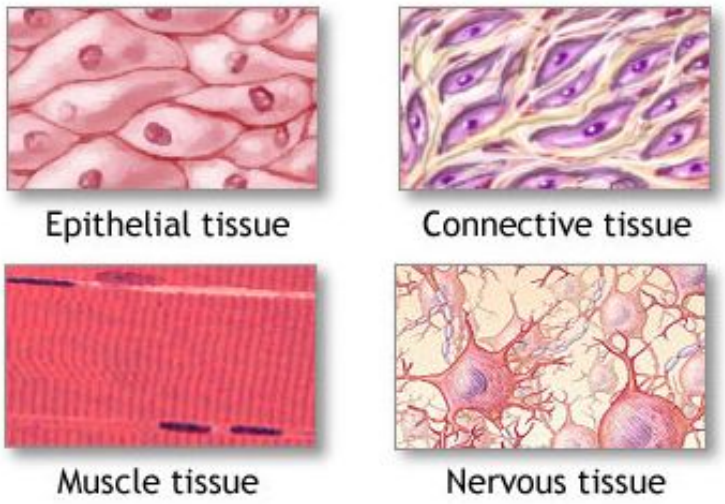
- In flat animals such as tapeworms, most cells are in direct contact with their environment
- More complex organisms are composed of compact masses of cells with complex internal organization
- Evolutionary adaptations such as specialized, extensively branched or folded structures enable sufficient exchange with the environment
- In animals, the space between cells is filled with **interstitial fluid**, which links exchange surfaces to body cells
- A complex body plan helps an animal living in a variable environment to maintain a relatively stable internal environment


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

# Hierarchical Organization of Body Plans

- Most animals are composed of 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
- There are four main types of animal tissues:

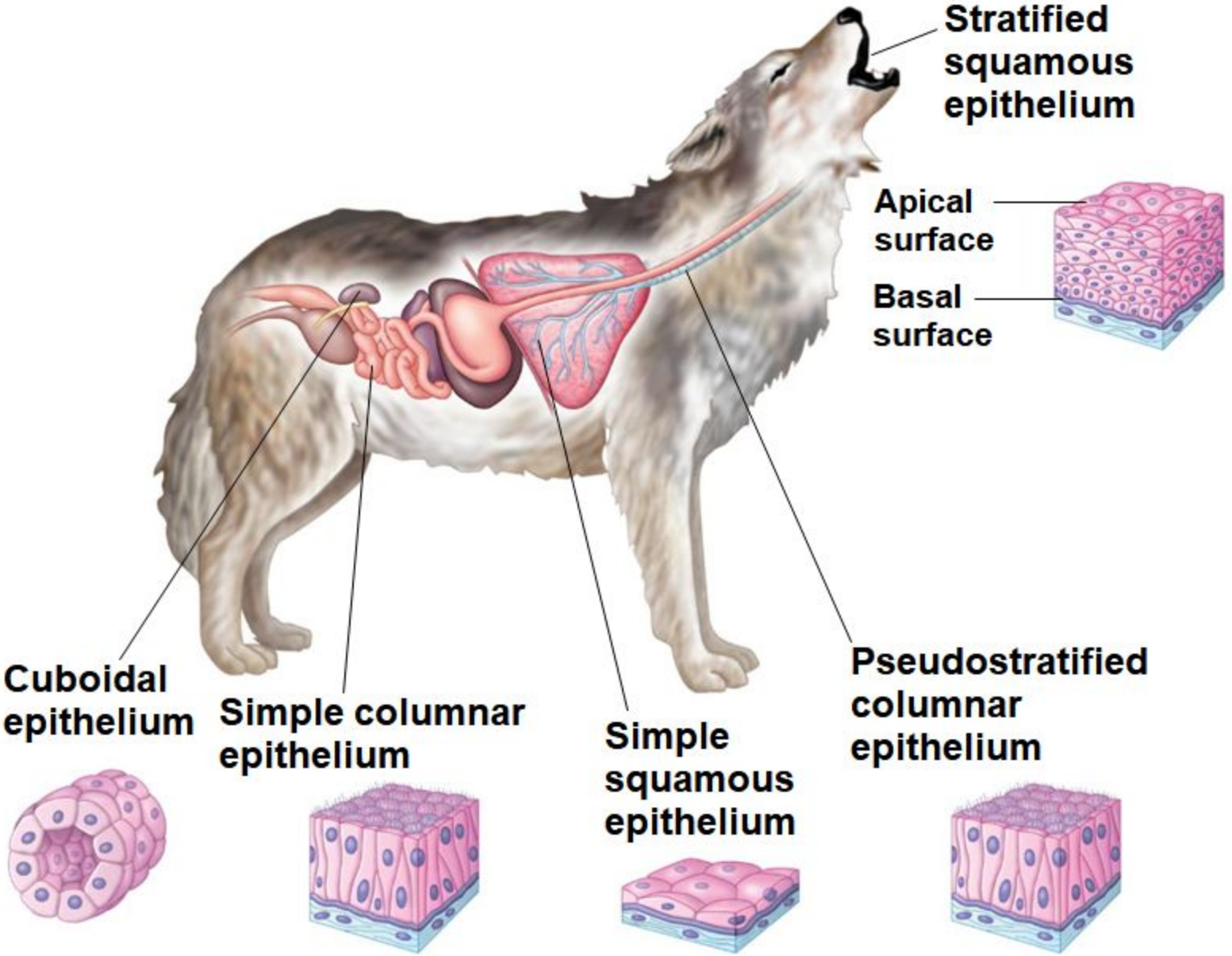
1. Epithelial
2. Connective
3. Muscle
4. Nervous



# 1. 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)

# Epithelial Tissue



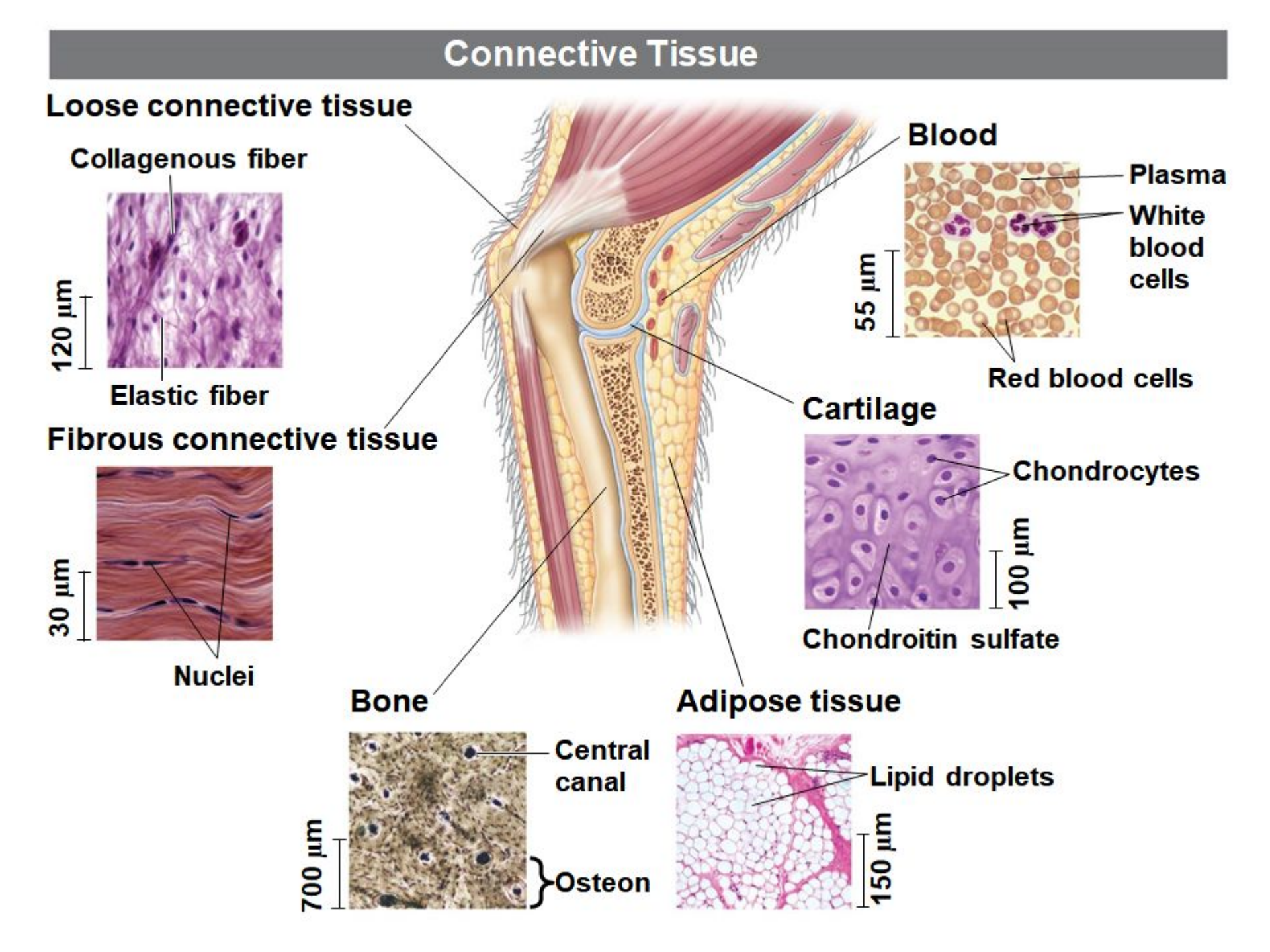
# 2. Connective Tissue

- **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
  - *Reticular* fibers join connective tissue to adjacent tissues
  - *Elastic* fibers stretch & snap back to their original length

- Connective tissue contains cells, including
  - **Fibroblasts:** secrete the protein of extracellular fibers
  - **Macrophages:** involved in the immune system
- In vertebrates, there are 6 types of connective tissue:

1. Loose tissue binds epithelia to underlying tissues and holds organs in place
2. Fibrous tissue is found in **tendons** (attach muscles to bones) and **ligaments** (connect bones at joints)
3. **Bone** is mineralized and forms the skeleton
4. **Adipose tissue** stores fat for insulation and fuel
5. **Blood** is composed of blood cells and cell fragments in blood plasma
6. **Cartilage** is a strong and flexible support material

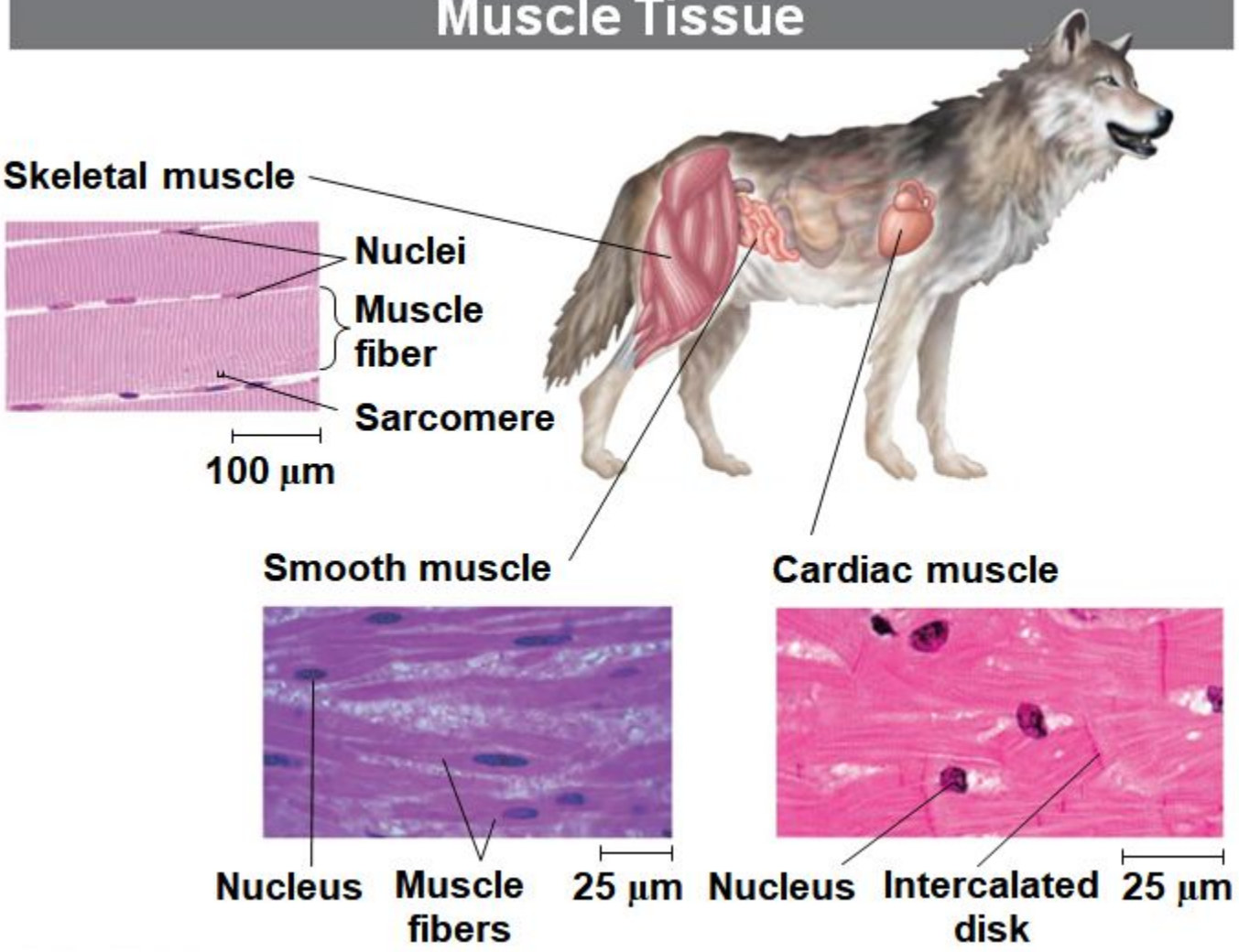
# Connective Tissue



# 3. Muscle Tissue

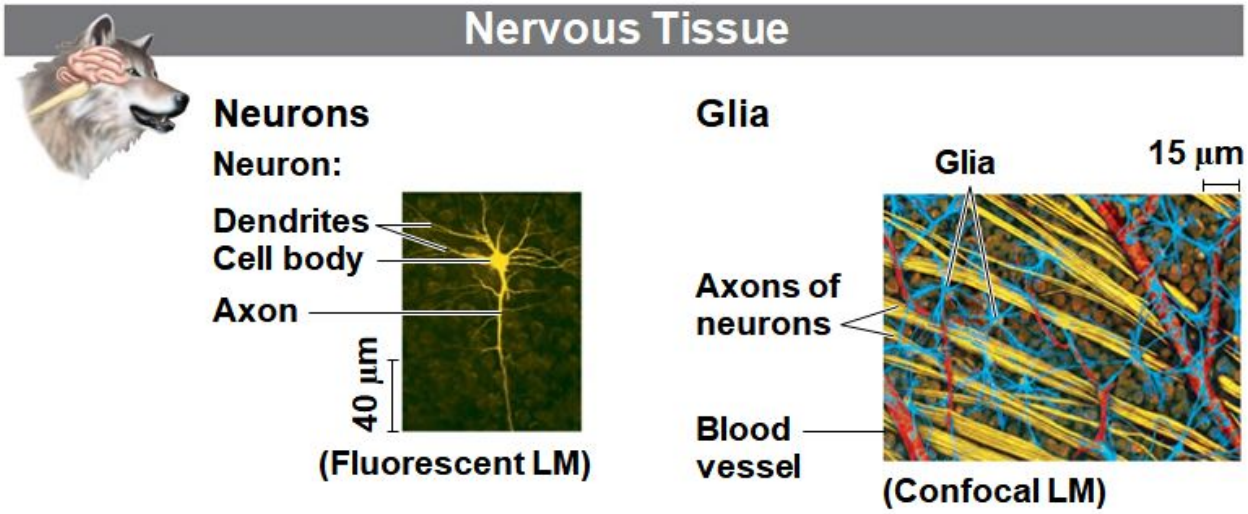
- **Muscle tissue** is responsible for nearly all types of body movement
- Muscle cells consist of filaments of the proteins actin and myosin, which together enable muscles to contract
- Muscle tissue in the vertebrate body is divided into three types:
  - **Skeletal muscle**, or striated muscle, is responsible for voluntary movement
  - **Smooth muscle** is responsible for involuntary body activities
  - **Cardiac muscle** is responsible for contraction of the heart

# Muscle Tissue



# 4. Nervous Tissue

- **Nervous tissue** functions in the receipt, processing, and transmission of information
- Nervous tissue contains
  - **Neurons**, or nerve cells, which transmit nerve impulses
  - **Glial cells**, or **glia**, which support cells



# Coordination and Control

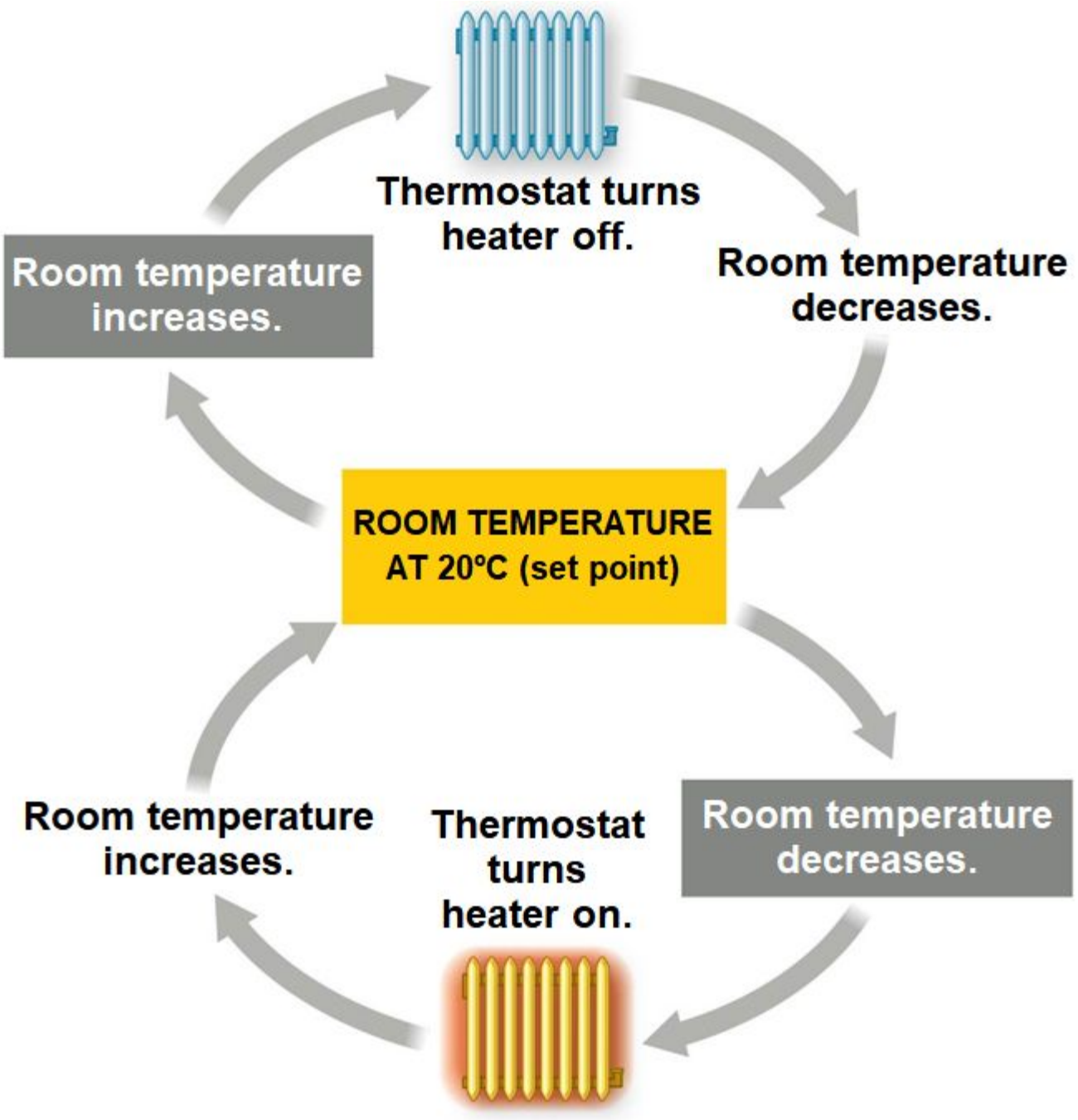
- Control and coordination within a body depend on the endocrine system and the nervous system
- The **endocrine system** releases signaling molecules called **hormones** into the bloodstream
- A hormone may affect ***1 or more*** regions in the body
- Hormones are relatively slow acting, but can have long-lasting effects over ***large areas*** of the body
- The **nervous system** transmits information between ***specific*** locations
- Nerve signal transmission is very fast
- The endocrine and nervous systems often work in close coordination

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

- Faced with environmental fluctuations, animals manage their internal environment by either regulating or conforming
- A **regulator** uses internal control mechanisms to control internal change in the face of external fluctuation
- A **conformer** allows its internal condition to vary with certain external changes
- Animals may regulate some environmental variables while conforming to others

# Homeostasis

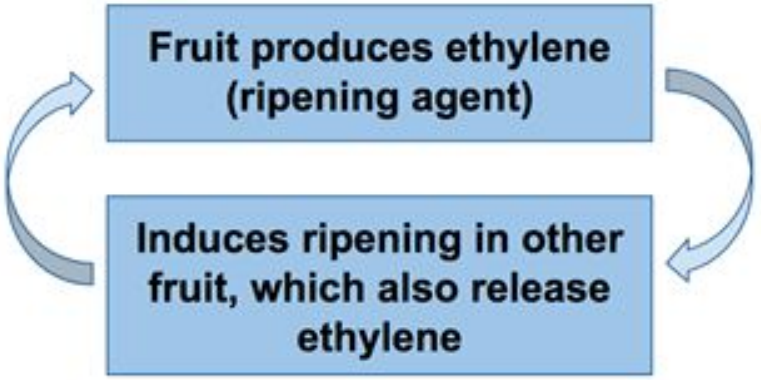
- Organisms use **homeostasis** to maintain a "steady state" or internal balance regardless of external environment
- In humans, body temperature, blood pH, and glucose concentration are each maintained at a constant level
- Mechanisms of homeostasis moderate changes in the internal environment
- Fluctuations above or below a **set point** serve as a **stimulus**; these are detected by a **sensor**
- A control center then generates output that triggers a **response**
- The response returns the variable to the set point


Thermostat turns heater off.
Room temperature decreases.
ROOM TEMPERATURE AT 20°C (set point)
Room temperature decreases.
Thermostat turns heater on.
Room temperature increases.
Room temperature increases.

# *Feedback Control in Homeostasis*

- Homeostasis in animals relies largely on **negative feedback**, which helps to return a variable to a normal range
- **Positive feedback** amplifies a stimulus and does not usually contribute to homeostasis in animals

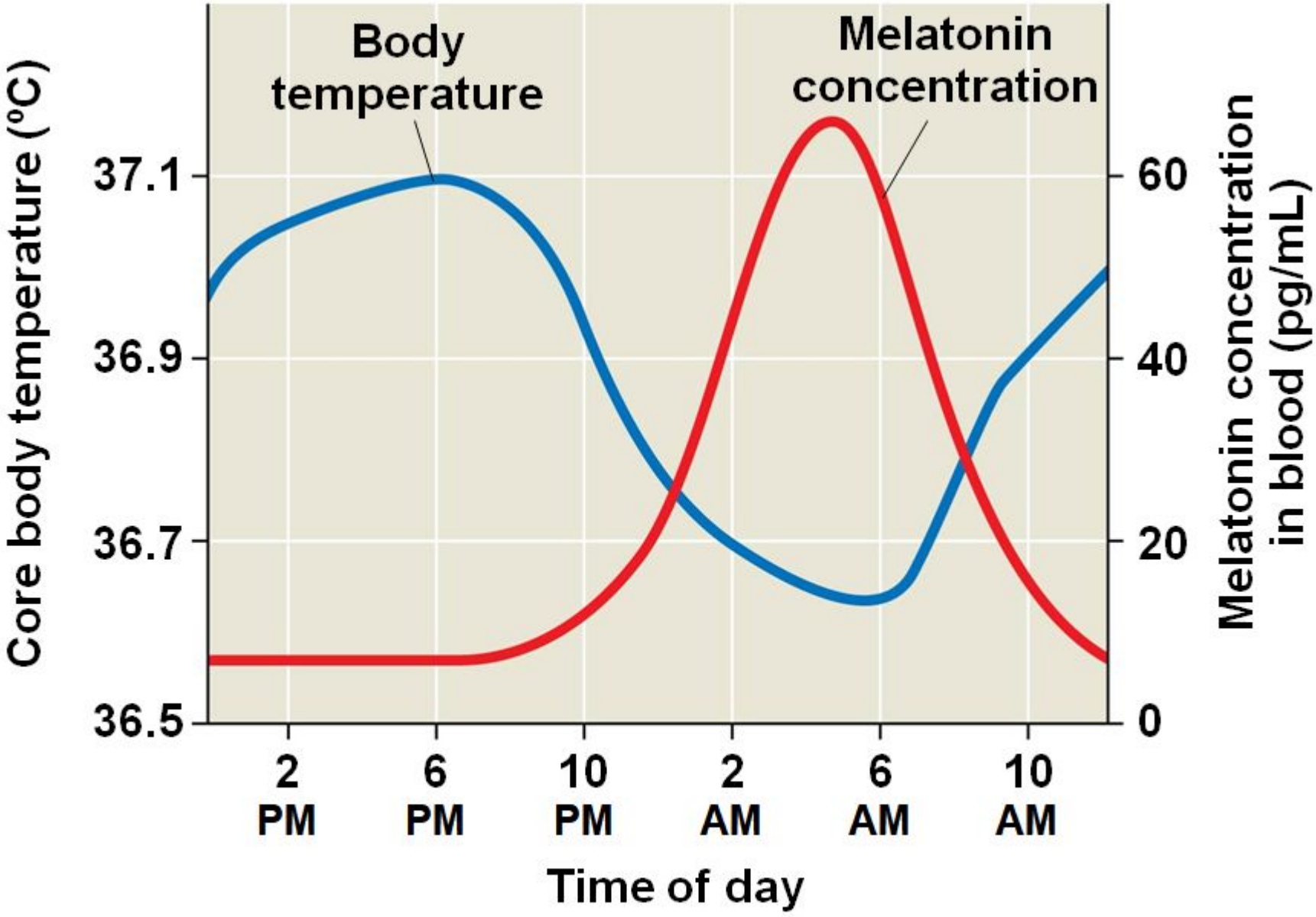

**Negative Feedback**



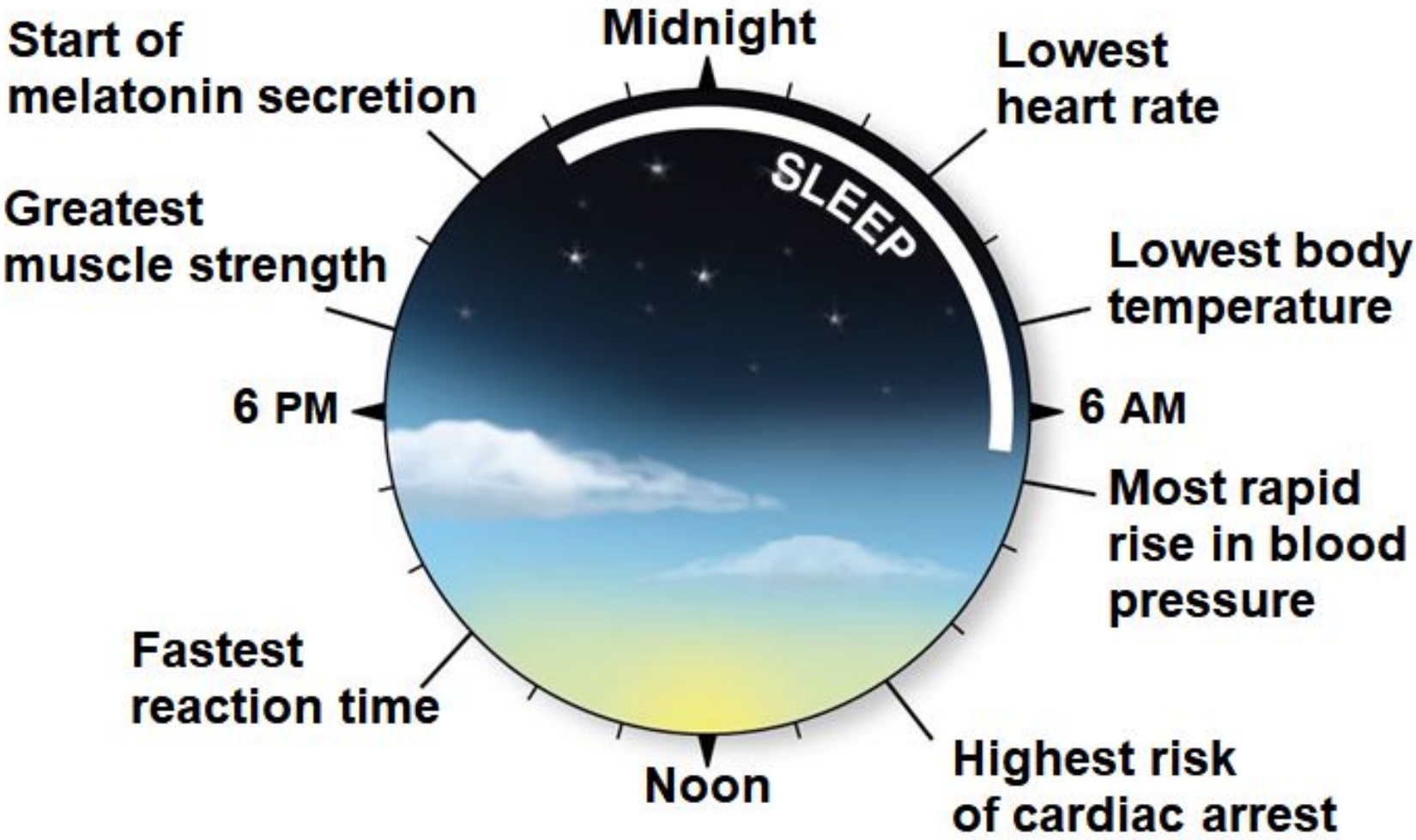

**Positive Feedback**

# *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
- Homeostasis can adjust to changes in external environment, a process called **acclimatization**
- Acclimatization is a temporary change during an animal's lifetime




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




(b) The human circadian clock

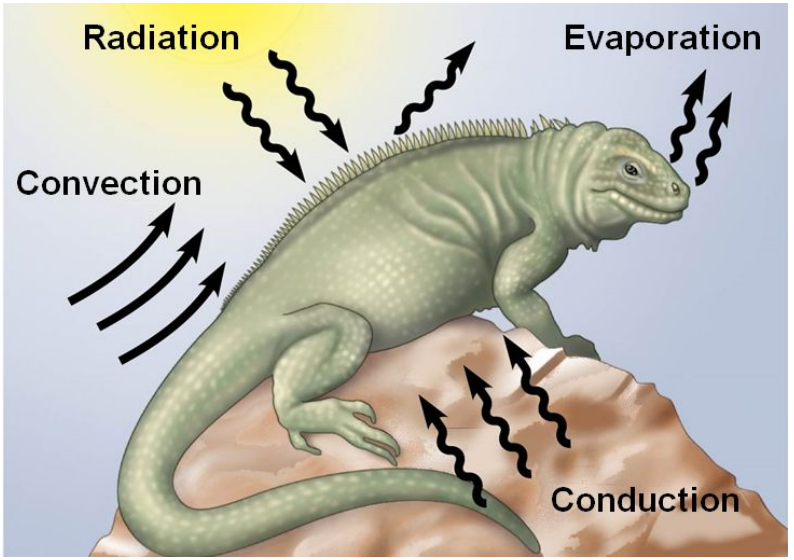
# Concept 40.3: Thermoregulation processes involve form, function, and behavior

- **Thermoregulation** is the process by which animals maintain an internal temperature in a normal range
- **Endothermic** animals generate heat by metabolism; birds and mammals are endotherms (walrus, human)
- **Ectothermic** animals gain heat from external sources (fish, amphibians, and non-avian reptiles)
- Endotherms can maintain a stable body temperature even with large environmental fluctuations
- Endothermy is more energetically expensive
- Ectotherms tolerate greater variation in internal temperature

# Variation in Body Temperature

- The body temperature of a poikilotherm varies with its environment
- The body temperature of a homeotherm is relatively constant
- Not all poikilotherms are ectotherms
- Organisms exchange heat by four physical processes:

1. Radiation
2. Evaporation
3. Convection
4. Conduction



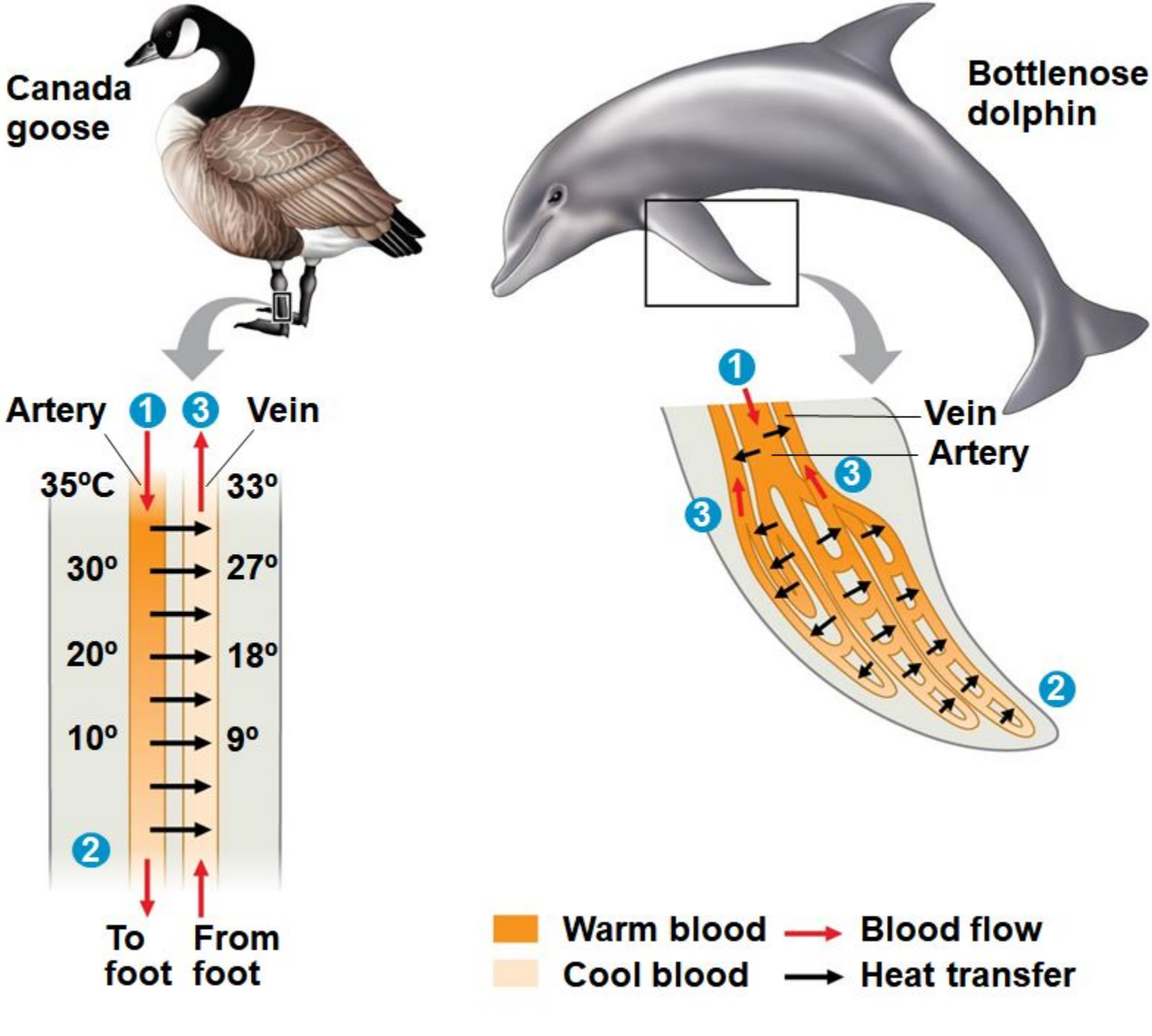
- Heat regulation in mammals often involves the **integumentary system**: skin, hair, and nails
- Five adaptations help animals thermoregulate:
  1. Insulation
  2. Circulatory adaptations
  3. Cooling by evaporative heat loss
  4. Behavioral responses
  5. Adjusting metabolic heat production

# 1. *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
- 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 thereby reduce heat loss

## 2. *Circulatory Adaptations*

- Regulation of blood flow near the body surface significantly affects thermoregulation
- Many endotherms & some ectotherms can alter the amount of blood flow between the body core and skin
- In vasodilation, blood flow in the skin increases, facilitating heat loss
- In vasoconstriction, blood flow in the skin decreases, lowering heat loss
- Certain sharks, fishes, and insects also use countercurrent heat exchanges
- Many insects have countercurrent heat exchangers that help maintain a high temperature in the thorax


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

# 3. *Cooling by Evaporative Heat Loss*

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

# 4. *Behavioral Responses*

- Ectotherms, and sometimes endoderms, use behavioral responses to control body temperature
- They may seek warm places when cold and orient themselves toward heat sources
- When hot, they bathe, move to cooler areas, or change orientation to minimize heat absorption

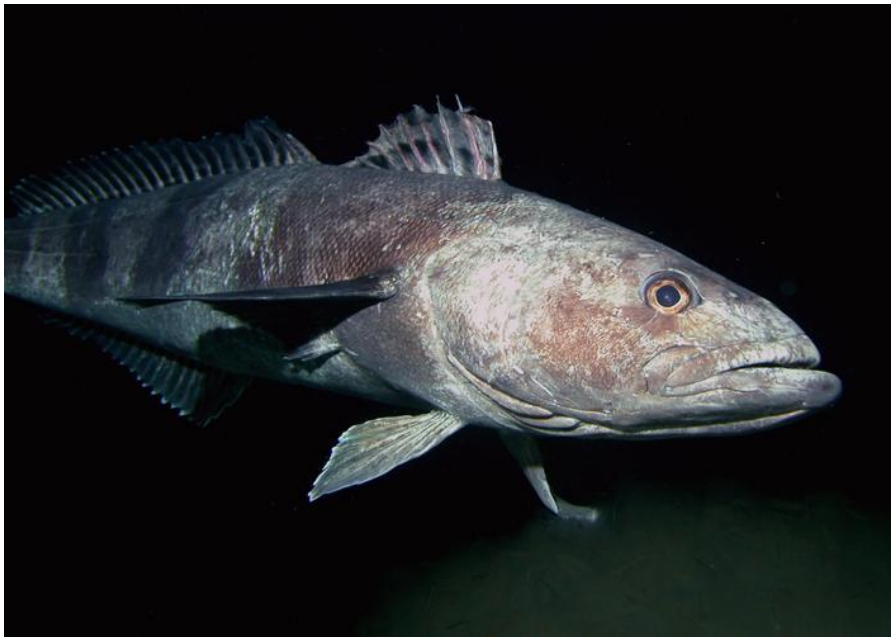
# 5. *Adjusting Metabolic Heat Production*

- Thermogenesis is the adjustment of metabolic heat production to maintain body temperature
- Thermogenesis is increased by muscle activity
- Non-shivering thermogenesis is when hormones cause mitochondria to increase metabolic activity
- Some mammals have a tissue called ***brown fat*** that is specialized for rapid heat production
  - found in mammals infants and hibernating mammals
  - amount of brown fat varies depending on the temperature of the surrounding environment
- Birds and some non-avian reptiles can also raise body temperature through shivering

# Acclimatization in Thermoregulation

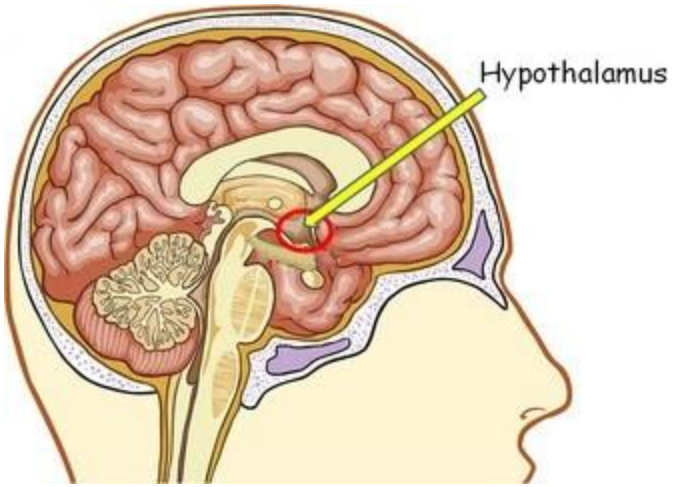
- Birds and mammals can vary their insulation to acclimatize to seasonal temperature changes
- Lipid composition of cell membranes may change with temperature
- When temperatures are subzero, some ectotherms produce "antifreeze" compounds to prevent ice formation in their cells

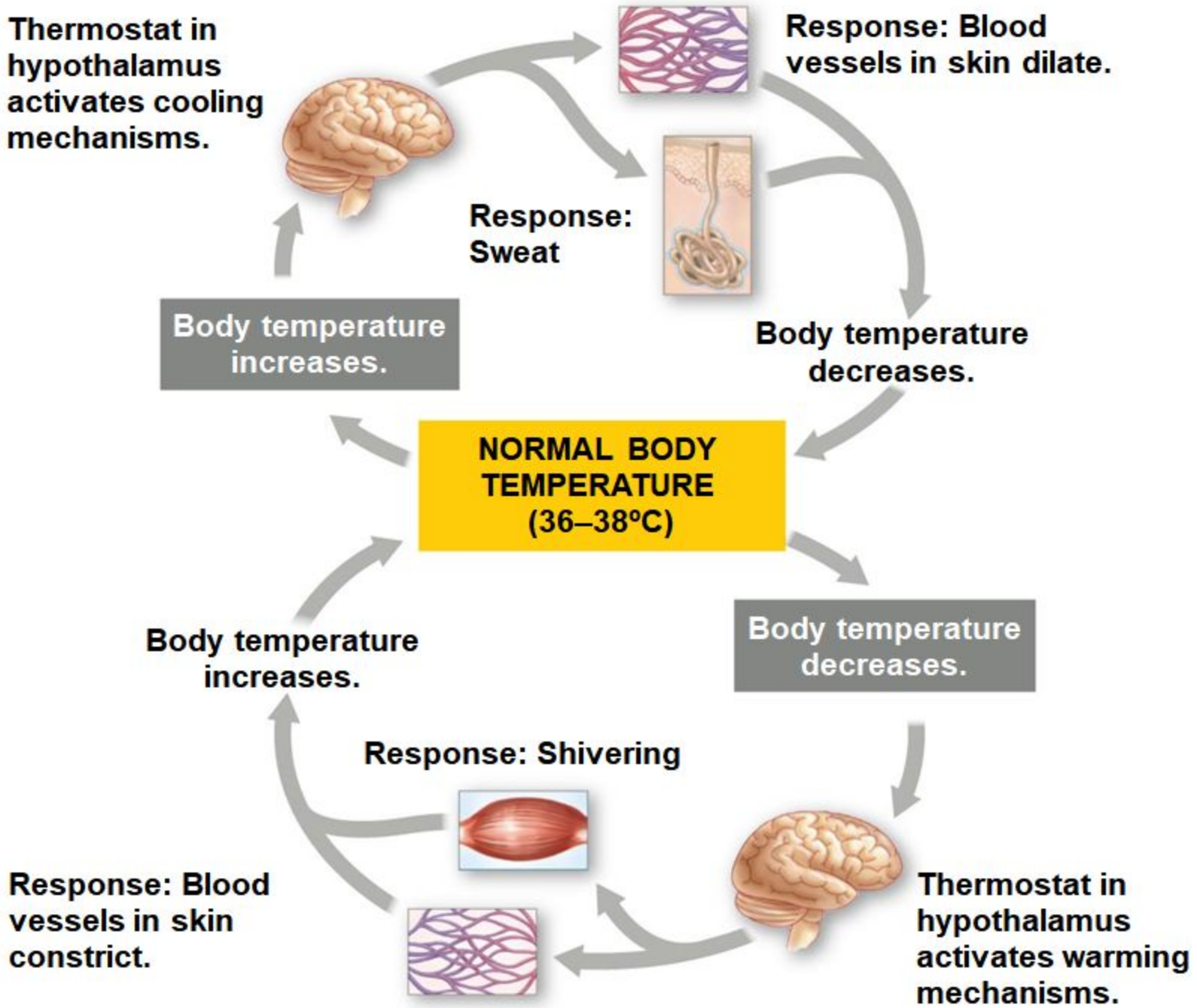
The **Antarctic Toothfish** can't produce their own heat, but still survive in freezing waters. Their blood is filled with "antifreeze" proteins which stop ice formation and keep the fish alive.



# Physiological Thermostats and Fever

- Thermoregulation in mammals is controlled by a region of the brain called the **hypothalamus**
- The hypothalamus triggers heat loss/generating mechanisms
- Fever, an infection response, reflects an increase in the normal range for the biological thermostat
- Some ectothermic organisms seek warmer environments to increase their body temperature in response to certain infections




Thermostat in hypothalamus activates cooling mechanisms.
Response: Blood vessels in skin dilate.
Response: Sweat
Body temperature increases.
Body temperature decreases.
NORMAL BODY TEMPERATURE (36–38°C)
Body temperature increases.
Body temperature decreases.
Response: Shivering
Response: Blood vessels in skin constrict.
Thermostat in hypothalamus activates warming mechanisms.

# 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 an animal's nutritional needs, and it relates to an animal's size, activity, and environment
- 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, synthesizing storage material such as fat, and production of gametes

# Quantifying Energy Use

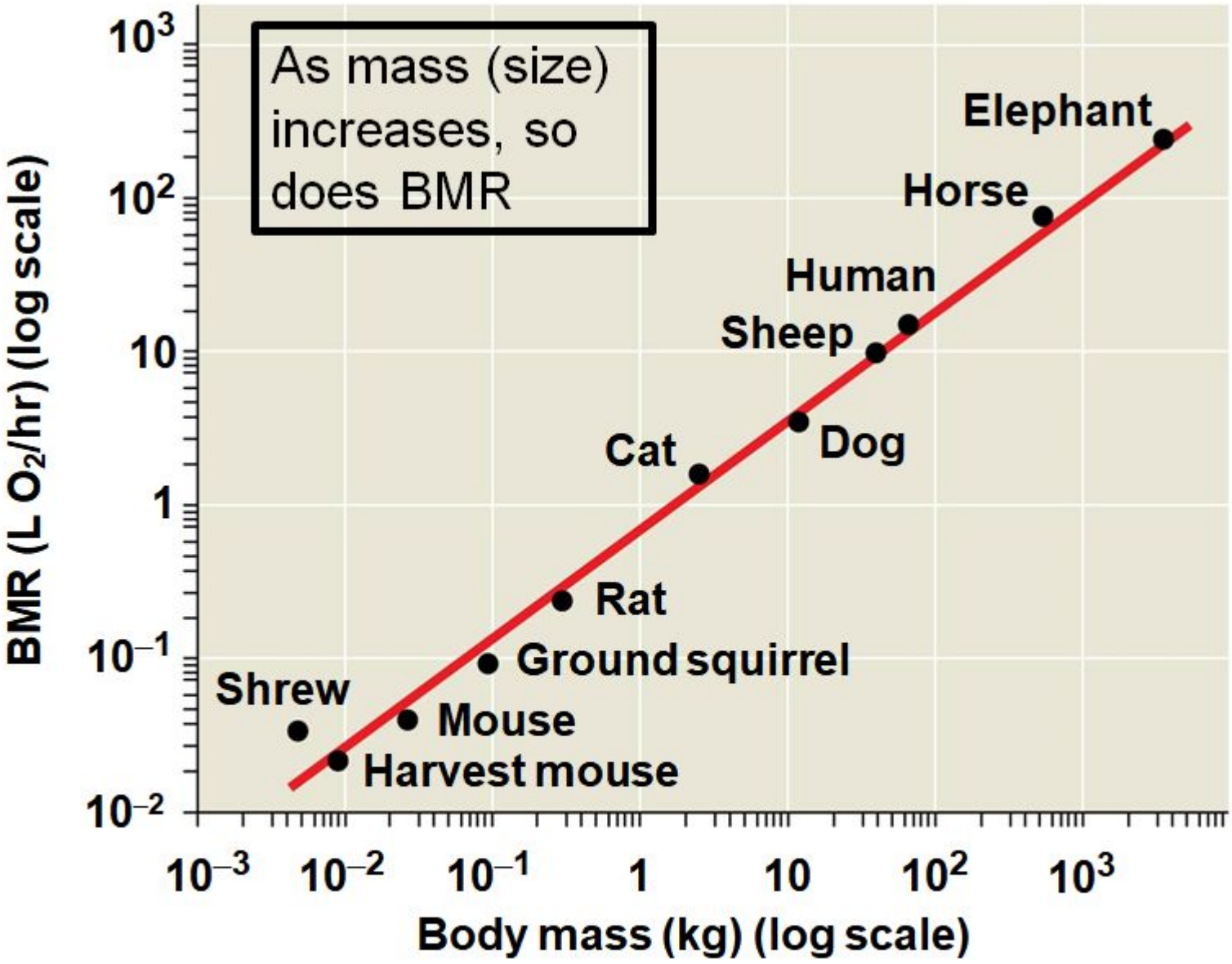
- **Metabolic rate** is the sum of all the energy an animal uses in a unit of time
- Metabolic rate can be determined by
  - An animal's heat loss
  - The amount of oxygen consume or carbon dioxide produced
  - Measuring energy content of food consumed and energy lost in waste products

# Minimum Metabolic Rate and Thermoregulation

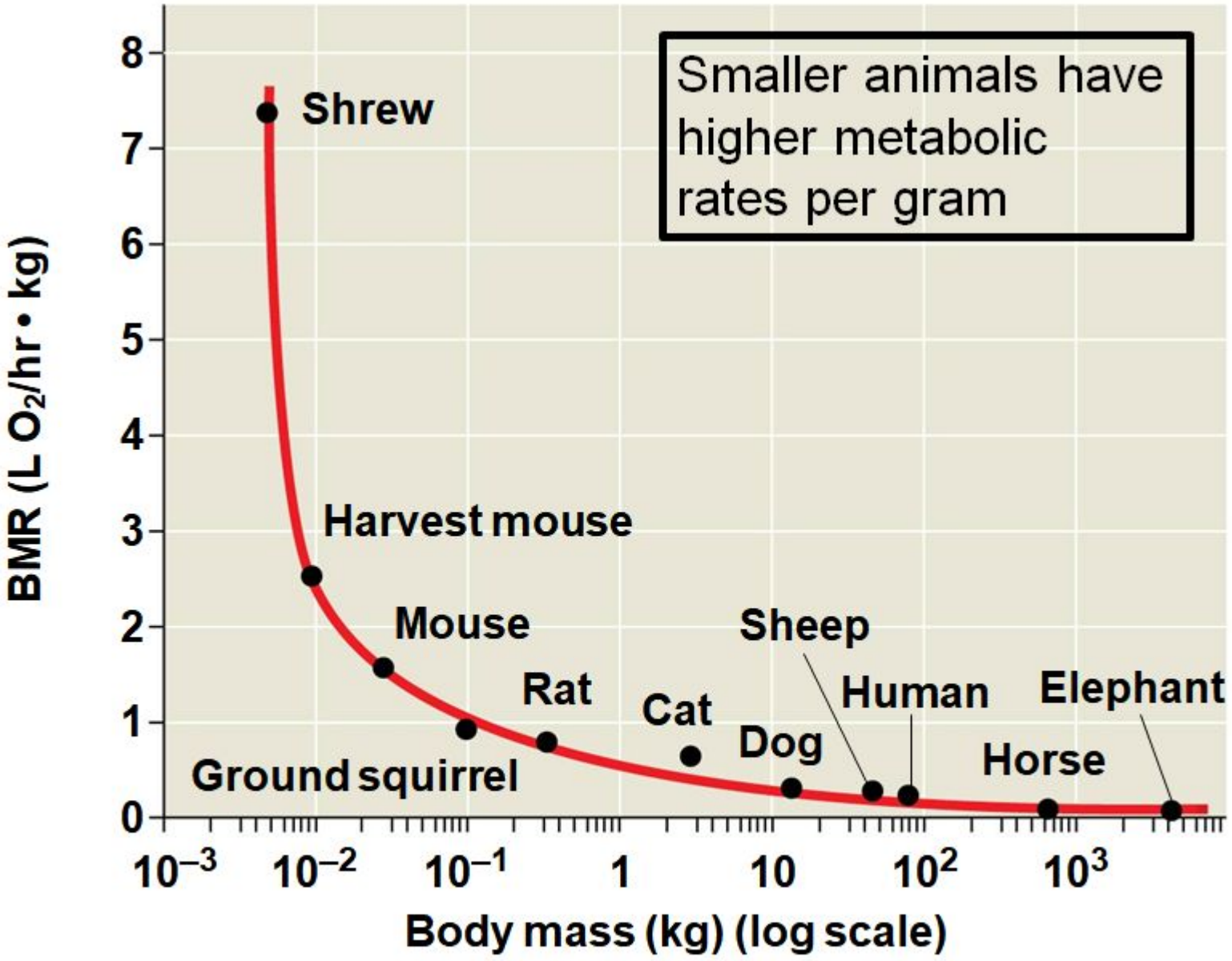
- **Basal metabolic rate** (**BMR**) is the metabolic rate of an endotherm at rest at a "comfortable" temperature
- **Standard metabolic rate** (**SMR**) is the metabolic rate of an ectotherm at rest at a specific temperature
- Both rates assume a non-growing, fasting, and non-stressed animal
- Ectotherms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

# *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




(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

# *Activity and Metabolic Rate*

- Activity greatly affects metabolic rate for both endoterms and ectotherms
- In general, the maximum metabolic rate an animal can sustain is inversely related to the duration of the activity
- For most terrestrial animals, the average daily rate of energy consumption is two to four times BMR (endotherms) or SMR (ectotherms)
- The fraction of an animal's energy budget devoted to activity depends on factors such as environment, behavior, size, and thermoregulation

# Torpor and Energy Conservation

- **Torpor:** state of decreased activity and metabolism
- Torpor enables animals to save energy while avoiding difficult and dangerous conditions
- **Hibernation:** long-term torpor that is an adaptation to winter cold and food scarcity
- Metabolic rates during hibernation can be 20 times lower than normal rates
- Summer torpor, called estivation, enables animals to survive long periods of high temperatures and scarce waters
- Daily torpor is exhibited by many small mammals and birds and seems adapted to feeding patterns