Chapter 40: Basic Principles of Animal Form and Function

1. Explain how amoebas, hydras, tapeworms, and whales exchange materials with their environment.

Exchange occurs as substances dissolved in an aqueous solution move across the plasma membrane of each cell. The rates of exchange for nutrients, waste products, and gases are proportional to membrane surface area, whereas the amount of material that must be exchanged to sustain life is proportional to cell volume. A single-celled organism, such as the amoeba, has a sufficient membrane surface area in contrast with its environment to carry out all necessary exchange. In contrast, an animal is composed of many cells, each with its won plasma membrane across which exchange must occur.

A multicellular organization therefore works only if every cell has access to a suitable aqueous environment, either inside or outside the animal's body. A pond-dwelling hydra, which has a sac-like body plan, has a body wall only two cell layers thick. Because its gastrovascular cavity opens to the external environment, both the outer and inner layers of cells are constantly bathed by pond water. A parasitic tapeworm has a thin, flat shape which places most cells of the worm in direct contact with its particular environment (the nutrient-rich intestinal fluid of a vertebrate host).

For a more complex body plan, increasing the number of cells decreases the ratio of outer surface area to total volume. Thus, specialized surfaces that are extensively branched or folded facilitate the movement of bodily fluids. In humans, the internal exchange surfaces of the digestive, respiratory, and circulatory systems each have an area more than 25 times that of the skin.

2. What is interstitial fluid?

Internal body fluids link exchange surfaces to body cells. The spaces between cells are filled with fluid, in many animals called interstitial fluid. Complex body plans also include a circulatory fluid, such as blood. Exchange between the interstitial fluid and the circulatory fluid enables cells throughout the body to obtain nutrients and get rid of wastes.

3. What is a tissue?

Cells are organized into tissues, groups of cells with a similar appearance and a common function. Different types of tissues are further organized into functional units called organs. Groups of organs that work together provide an additional level of organization and coordination and make up an organ system.

4. What are the four types of tissues?

Tissue	Examples	Function	Appearance & Location
epithelial	cuboidal, simple columnar, simple squamous, stratified squamous, pseudostratified columnar	barrier against mechanical injury, pathogens, and fluid loss; forms active interfaces with environment	closely packed, often with tight junctions; cover outside of the body and line organs and cavities within the body
connective	cartilage, adipose, blood, bone, fibrous connective, loose connective	holds many tissues, organs together and in place; collagenous fibers provide strength, flexibility; reticular fibers join connective tissue to adjacent tissues; elastic fibers make tissues elastic	consists of sparse population of cells scattered through an extracellular matrix
muscle	skeletal, smooth, cardiac	responsible for nearly all types of body movement	skeletal muscle striated; smooth muscle lacks striations; cardiac muscle forms contractile wall of heart
nervous	neurons, glial cells	functions in receipt, processing, transmission of information	concentration of nervous tissues forms brain

5. Explain the difference between animals that are regulators and those that are conformers.

An animal is said to be a regulator for a particular environmental variable if it uses internal control mechanisms to regulate internal change in the face of external fluctuation. For example, the river otter is a regulator for temperature,

keeping its body at a temperature that is largely independent of that of the water in which it swims. An animal is said to be a conformer for a particular environmental variable if it allows its internal condition to conform to external changes in that variable. For instance, the largemouth bass conforms to the temperature of the lake in which it lives.

6. Would ectotherms be regulators or conformers?

Internal metabolism and the external environment provide the sources of heat for thermoregulation. Birds and mammals are mainly endothermic, i.e. warmed mostly by heat generated by metabolism. A few nonavian reptiles, some fishes, and many insect species are also mainly endothermic. Amphibians, lizards, snakes, turtles, many fishes, and most invertebrates are mainly ectothermic, i.e. gaining most of their heat from external sources. Thus, ectotherms would be conformers for heat.

7. What is meant by a set point?

Like a home heating system, an animal achieves homeostasis by maintaining a variable, such as body temperature or solute concentration, at or near a particular value, or set point. Fluctuations in the variable above or below the set point serve as the stimulus. A receptor, or sensor, detects the stimulus and triggers a response, a physiological activity that helps return the variable to the set point.

8. Describe an example of a negative feedback loop. Clearly identify the set point, the stimulus, and the response.

Homeostasis in animals relies largely on negative feedback, a response that reduces the stimulus. For example, when a human exercises vigorously, she produces heat, which increases body temperature. Her nervous system detects this increase and triggers sweating. As she sweats, the evaporation of moisture from her skin cools her body, helping return her body temperature to its set point. In this example, a constant body temperature is the set point, heat production is the stimulus, and sweating is the response.

9. Describe an example of a positive feedback loop.

Unlike negative feedback, positive feedback triggers mechanisms that amplify rather than diminish the stimulus. During childbirth, for instance, the pressure of the baby's head against receptors near the opening of the mother's uterus stimulates the uterus to contract. These contradictions result in greater pressure against the opening of the uterus, heightening the contractions and thereby causing even greater pressure, until the baby is born.

10. What is thermoregulation?

Thermoregulation is the process by which animals maintain an internal temperature within a tolerable range. Thermoregulation is critical to survival because most biochemical and physiological processes are very sensitive to changes in body temperature.

11. Describe the difference between endothermy and ectothermy.

Property	Description	Example
endothermy	can maintain stable body temperatures even during large environmental temperature fluctuations; can withstand cold and hot extremes intolerable for most ectotherms	
ectothermy	generally need to consume much less food than endotherms of equivalent size; tolerate larger fluctuations in their internal temperatures; do not generate enough heat for thermoregulation; may adjust body temperature by behavioral means (such as sun-basking)	

12. What are the four processes by which heat is exchanged with the environment?

Radiation is the emission of electromagnetic waves by all objects warmer than absolute zero. Radiation can transfer heat between objects that are not in direct contact, as when a lizard absorbs heat radiating from the sun. Evaporation is the removal of heat from the surface of a liquid that is losing some of its molecules as gas. Evaporation of water from a lizard's moist surfaces that are exposed to the environment has a strong cooling effect. Convection is the transfer of heat by the movement of air or liquid past a surface, as when a breeze contributes to heat loss from a lizard's dry skin, or blood moves heat from the body core to the extremities. Conduction is the direct transfer of thermal motion (heat) between molecules of objects in direct contact with each other, as when a lizard sits on a hot rock.

13. Discuss six varieties of thermoregulation.

Insulation, a major thermoregulatory adaptation in mammals and birds, reduces the flow of heat between an animal and its environment. Sources of insulation include hair, feathers, and layers of fat formed by adipose tissue. Most land mammals and birds react to cold by raising their fur or feathers. Lacking feathers or fur, humans must rely primarily on fat for insulation. "Goose bumps" are a vestige of hair raising inherited from our furry ancestors.

In response to changes in the temperature of their surroundings, many animals alter the amount of blood (and hence heat) flowing between their body core and their skin. Nerve signals that relax the muscles of the vessel walls result in vasodilation, an increase in the diameter of superficial blood vessels (those near the surface). As a consequence of the increase in vessel diameter, blood flow in the skin is elevated. The reverse process, vasoconstriction, reduces blood flow and heat transfer by decreasing the diameter of superficial vessels.

If environmental temperature is above body temperature, animals gain heat from the environment as well as from metabolism, and evaporation is the only way to keep body temperature from rising rapidly. Terrestrial animals lose water by evaporation across the skin and when they breathe. Water absorbs considerable heat when it evaporates; this heat is carried away from the body surface with water vapor. Sweating or bathing moistens the skin and enhances evaporative cooling. Many terrestrial mammals have sweat glands controlled by the nervous system.

Both endotherms and ectotherms control body temperature through behavioral responses, such as hibernation, sunning, or burrowing. When cold, reptiles other than birds seek warm places, orienting themselves toward heat sources and exposing the portion of their body surface exposed to the heat source.

14. Explain the concept of countercurrent exchange.

In many birds and mammals, reduction of heat loss relies on countercurrent exchange, the flow of adjacent fluids in opposing directions that maximizes transfer rates of heat or solutes. Heat transfer involves an antiparallel arrangement of blood vessels called a countercurrent heat exchanger. When tissues are organized this way, arteries and veins are located adjacent to each other As warm blood passes through arteries, it transfers heat to the colder blood returning from the extremities in the veins. Because the arteries and veins contain countercurrent blood flow – blood flowing in opposite directions – heat transfer occurs along the entire length of the exchanger. Certain sharks, bony fishes, and insects also use countercurrent heat exchange.

15. What is the role of the hypothalamus in temperature regulation?

The sensors that control thermoregulation are concentrated in the hypothalamus, a region of the brain near the ears. The hypothalamus contains a group of nerve cells that functions as a thermostat, responding to body temperatures outside a normal range by activating mechanisms that promote heat loss or gain. Warm receptors signal the hypothalamic thermostat when temperatures increase; cold receptors signal when temperatures decrease. Fever reflects an increase in the set point for the biological thermostat. Artificially raising the temperature of the hypothalamus in an infected animal reduces fever in the body.

16. What is the metabolic rate and in what units is it usually measured?

The amount of energy an animal uses in a unit of time is called its metabolic rate: the sum of all the energy-requiring biochemical reactions over a given time interval. Energy is measured in joules or in calories and kilocaries. A kilocalorie equals 1,000 calories. The unit Calorie, with a capital C, is actually a kilocalorie.

17. What is basal metabolic rate (BMR)?

The minimum metabolic rate of a nongrowing endotherm that is at rest, has an empty stomach, and is not experiencing stress is called the basal metabolic rate (BMR). BMR is measured under a "comfortable" temperature range that requires no generation or shedding of heat above the minimum. The metabolic rate of a fasting, nonstressed ectotherm at rest at a particular temperature is called its standard metabolic rate (SMR).

18. What is the relationship between BMR and body mass?

Larger animals have more body mass and therefore require more chemical energy. Remarkably, the relationship between overall metabolic rate and body mass is constant across a wide range of sizes and forms. For creatures ranging in size from bacteria to blue whales, metabolic rate is roughly proportional to body mass to the three-quarter power $(m^{\frac{1}{4}})$. One hypothesis is that for endotherms the smaller the animal, the greater the energy cost of maintaining a stable body temperature. However, it does not explain the fact that the inverse relationship between metabolism and size is also observed in ectotherms.

19. What are the evolutionary advantages of torpor and hibernation?

Torpor, a physiological state in which activity is low and metabolism decreases, is an adaptation that 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. When vertebrate endotherms (birds and mammals) enter hibernation, their body temperatures decline as their body's thermostat is turned down. The temperature reduction may be dramatic, even reaching a supercooled state.

20. If a mouse and a small lizard of the same mass (both at rest) were placed in experimental chambers under identical environmental conditions, which animal would consume oxygen at a higher rate? Explain.

The endothermic mouse, because its basal metabolic rate is higher than the ectothermic lizard's standard metabolic rate.

Mammalian Organ Systems

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, other hormone-secreting glands	coordination of body activities (e.g. digestion, metabolism)
reproductive	ovaries or testes and associated organs	reproduction
nervous	brain, spinal cord, nerves, sensory organs	coordination of body activities; detection of stimuli; formulation of responses
integumentary	skin and its derivatives (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; other movement

Structure and Function in Animal Tissues

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Tissue Type	Appearance & Main Functions	Location
cuboidal epithelium	dice-shaped cells specialized for secretion	makes up epithelium of kidney tubules, many glands, e.g. thyroid gland, salivary glands
simple columnar epithelium	large, brick-shaped cells; absorption	often found where secretion or active absorption is important; e.g. lines intestines
pseudostratified columnar epithelium	single layer of cells varying in height; beating cilia of ciliated cells sweep film of mucus along surface; facilitate movement of liquids	in many vertebrates, ciliated cells form mucous membrane that lines portions of respiratory tract
simple squamous epithelium	single layer of platelike cells; thin and leaky; exchange of material by diffusion	lines blood vessels, air sacs of lungs where diffusion of nutrients, gases is critical
stratified squamous epithelium	multilayered, regenerates rapidly	commonly found on surfaces subject to abrasion, e.g. outer skin, linings of mouth, anus, vagina
loose connective tissue	fibers loosely woven; binds epithelia to underlying tissues, holds organs in place	most widespread connective tissue in vertebrates; found in skin, throughout body
fibrous connective tissue	dense with collagenous fibers; tendons attach muscles to bones; ligaments connect bones at joints	in tendons, ligaments
bone	mineralized connective tissue	concentric layers of the mineralized matrix deposited around a central canal containing blood vessels and nerves
adipose tissue	specialized loose connective tissue; stores fat in adipose cells distributed throughout its matrix; tissue pads, insulate body, store fuel as fat molecules; each adipose cell contains a fat droplet that swells when fat is stored and shrinks when the body uses that fat as fuel	where padding is useful
cartilage	collagenous fibers embedded in chondroitin sulfate, a rubbery protein-carbohydrate complex; chondrocytes secrete collagen, chondroitin sulfate, which together make cartilage, a strong yet flexible support material	skeletons of many vertebrate embryos contain cartilage that is replaced by bone as the embryo matures; remains in some locations, such as the disks that act as cushions between vertebrae
blood	liquid extracellular matrix called plasma consisting of water, salts, dissolved proteins; erythrocytes (red blood cells), leukocytes (white blood cells), cell fragments called platelets suspended in plasma; red cells carry oxygen, white cells function in defense, platelets aid in blood clotting	veins
skeletal muscle	responsible for voluntary movements; consists of bundles of long cells called muscle fibers; arrangement of contractile units (sarcomeres) along fibers gives cells striped (striated) appearance; in adult mammals, building muscle increases the size but not the number of muscle fibers	attached to bones by tendons
smooth muscle	lacks striations, spindle-shaped; responsible for involuntary body activities, such as churning of the stomach and constriction of arteries	in walls of digestive tract, urinary bladder, arteries, other internal organs
cardiac muscle	striated like skeletal muscle, has similar contractile properties; unlike skeletal muscle, has fibers that interconnect via intercalated disks, which relay signals from cell to cell, help synchronize heart contraction	forms the contractile wall of the heart
neuron	basic unit of the nervous system; receives nerve impulses from other neurons via its cell body and multiple extensions (dendrites); transmits impulses to neurons, muscles, or other cells via extensions	in many animals, concentration of nervous tissue forms brain, an information-processing center

	(axons), often bundled together into nerves	
glia	help nourish, insulate, replenish neurons; in some cases, modulate neuron function	surround neurons