animal sciences

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VOLUME 1
A–Crep

Allan B. Cobb, Editor in Chief

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Preface

Six hundred million years of animal evolution and adaptation have produced a stunning range and variety of life on Earth. From the oldest, single-celled creatures to the most complex mammalian forms, animal diversity defies easy categorization or explanation. The Macmillan *Animal Sciences* encyclopedia provides a clear and comprehensive resource for better understanding this vast domain. By the nature of its interdisciplinary scope, the subject of animal sciences demands an approach that is both specific and general, detailed and thematic. *Animal Sciences* achieves this end in the course of nearly three hundred well-researched, clearly presented entries that explore the wide ranging diversity that exists within the animal kingdom.

Students will learn how animals develop throughout their lives, how they adapt to their changing environments, and how they develop specialized structures over time. Entries in this category explain how animals develop from fertilized eggs to adults. While some forms of development are straightforward—like a puppy maturing to become a dog—other changes are more dramatic—like a caterpillar changing its body forms over the course of its metamorphosis into a butterfly. Other entries study the various forms of animals and how body parts function.

The encyclopedia gives significant attention to animal ecology and behavior. Entries show how animals are part of the world environment while exhibiting unique behaviors within their own particular environments. Animal ecology addresses how animals are a part of ecosystems and how they interact with plants and other animals, both within and beyond their individual species. Given the close relationship of animal behavior and ecology, a number of entries discuss how animals select mates, whether they live alone or as members of groups, or how they share resources within an ecosystem, to give just a few examples.

Finally, *Animal Sciences* surveys the connection between animals and humans. Humans are unique in the animal kingdom because of their ability to alter environments significantly. Agriculture, which includes the domestication of animals and farming, serves as the chief example of such human-inspired environmental change and its impact on animal life worldwide. In addition, humans are the most social of animals and have developed complex social interactions. As human populations grow, habitat once occupied

by other animals is converted to human use. One consequence of such socialization is the pollution generated from an expanding human population and its deleterious effect on animal environments.

Animal Sciences also presents biographies of selected scientists who have made significant contributions to the many related fields, and introduces readers to the myriad career opportunities in the discipline.

The authors who contributed entries to *Animal Sciences* represent diverse backgrounds, and include members of academic and research institutions, as well as practicing scientists. The editorial board sought informative, up-to-date, and engaging articles, most of which include cross references, photographs or illustrations that prove helpful in understanding challenging concepts. A generous collection of sidebars accent related subjects. Every attempt has been made to avoid overly technical terms or scientific jargon, and whenever necessary such terms are highlighted and defined in the margin. Selected bibliographies guide readers to additional up-to-date resources, including those found on the Internet. Each of the four volumes also includes a geologic time scale, with particular emphasis on animals, as well as a phylogenetic tree and an alternative table of contents that groups articles under more general topic headings.

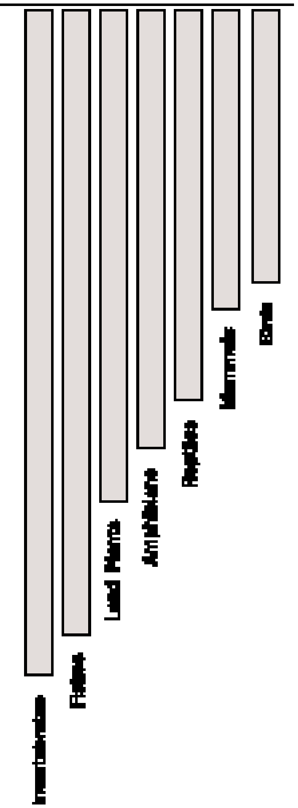
I wish to thank the staff at Macmillan Reference USA and the Gale Group for their hard work and attention to detail. In particular, I would like to thank Hélène Potter, Elly Dickason, Linda Hubbard, and Christa Brelin. I want to offer special thanks to Kate Millson for all her efforts and long hours in helping guide this project to fruition. I wish to thank the editorial board members—Amy Bryan, Andrew Gluesenkamp, and Marvin Elliot Richmond—for their vast knowledge and hard work. Finally, it is my hope that *Animal Sciences* can spark the interest of the next generation of committed scholars, researchers, and laypersons.

Allan B. Cobb
Editor in Chief

Geological Time Scale

Eon	Era	Period	Epoch	Significant Events	Million Years Before Present
Phanerozoic	Cenozoic	Quaternary	Holocene	recorded human history, rise and fall of civilizations, global warming, habitat destruction, pollution mass extinction	0.01
			Pleistocene	Homo sapiens, ice ages	1.6
		Tertiary	Pliocene	global cooling, savannahs, grazing mammals	5.3
			Miocene	global warming, grasslands, Chalicotherium	24
			Oligocene		37
			Eocene	modern mammals flourish, ungulates	58
			Paleocene		66
	Mesozoic	Cretaceous		last of age of dinosaurs, modern mammals appear, flowering plants, insects	144
		Jurassic		large plant-eating dinosaurs, carnivorous dinosaurs, first birds, breakup of Pangea	208
		Triassic		lycophytes, glossopterids, and dicynodonts, and the dinosaurs	245
	Paleozoic	Permian		Permian ends with largest mass extinction in history of Earth, most marine invertebrates extinct	286
		Pennsylvanian		vast coal swamps, evolution of amniote egg allowing exploitation of land	320
		Mississippian		shallow seas cover most of Earth	360
		Devonian		vascular plants, the first tetrapods, wingless insects, arachnids, brachiopods, corals, and ammonite were also common, many new kinds of fish appeared	408
		Silurian		Coral reefs, rapid spread of jawless fish, first freshwater fish, first fish with jaws, first good evidence of life on land, including relatives of spiders and centipedes	438
		Ordovician		most dry land collected into Gondwana, many marine invertebrates, including graptolites, trilobites, brachiopods, and the conodonts (early vertebrates), red and green algae, primitive fish, cephalopods, corals, crinoids, and gastropods, possibly first land plants	505
		Cambrian		most major groups of animals first appear, Cambrian explosion	570
Precambrian	Proterozoic			stable continents first appear, first abundant fossils of living organisms, mostly bacteria and archaebacteria, first eukaryotes, first evidence of oxygen build-up	2500
	Archean			atmosphere of methane, ammonia, rocks and continental plates begin to form, oldest fossils consist of bacteria microfossils stromatolites, colonies of photosynthetic bacteria	3800
	Hadean			pre-geologic time, Earth in formation	4600

Time Range of Several Groups of Plants & Animals



COMPARISON OF THE FIVE-KINGDOM AND SIX-KINGDOM CLASSIFICATION OF ORGANISMS

Five Kingdom

- Kingdom: Monera
  - Phylum: Bacteria
  - Phylum: Blue-green algae (cyanobacteria)

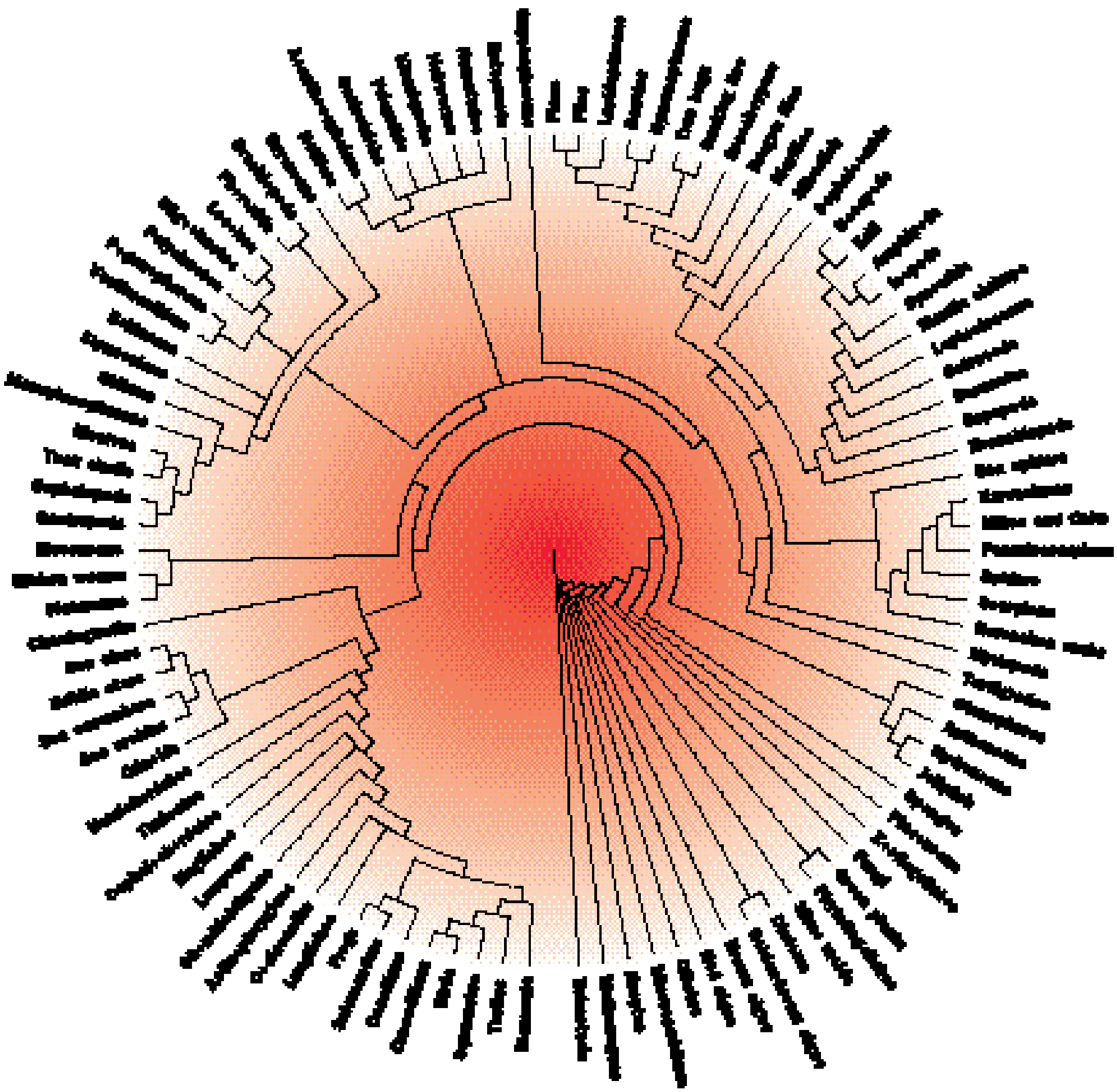
Six Kingdom

- Kingdom: Archaebacteria
- Kingdom: Eubacteria

- Kingdom: Protista
  - Phylum: Protozoans
    - Class: Ciliophora
    - Class: Mastigophora
    - Class: Sarcodina
    - Class: Sporozoa
  - Phylum: Euglenas
  - Phylum: Golden algae and diatoms
  - Phylum: Fire or golden brown algae
  - Phylum: Green algae
  - Phylum: Brown algae
  - Phylum: Red algae
  - Phylum: Slime molds
- Kingdom: Fungi
  - Phylum: Zygomycetes
  - Phylum: Ascomycetes
  - Phylum: Basidiomycetes
- Kingdom: Plants
  - Phylum: Mosses and liverworms
  - Phylum: Club mosses
  - Phylum: Horsetails
  - Phylum: Ferns
  - Phylum: Conifers
  - Phylum: Cone-bearing desert plants
  - Phylum: Cycads
  - Phylum: Ginko
  - Phylum: Flowering plants
    - Subphylum: Dicots (two seed leaves)
    - Subphylum: Monocots (single seed leaves)
- Kingdom: Animals
  - Phylum: Porifera
  - Phylum: Cnidaria
  - Phylum: Platyhelminthes
  - Phylum: Nematodes
  - Phylum: Rotifers
  - Phylum: Bryozoa
  - Phylum: Brachiopods
  - Phylum: Phoronida
  - Phylum: Annelids
  - Phylum: Mollusks
    - Class: Chitons
    - Class: Bivalves
    - Class: Scaphopoda
    - Class: Gastropods
    - Class: Cephalopods
  - Phylum: Arthropods
    - Class: Horseshoe crabs
    - Class: Crustaceans
    - Class: Arachnids
    - Class: Insects
    - Class: Millipedes and centipedes
  - Phylum: Echinoderms
  - Phylum: Hemichordata
  - Phylum: Cordates
    - Subphylum: Tunicates
    - Subphylum: Lancelets
    - Subphylum: Vertebrates
      - Class: Agnatha (lampreys)
      - Class: Sharks and rays
      - Class: Bony fishes
      - Class: Amphibians
      - Class: Reptiles
      - Class: Birds
      - Class: Mammals
          - Order: Monotremes
          - Order: Marsupials
        - Subclass: Placentals
          - Order: Insectivores
          - Order: Flying lemurs
          - Order: Bats
          - Order: Primates (including humans)
          - Order: Edentates
          - Order: Pangolins
          - Order: Lagomorphs
          - Order: Rodents
          - Order: Cetaceans
          - Order: Carnivores
          - Order: Seals and walruses
          - Order: Aardvark
          - Order: Elephants
          - Order: Hyraxes
          - Order: Sirenians
          - Order: Odd-toed ungulates
          - Order: Even-toed ungulates

PHYLOGENETIC TREE OF LIFE

This diagram represents the phylogenetic relationship of living organisms, and is sometimes called a “tree of life.” Often, these diagrams are drawn as a traditional “tree” with “branches” that represent significant changes in the development of a line of organisms. This phylogenetic tree, however, is arranged in a circle to conserve space. The center of the circle represents the earliest form of life. The fewer the branches between the organism’s name and the center of the diagram indicate that it is a “lower” or “simpler” organism. Likewise, an organism with more branches between its name and the center of the diagram indicates a “higher” or “more complex” organism. All of the organism names are written on the outside of the circle to reinforce the idea that all organisms are highly evolved forms of life.



SI BASE AND SUPPLEMENTARY UNIT NAMES AND SYMBOLS

Physical Quality	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd
Plane angle	radian	rad
Solid angle	steradian	sr

Temperature

Scientists commonly use the Celsius system. Although not recommended for scientific and technical use, earth scientists also use the familiar Fahrenheit temperature scale (°F). 1°F = 1.8°C or K. The triple point of H_2O, where gas, liquid, and solid water coexist, is 32°F.

- To change from Fahrenheit (F) to Celsius (C):
  °C = (°F-32)/(1.8)
- To change from Celsius (C) to Fahrenheit (F):
  °F = (°C x 1.8) + 32
- To change from Celsius (C) to Kelvin (K):
  K = °C + 273.15
- To change from Fahrenheit (F) to Kelvin (K):
  K = (°F-32)/(1.8) + 273.15

UNITS DERIVED FROM SI, WITH SPECIAL NAMES AND SYMBOLS

Derived Quantity	Name of SI Unit	Symbol for SI Unit	Expression in Terms of SI Base Units
Frequency	hertz	Hz	s-1
Force	newton	N	m kg s-2
Pressure, stress	Pascal	Pa	N m-2 =m-1 kg s-2
Energy, work, heat	Joule	J	N m =m2 kg s-2
Power, radiant flux	watt	W	J s-1 =m2 kg s-3
Electric charge	coulomb	C	A s
Electric potential, electromotive force	volt	V	J C-1 =m-2 kg s-3 A-1
Electric resistance	ohm	_	V A-1 =m2 kg s-3 A-2
Celsius temperature	degree Celsius	C	K
Luminous flux	lumen	lm	cd sr
Illuminance	lux	lx	cd sr m-2

UNITS USED WITH SI, WITH NAME, SYMBOL, AND VALUES IN SI UNITS

The following units, not part of the SI, will continue to be used in appropriate contexts (e.g., angtsrom):

Physical Quantity	Name of Unit	Symbol for Unit	Value in SI Units
Time	minute	min	60 s
	hour	h	3,600 s
	day	d	86,400 s
Plane angle	degree	°	(π/180) rad
	minute	'	(π/10,800) rad
	second	"	(π/648,000) rad
Length	angstrom	Å	10^{-10} m
Volume	liter	l, L	1 dm^3 = 10^{-3} m^3
Mass	ton	t	1 mg = 10^3 kg
	unified atomic mass unit	u (=$m_a(^{12}C)/12$)	≈1.66054 x 10^{-27} kg
Pressure	bar	bar	10^5 Pa = 10^5 N m^{-2}
Energy	electronvolt	eV (= e X V)	≈1.60218 x 10^{-19} J

CONVERSIONS FOR STANDARD, DERIVED, AND CUSTOMARY MEASUREMENTS

Length

1 angstrom (Å)	0.1 nanometer (exactly) 0.000000004 inch
1 centimeter (cm)	0.3937 inches
1 foot (ft)	0.3048 meter (exactly)
1 inch (in)	2.54 centimeters (exactly)
1 kilometer (km)	0.621 mile
1 meter (m)	39.37 inches 1.094 yards
1 mile (mi)	5,280 feet (exactly) 1.609 kilometers
1 astronomical unit (AU)	1.495979 x 10^{13} cm
1 parsec (pc)	206,264.806 AU 3.085678 x 10^{18} cm 3.261633 light-years
1 light-year	9.460530 x 10^{17} cm

Area

1 acre	43,560 square feet (exactly) 0.405 hectare
1 hectare	2.471 acres
1 square centimeter (cm^2)	0.155 square inch
1 square foot (ft^2)	929.030 square centimeters
1 square inch (in^2)	6.4516 square centimeters (exactly)
1 square kilometer (km^2)	247.104 acres 0.386 square mile
1 square meter (m^2)	1.196 square yards 10.764 square feet
1 square mile (mi^2)	258.999 hectares

MEASUREMENTS AND ABBREVIATIONS

Volume

1 barrel (bbl)*, liquid	31 to 42 gallons
1 cubic centimeter (cm^3)	0.061 cubic inch
1 cubic foot (ft^3)	7.481 gallons 28.316 cubic decimeters
1 cubic inch (in^3)	0.554 fluid ounce
1 dram, fluid (or liquid)	⅛ fluid ounce (exactly) 0.226 cubic inch 3.697 milliliters
1 gallon (gal) (U.S.)	231 cubic inches (exactly) 3.785 liters 128 U.S. fluid ounces (exactly)
1 gallon (gal) (British Imperial)	277.42 cubic inches 1.201 U.S. gallons 4.546 liters
1 liter	1 cubic decimeter (exactly) 1.057 liquid quarts 0.908 dry quart 61.025 cubic inches
1 ounce, fluid (or liquid)	1.805 cubic inches 29.573 milliliters
1 ounce, fluid (fl oz) (British)	0.961 U.S. fluid ounce 1.734 cubic inches 28.412 milliliters
1 quart (qt), dry (U.S.)	67.201 cubic inches 1.101 liters
1 quart (qt), liquid (U.S.)	57.75 cubic inches (exactly) 0.946 liter

* There are a variety of "barrels" established by law or usage. For example, U.S. federal taxes on fermented liquors are based on a barrel of 31 gallons (141 liters); many state laws fix the "barrel for liquids" as 31½ gallons (119.2 liters); one state fixes a 36-gallon (160.5 liters) barrel for cistern measurement; federal law recognizes a 40-gallon (178 liters) barrel for "proof spirits"; by custom, 42 gallons (159 liters) comprise a barrel of crude oil or petroleum products for statistical purposes, and this equivalent is recognized "for liquids" by four states.

Units of mass

1 carat (ct)	200 milligrams (exactly) 3.086 grains
1 grain	64.79891 milligrams (exactly)
1 gram (g)	15.432 grains 0.035 ounce
1 kilogram (kg)	2.205 pounds
1 microgram (μg)	0.000001 gram (exactly)
1 milligram (mg)	0.015 grain
1 ounce (oz)	437.5 grains (exactly) 28.350 grams
1 pound (lb)	7,000 grains (exactly) 453.59237 grams (exactly)
1 ton, gross or long	2,240 pounds (exactly) 1.12 net tons (exactly) 1.016 metric tons
1 ton, metric (t)	2,204.623 pounds 0.984 gross ton 1.102 net tons
1 ton, net or short	2,000 pounds (exactly) 0.893 gross ton 0.907 metric ton

Pressure

1 kilogram/square centimeter (kg/cm^2)	0.96784 atmosphere (atm) 14.2233 pounds/square inch (lb/in^2) 0.98067 bar
1 bar	0.98692 atmosphere (atm) 1.02 kilograms/square centimeter (kg/cm^2)

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Absorption

The process by which substances are taken into the tissues of organisms is called absorption. It is essential to functions such as digestion, circulation, and respiration.

During digestion, valuable nutrients are absorbed across the **epithelial lining** of the digestive tract. Absorption occurs largely in the small intestine, which has developed a large surface area for this purpose. The walls of the small intestine contain numerous finger-like projections called villi, which are in turn covered by countless microvilli. Different nutrients are absorbed across the gut epithelium in different ways.

The methods of absorption include **active transport**, **facilitated diffusion**, and **passive diffusion**. Active transport requires energy in the form of **adenosine triphosphate** (**ATP**), as well as special carrier molecules that ferry nutrients, (their substrates), across the gut lining. Active transport is involved in the absorption of proteins, which have usually been processed into amino acids or other small peptides. Most ions are also absorbed through active transport, as are most carbohydrates.

Some carbohydrates, however, are absorbed in a process known as facilitated diffusion. Facilitated diffusion describes a situation in which special carrier molecules are necessary, but energy (ATP) is not. Fructose is an example of a carbohydrate that is absorbed through facilitated diffusion.

Other nutrients, such as **lipids**, are absorbed through passive diffusion. In passive diffusion, neither energy expenditure nor a special carrier molecule is required. Lipids interact with bile salts from the liver, combining with them to form structures known as micelles. Micelles are able to diffuse freely through cell membranes and so can pass directly across the gut lining. Water is another substance that diffuses passively across the gut walls.

The circulatory system transfers nutrients and other products throughout the body. Tissues absorb the products they need from tiny blood vessels called capillaries. Capillaries are characterized by very high surface areas and very low blood-flow rates, both of which facilitate absorption. The walls of capillaries are also very thin, consisting of only one or a few layers of flattened endothelial cells. Capillaries also possess small pores through which transport and absorption can occur.

epithelial lining sheets of tightly packed cells that cover organs and body cavities

active transport a process requiring energy where materials are moved from an area of lower concentration to an area of higher concentration

facilitated diffusion the spontaneous passing of molecules attached to a carrier protein across a membrane

passive diffusion the passing of molecules across a membrane from an area of higher concentration to an area of lower concentration without any energy input

adenosine triphosphate (ATP) an energy-storing molecule that releases energy when one of the phosphate bonds is broken; often referred to as ATP

lipids fats and oils; organic compounds that are insoluble in water

The absorption of materials from the capillaries occurs in one of several ways. Lipid-soluble substances are able to diffuse directly across the cell membranes of capillary cells into the tissues. Water diffuses directly as well, although it makes use of special pores in the cell membranes of capillary cells. Exchange via diffusion is comparatively rapid.

The absorption of other nutrients from the blood requires transportation through the capillary walls inside special vesicles. This process is called transcytosis. The vesicles are membrane-bound and are believed to be constructed by a cellular organelle known as the Golgi apparatus. Vesicles shuttle products repeatedly between the inner and outer walls of capillary cells. Because capillary beds in the brain are characterized by fewer transport vesicles, many substances cannot be absorbed into brain tissue, and the absorption of those that can be is slowed. This is often referred to as the blood-brain barrier.

integument a natural outer covering

lungs sac-like, spongy organs where gas exchange takes place

gills site of gas exchange between the blood of aquatic animals such as fish and the water

trachea the tube in air-breathing vertebrates that extends from the larynx to the bronchi

erythrocytes red blood cells, containing hemoglobin that carry oxygen through the body

respiratory pigments any of the various proteins that carry oxygen

hemoglobin an iron-containing protein found in red blood cells that binds with oxygen

In the process of respiration, oxygen is absorbed by the **integument**, **lungs**, **gills**, or **trachea** from the air or water. As with the circulatory and digestive systems, large respiratory surface areas allow for efficient absorption.

Oxygen is absorbed from the environment by the red blood cells, or **erythrocytes**. Erythrocytes contain **respiratory pigments**, which bind oxygen and works to transport it to tissues. These specialized oxygen-binding molecules are called pigments because they are often brightly colored when carrying bound oxygen. Respiratory pigments have a high affinity for oxygen and are also able to dramatically increase the oxygen-carrying capacity of blood.

Hemoglobin is the respiratory pigment in vertebrate erythrocytes and is also common throughout the animal kingdom. Hemoglobin is a large molecule consisting of four polypeptide chains, each of which is capable of binding an oxygen molecule. The oxygen-binding part of the chain is called the heme group and includes an iron atom. Hemoglobin binds oxygen cooperatively, meaning that once it has bound a single oxygen molecule, it is more likely to bind additional oxygen molecules. Hemoglobin's oxygen affinity, or the degree to which oxygen binds to it, varies according to such external factors as pH. This plasticity (flexibility) of oxygen affinity allows hemoglobin simultaneously to bind oxygen in the oxygen-rich environment of the lungs and to release it in the oxygen-poor environments of the tissues.

Another respiratory pigment, myoglobin, is present in the muscles and is responsible for pulling oxygen molecules from the blood into the tissues. Myoglobin resembles hemoglobin but consists of only a single polypeptide chain. SEE ALSO DIGESTION; TRANSPORT.

Jennifer Yeh

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Acoustic Signals

Acoustic signals are noises that animals produce in response to a specific stimulus or situation, and that have a specific meaning. These may be vocal communications emitted from the animal's larynx, such as a wolf's howl; sounds produced by appendages, such as a cricket's chirp; or sounds created by an animal's interaction with its environment, such as a rabbit thumping the ground with its hind foot when it sights danger. The **physiological** characteristics of animals, such as throat shape or lung size, create constraints on the type of acoustic signals an animal produces. Similarly, the anatomical properties of the ear, and the processing capabilities of the auditory regions of the brain, can limit the range of sound that a species is capable of detecting. Compared with most mammals, humans have an abnormally complex system of **vocalization** that is supported by the expanded language centers of the brain, a dexterous tongue and throat, and powerful lungs. However, humans are unable to hear in the frequency range of animals that communicate at much higher pitches, such as voles, or animals that vocalize with lower pitches, such as certain species of whale.

physiological the basic activities that occur in the cells and tissues of an animal

vocalization the sounds used for communications

Signal Characteristics

Several features combine to create a meaningful auditory signal. The first of these is the frequency, or pitch, of a sound. Another variable is the amplitude, or loudness. Different combinations of these two features can drastically alter the meaning of a sound. For example, a dog that whines quietly is communicating pain with a high-frequency, low-amplitude sound; a dog that growls loudly is expressing anger with a low-frequency, high-amplitude sound. The repetition rate and duration of a particular sound are likewise important. Male frogs of certain species, such as the plains leopard frog, call during breeding season to attract females; females recognize the calls of their own species by the length of the call and its repetition rate (calls per minute). Other species of frog in the vicinity use the same frequency call but vary its length and repetition rate.

The circumstances that surround acoustic signals can also alter their meaning. These include the time of year, time of day, spatial location, weather conditions, and physiological state of the organism (such as reproductive state). A mating call presented to females outside of the mating season may have no effect—the females are not hormonally prepared to respond.

The Uses of Acoustic Signals

Animals use acoustic signals in several instances: conspecific communication, **sexual selection**, mother-young interactions, interspecies communication, orientation, and language.

sexual selection selection based on secondary sex characteristics that leads to greater sexual dimorphism or differences between the sexes

Conspecific communication. This (intraspecies communication) occurs between animals of the same species. Although sexual selection, mother-young interactions, and language are included in the category of conspecific communication, they will be explained separately because of their ecological importance. Conspecific communication can be very complex. For example, black-tailed prairie dogs live in very structured colonies that can cover tens of acres. When a prairie dog recognizes danger, it gives a warning call to