Diversity

- Over 9000 species have been described worldwide; only fishes have more species among vertebrates.
- Birds live in all biomes, from mountains to prairies, on all oceans, and from the North to the South Pole.
- Some live in dark caves, and some dive to 45 meters depth.
- The “bee” hummingbird is one of the smallest vertebrate endotherms.

Feather is the unique and essential feature or hallmark of birds; however, feathers were also present in some theropod dinosaurs, although these feathers were not capable of supporting flight and obviously served in other capacities such as thermoregulation or mating behavior.

Uniformity in Structure

- Despite 150 million years of evolution, birds are still readily recognized.
- Forelimbs are modified as wings, although not all are capable of flight.
- Hindlimbs are adapted for walking, swimming or perching.
- All birds have horny, keratinized beaks.
- All birds lay eggs.

Mammals, the endothermic evolutionary peers, have developed far more diverse forms

Adaptations necessary for flight

- Wings are present for support and propulsion.
- The respiratory system must meet high oxygen demands and cool the body.
- Bones must provide a light but rigid airframe.
- Digestion and circulation must meet the high-energy demands of flight.
- And the nervous system must have superb sensory systems for high-velocity flight.

History

Zoologists had long recognized that birds and reptiles shared many similarities.
- Both have skulls that abut the first neck vertebra by a single ball-and-socket joint.
- Both have a single middle ear bone, the stapes.
- The lower jaw in both is composed of five or six bones; in mammals there is one mandibular bone.
- Both birds and reptiles excrete nitrogenous wastes as uric acid; mammals excrete urea.
- Both lay similar yolked eggs; the embryo develops on the surface by shallow cleavage patterns.

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**Form and Function**

- **Feathers**
  - Several types
  - Homologous with reptile scales
  - The fully-grown feather is a dead structure; shedding or molting is an orderly process
    - Flight and tail feathers are lost in pairs, one on each side, to maintain balance.
    - In some species, replacement is continuous; therefore flight is unimpaired.
    - In many water birds, primary feathers are molted all at once and the birds are temporarily grounded.
    - Most birds molt once a year, usually in late summer after the nesting season.

**Skeleton**

- Modern birds have light, delicate bones laced with air cavities.
  - These are termed pneumatized bones; they are nevertheless strong.
- The total weight of a bird’s feathers may outweigh its skeleton.
- The skull is fused into one piece; the braincase and orbits are large to hold a larger brain and eyes.
- While the skull is lighter, the legs are heavier than in mammals; this lowers the center of gravity.

**Other Skeletal Features**

- Modern birds have a horny keratinous beak molded around bony jaws.
- Most birds have kinetic skulls; in some, the upper jaw is hinged to the skull.
- Vertebral column is very rigid; vertebrae are fused except for the cervical vertebrae.
- Much fusing of forelimbs to support flight

**Plan of Vertebrate Circulatory Systems**

- The principal difference in vertebrate systems is the separation of the heart into two pumps.
- These changes occurred as vertebrates converted from gill breathing to lungs.
- In fish, oxygenated blood is provided to the body organs before the veins return to the heart.
- Terrestrial animals evolved lung breathing and eliminated gills between heart and aorta.
Double Circulation

- This provided a high pressure system that provided oxygenated blood to capillary beds and a pulmonary circuit to serve the lungs.
- This change is seen in lungfishes and amphibians.
- Modern amphibians have separate atria.
  - The right atrium receives venous blood from the body.
  - The left receives oxygenated blood from the lungs.
- The ventricle is undivided but venous and arterial blood do not heavily mix.
- Ventricles are nearly separate in crocodilians and completely separate in birds and mammals.
- Systemic and pulmonary circulations are served by one half of a dual heart.

Circulation in Birds

- The four-chambered heart is large, with strong ventricular walls.
- Birds share with mammals a complete separation of respiratory and systemic circulations.
- The right aortic arch, instead of the left as in mammals, leads to the dorsal aorta.
- The heartbeat is relatively fast compared to mammals and is inversely proportional to size.
  - A turkey heart beats 93 times per minute.
  - A chicken heart beats 250 times per minute.
  - A small black-capped chickadee heart beats 500 times per minute.
- Bird red blood cells (erythrocytes) are nucleated and biconvex.
- Mobile phagocytes are active and efficient in repairing wounds and destroying microbes.

Respiration

- The bird respiratory system differs radically from the lungs of both reptiles and mammals.
- Bird Lungs
  - The finest branches of the bronchi do not terminate in alveoli but are tube-like parabronchi.
  - Air sacs extend into the thorax, abdomen, and even the long bones.
  - A large portion of the air bypasses the lungs and flows directly to the air sacs on inspiration.
  - On expiration, this oxygenated air flows through the lungs; therefore there is continuous air flow.
- Thus it takes two respiratory cycles for a single breath of air to pass through the system.
- This is the most efficient respiratory system of any vertebrate.
- An air sac system helps cool a bird during vigorous exercise when up to 27 times more heat is produced.
- The air sacs extend into bones, legs and wings, providing considerable buoyancy to the bird.

Excretory System

- Birds also use the reptilian adaptation of excreting nitrogenous wastes as uric acid.
- In shelled eggs, all excretory products remain within the eggshell; uric acid is stored harmlessly.
- Since uric acid has low solubility, a bird can use far less water to excrete wastes.
- Concentration of uric acid occurs almost entirely in the cloaca where water is absorbed.
- A bird kidney is less efficient than a mammal kidney in removing ions of sodium, etc.
Nervous System

- A bird’s nervous and sensory system must accommodate the problems of flight and a visual lifestyle.
- The bird’s brain has well-developed cerebral hemispheres, cerebellum and midbrain tectum.
- The cerebral cortex, a chief coordinating center in mammals, is thin, unfissured and poorly developed.
- The core of the cerebrum, the corpus striatum, is enlarged into the principal integrating center.
- The size of the cerebral hemisphere is directly related to the intelligence of the bird.
- The cerebellum is where muscle-position sense (proprioception), equilibrium sense and visual cues are assembled.

Special Senses

- The optic lobes bulge to each side of the midbrain and form a visual association apparatus.
- Sense of smell is poorly developed except in flightless birds, ducks and vultures.
- Birds have good hearing and superb vision, the best in the animal kingdom.
- The bird ear is similar to the ear of mammals.
  - The external ear canal leads to an eardrum.
  - The middle ear contains a rod-like columella that transmits vibrations to the inner ear.
  - An inner ear has a short cochlea; it allows birds to hear about the same range of sound as humans.

Vision

- Eye is similar to the mammal eye, but it is relatively larger for a given body size.
- A bird eye is less spherical and almost immobile; a bird turns its head rather than its eyes.
- The light-sensitive retina has both rods and cones.
- Diurnal birds have more cones; nocturnal birds have more rods.

Eye Placement

- Vegetarians must avoid predators and they have eyes placed to each side to view all directions.
- Birds of prey have eyes directed forward to provide better depth perception.
- Many birds have two foveae or regions of detailed vision; this provides both sharp monocular and binocular vision.
- A hawk has eight times the visual acuity of a human and can see a rabbit over a kilometer away.
- An owl’s ability to see in dim light is more than ten times that of a human.
- Many birds can see partially into the ultraviolet spectrum, seeing flower nectar guides.

Flight

- The early airspace was an unexploited habitat with flying insects for food.
- Flight also provided rapid escape from predators and ability to travel to better environments.
- There are two hypotheses on the evolution of bird flight.
  1) The “ground-up” hypothesis is based on running birds with primitive wings to snare insects.
  2) The “trees-down” hypothesis has birds passing through tree-climbing, leaping, parachuting, gliding, and finally powered flight.
- Feathers preceded flight and arose for thermoregulatory purposes.
- There is no evidence for bird ancestors first being membrane-winged.
- The debate about the origin of flight has not been settled.
**Bird Wing as a Lift Device**

- The modified hand bones with attached primary feathers provide the propulsion.
- Lift is provided by the more medial part of the wing and secondary feathers of the forearm.
- A wing is streamlined with a concave lower surface.
- The leading edge of the wing has small tight-fitting feathers.
- Over two-thirds of the total lift comes from negative pressure from the airstream flowing a longer distance over the top of the wing, the convex surface.
- Lift-to-drag ratio is determined by the angle of tilt and the airspeed.

**Flight**

- A wing can carry a given load by high speed and small angle of attack, or low speed and larger angle of attack.
- As speed decreases, increasing the angle of attack increases lift, but this also increases drag.
- At a point near 15°, the angle of attack becomes too steep and stalling occurs.
- Stalling is delayed or prevented by a wing slot along the leading edge to direct rapidly moving air across the leading surface.

**Basic Forms of Bird Wings**

- **Elliptical Wings**
  1) Birds that must maneuver in forested habitats have elliptical wings.
  2) Elliptical wings are slotted between primary feathers to prevent stalling at low speeds, etc.
  3) The small chickadee can change its course within 0.03 seconds.

- **High-Speed Wings**
  1) Birds that feed on the wing or make long migrations have high-speed wings.
  2) These wings sweep back and taper to a slender tip; this reduces "tip vortex" turbulence.
  3) They are flat in section and lack wing-tip slotting.

- **Soaring Wings**
  1) Albatrosses, gannets and other oceanic soaring birds have wings with long, narrow wings.
  2) The high-aspect ratio of long, narrow wings lack wing slots and allow high speed, high lift and dynamic soaring.
  3) They have the highest aerodynamic efficiency of any design, but are less maneuverable.
  4) These birds exploit the highly reliable sea winds and air currents of different velocities.

- **High-Lift Wings**
  1) Vultures, hawks, eagles, owls and other birds of prey that carry heavy loads have wings with slotting, alulas and pronounced camber.
  2) This produces high lift at slow speed.
  3) Many are land soarers; their broad, slotted wings allow sensitive response for static soaring.

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**Fig. 27.19**

1. Elliptical wings
2. High-speed wings
3. Soaring wings
4. High-lift wings
Reproductive System

• Bird testes are very small until the approach of the breeding season, when they may enlarge 300 times.
• Before discharge, sperm are stored in a greatly enlarged seminal vesicle.
• Males of most species lack a penis; mating involves bringing cloacal surfaces in contact.
• In most birds, the left ovary and oviduct develop and the right ovary and oviduct degenerate.

Egg Production

• The expanded end of the oviduct, the infundibulum, receives the discharged eggs.
• Special glands add albumin or egg white to the egg as it passes down the oviduct.
• Farther down the oviduct, the shell membrane, shell, and shell pigments are also secreted.
• Fertilization must therefore take place in the upper oviduct before albumin and shell are added.
• Sperm remain alive in the oviduct for many days after a single mating.

Nesting and Care of Young

• Nearly all birds lay eggs that must be incubated by one or both parents.
• Eggs of most songbirds require 14 days for hatching; those of ducks and geese may require a month.
• Often the female performs most of the duties of incubation; rarely the male has equal or sole duties.

Parental Care

• Precocial birds are able to feed and run or swim as soon as they are hatched.
• Altricial birds are naked and helpless at birth and must be fed in the nest for a week or more.
• Nesting success in altricial birds is very low; sometimes barely 20% of nests produce young.