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HIGHLIGHTED HANDOUT

ZOO517T

Animal Form & Function-II (Theory)

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Animal Form & Function-II (Theory)

Comparative Physiology of Organ Systems — Study Handout

This handout covers ZOO517T Animal Form & Function-II (Theory): how animal organ systems are built (form) and how they work (function), compared across taxa from invertebrates to vertebrates. The comparative method is the heart of the course — for every system, learn the invertebrate solution, the vertebrate solution, and the evolutionary logic connecting them.

Answer pattern for exams: describe the structure, explain the mechanism, compare across two or three animal groups, and state the adaptive significance.

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Unit 1: Organization Levels and Body Plans

Lectures 1–4

Learning Objectives

- Describe levels of organization from cell to organ system
- Explain symmetry, cephalization and body cavities
- Compare acoelomate, pseudocoelomate and coelomate plans
- Relate body plan to physiological possibilities

Levels of Organization

Cells → tissues (epithelial, connective, muscle, nervous) → organs → organ systems. **Form constrains function:** surface-area-to-volume ratio dictates whether diffusion suffices (flatworms) or transport systems are needed (vertebrates); a rigid exoskeleton limits size but a hydrostatic skeleton limits it differently.

Symmetry and Cephalization

Asymmetry — sponges; no axis. Radial — cnidarians, echinoderms (adults); sessile or planktonic life. Bilateral — active directional movement; paired structures.

- **Cephalization:** concentration of sense organs and nerve tissue anteriorly — the prerequisite for a brain; most developed in active bilateral predators (cephalopods, vertebrates).

Body Cavities

Acoelomate — no cavity (platyhelminths); gut surrounded by parenchyma; diffusion-limited, flattened body.

Pseudocoelomate — cavity between mesoderm and endoderm (nematodes); hydrostatic skeleton for movement.

Coelomate — true cavity lined by mesoderm (annelids to vertebrates); space for organ systems, hydrostatic skeleton, shock absorption.

- The coelom was a physiological breakthrough: room for a through-gut, separate muscle layers for peristalsis, and transport systems independent of body-wall movement.

> *Why are flatworms flat? No circulatory or respiratory system — every cell must lie near the surface for diffusion. The body plan IS the physiology: flattening is the acoelomate solution to the surface-area problem that coelomates solve with circulatory systems.*

Unit Summary

- Organization: cells → tissues → organs → systems; form constrains function.
- Bilateral symmetry + cephalization = active, directed life with brains.
- Acoelomate/pseudocoelomate/coelomate: the cavity determines what physiology is possible.

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Exam Pointers

- ★ Relate the flatworm body plan to its lack of transport systems.
- ★ Compare the three body-cavity plans with one example each.
- ★ What is cephalization and which lifestyle selects for it?

Unit 2: Integument: Skin and Its Derivatives

Lectures 5–7

Learning Objectives

- Describe vertebrate skin structure: epidermis and dermis
- Compare fish, amphibian, reptile, bird and mammal integument
- Explain skin functions: protection, thermoregulation, sensation
- Describe derivatives: scales, feathers, hair, glands

Basic Structure

Epidermis (ectoderm): stratified epithelium, keratinized in terrestrial vertebrates; the barrier. **Dermis** (mesoderm): connective tissue with blood vessels, nerves, glands, chromatophores, and dermal bone/scales. Basement membrane joins them.

Comparative Survey

Fish — thin epidermis with mucous glands (slime reduces drag, fights infection); dermal scales (ganoid, cycloid).

Amphibians — thin, moist, highly vascular skin: cutaneous respiration; poison/mucous glands; must stay moist.

Reptiles — thick keratinized scales/scutes; waterproof; no skin glands (except scent glands).

Birds — thin skin; feathers (epidermal) for flight, insulation, display; uropygial (preen) gland only.

Mammals — hair (epidermal) for insulation; sweat, sebaceous and mammary glands (dermal/epidermal); thick dermis.

Functions

- **Protection:** keratin, scales, mucus vs abrasion, pathogens, UV, desiccation.
- **Thermoregulation:** insulation (fur, feathers, blubber), evaporative cooling (sweat, panting), vascular shunts.
- **Sensation, excretion** (minor), **vitamin D synthesis**, coloration (camouflage, warning, display via chromatophores).

Trade-off case: amphibian skin breathes but leaks water — confining amphibians to moist habitats. Reptilian keratin solved desiccation but sacrificed cutaneous respiration — lungs had to take over fully. Each integument is a bargain with the environment.

Unit Summary

- Skin = epidermis (barrier) + dermis (support, glands, vessels).
- Fish (mucus/scales) → amphibian (respiratory, moist) → reptile (keratinized, dry) → bird (feathers) → mammal (hair, glands).

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- Functions: protection, thermoregulation, sensation, coloration — each group optimizes differently.

Exam Pointers

★ Compare amphibian and reptile skin and relate to habitat.

★ List five skin functions with the structure serving each.

★ Feathers vs hair: common functions, different origins — discuss.

Unit 3: Skeletal System: Support and Movement

Lectures 8–11

Learning Objectives

- Compare hydrostatic, exoskeletal and endoskeletal systems
- Describe vertebrate axial and appendicular skeleton
- Explain bone structure and remodeling
- Relate skeletal design to locomotion

Three Skeletal Strategies

Hydrostatic — fluid-filled cavity + muscle antagonism (earthworms, nematodes); cheap but size-limited.

Exoskeleton — chitinous cuticle (arthropods) or shell (molluscs); great protection, must molt (vulnerable, growth stepwise).

Endoskeleton — internal bone/cartilage (vertebrates, echinoderms); grows continuously, muscles attach inside; needs mineral metabolism.

Vertebrate Skeleton

- **Axial:** skull, vertebral column (regionalized: cervical, thoracic, lumbar, sacral, caudal), ribs, sternum — protection (brain, cord, heart/lungs) and body axis.
- **Appendicular:** pectoral/pelvic girdles + limb bones — locomotion; homologous pentadactyl limb modified into wings, flippers, legs, arms.

Bone Biology

Bone = **compact** (dense, Haversian systems/osteons) + **spongy** (trabeculae along stress lines) + marrow. **Ossification:** intramembranous (flat bones) or endochondral (cartilage model replaced — long bones). **Remodeling:** osteoblasts build, osteoclasts resorb — bone adapts to stress (Wolff's law) and serves as calcium/phosphate reservoir regulated by parathyroid hormone and calcitonin.

> *Homology case: bat wing, whale flipper, human arm — same pentadactyl bones, different proportions and functions. This is the textbook evidence for common descent AND the form-function principle: one skeletal plan, many ecological solutions.*

Unit Summary

- Hydrostatic (soft-bodied), exoskeleton (molt-limited), endoskeleton (continuous growth).
- Axial (protection, axis) vs appendicular (locomotion); pentadactyl limb homology.
- Bone is living: osteons, remodeling by osteoblasts/osteoclasts, mineral reservoir.

Exam Pointers

★ Compare the three skeletal types with advantages and limits.

★ Explain bone remodeling and hormonal calcium control.

★ Use the pentadactyl limb to illustrate homology vs analogy.

Unit 4: Muscular System and Locomotion

Lectures 12–14

Learning Objectives

- Describe skeletal muscle ultrastructure and the sliding-filament mechanism
- Distinguish skeletal, cardiac and smooth muscle
- Explain muscle energetics: ATP, creatine phosphate, fiber types
- Compare swimming, flying and terrestrial locomotion

Sliding Filament Theory

Sarcomere (Z-line to Z-line): thin **actin** filaments slide past thick **myosin** filaments — filaments don't shorten, overlap increases. Cycle: 1) Ca²■ released from sarcoplasmic reticulum binds troponin, moving tropomyosin off actin's binding sites; 2) myosin heads (energized by ATP) bind actin; 3) power stroke pulls actin (ADP + Pi released); 4) new ATP detaches the head. Rigor mortis = no ATP, heads locked.

Muscle Types and Fibers

Skeletal — striated, voluntary, multinucleate; fast, fatigable.

Cardiac — striated, involuntary, branched with intercalated discs (gap junctions synchronize); tireless.

Smooth — non-striated, involuntary (gut, vessels); slow, sustained, economical.

- **Fiber types:** slow oxidative (Type I, red — endurance), fast glycolytic (Type IIb, white — sprint), fast oxidative (IIa, intermediate).

Locomotion Modes

- **Swimming:** undulation (fish lateral waves; muscle blocks/myomeres), jet propulsion (squid, scallops), paddling.
- **Flying:** powered (birds, bats — high metabolic cost, keeled sternum, air sacs) vs gliding/soaring.
- **Terrestrial:** crawling (peristalsis, hydrostatic), walking/running (limb levers, gaits), jumping, burrowing.

Energetics: ATP → immediate (seconds), creatine phosphate → seconds–~10s, anaerobic glycolysis → ~1 min (lactate), aerobic respiration → sustained. A cheetah's sprint runs on the first three; a migrating bird on the last — fiber-type ratios match lifestyle.

Unit Summary

- Contraction = Ca²■-triggered actin–myosin cross-bridge cycling powered by ATP; sarcomere shortens by overlap.
- Skeletal/cardiac/smooth differ in control, structure and fatigue resistance; fiber types match lifestyle.
- Locomotion: undulation, jet, flapping, limb gaits — each with musculoskeletal adaptations.

Exam Pointers

- ★ Describe the cross-bridge cycle step by step.
- ★ Compare the three muscle types in a table.
- ★ Relate fiber-type distribution to a sprinter vs marathoner (or cheetah vs migrant bird).

Unit 5: Digestive System: From Ingestion to Absorption

Lectures 15–18

Learning Objectives

- Compare intracellular vs extracellular digestion
- Trace the vertebrate gut plan and regional specializations
- Explain mechanical and chemical digestion
- Relate gut design to diet: herbivore, carnivore, ruminant

Digestive Strategies

Intracellular — sponges, cnidarians partly: food vacuoles, lysosomal enzymes; fine for small prey.

Extracellular — the through-gut (mouth → anus): food processed in a tube while the animal does other things; allows regional specialization and continuous feeding.

Vertebrate Gut Regions

- **Mouth/pharynx:** ingestion, mechanical breakdown (teeth — dentition matches diet), salivary amylase.
- **Esophagus → stomach:** acid (HCl) + pepsin; churning; the kill-chamber for pathogens.
- **Small intestine:** duodenum receives bile (fat emulsification, liver) and pancreatic enzymes; jejunum/ileum absorb via villi + microvilli (huge surface area).
- **Large intestine:** water absorption, fermentation by microbiota, feces formation.

Dietary Adaptations

- **Carnivores:** short gut, sharp teeth, expandable stomach.
- **Herbivores:** long gut, fermentation chambers — **ruminants** (multi-chambered stomach: rumen microbes digest cellulose, regurgitation/rumination), hindgut fermenters (horse, rabbit — cecum; rabbits practice coprophagy to recover nutrients).
- Birds: crop (storage), gizzard (grinding — stones replace teeth).

Surface-area math: human small intestine ~6 m long but villi + microvilli expand absorption area to ~200 m² (a tennis court). Exam questions on absorption always want: folds → villi → microvilli, rich blood supply, thin epithelium, lacteals for fats.

Unit Summary

- Through-gut enables regional specialization; intracellular digestion is the primitive alternative.
- Stomach = acid/churning; small intestine = digestion + massive absorption surface; large intestine = water/microbes.
- Gut length and fermentation chambers match diet: ruminants and hindgut fermenters solve cellulose.

Exam Pointers

- ★ Trace food through the vertebrate gut with the digestion at each region.
- ★ Explain four adaptations that maximize absorption area.
- ★ Compare ruminant and carnivore guts and relate to diet.

Unit 6: Respiratory System: Gas Exchange

Lectures 19–22

Learning Objectives

- State the principles: diffusion, surface area, ventilation
- Compare gills, tracheae, book lungs and vertebrate lungs
- Explain countercurrent exchange
- Describe breathing mechanics in mammals and birds

Exchange Principles

All respiratory surfaces are **thin, moist, large-area, and well-perfused**. Gases diffuse down partial-pressure gradients; ventilation (water/air flow) and perfusion (blood flow) maintain the gradients. Fick's law intuition: rate ∝ area × gradient / thickness.

Comparative Organs

Body surface — small/flat animals (diffusion only).

Gills — fish: filaments/lamellae with **countercurrent flow** (water vs blood in opposite directions) extracting up to 80–90% of dissolved O■.

Tracheae — insects: air tubes opening at spiracles, delivering O■ directly to tissues; no blood transport needed; size-limited by diffusion distances.

Book lungs — spiders/scorpions: stacked lamellae like book pages.

Lungs — amphibians (simple sacs + skin), reptiles (partitioned), mammals (alveoli: ~300 million, huge area), birds (parabronchi with cross-current flow + air sacs — the most efficient).

Ventilation Mechanics

- **Mammals:** negative-pressure breathing — diaphragm + rib muscles expand thorax; air in down the pressure gradient. Tidal flow (in-out same path) leaves dead-space air.
- **Birds:** air sacs drive **unidirectional** flow through parabronchi — fresh air on both inspiration and expiration; supports flight's extreme O■ demand.
- **Fish:** buccal-opercular pumping drives water over gills.

Countercurrent logic: if blood and water flowed the same way, blood could at best equilibrate to the outgoing (oxygen-poor) water. Opposing flows keep a gradient along the whole lamella, so blood keeps loading O■ — the same engineering as industrial heat exchangers.

Unit Summary

- Exchange needs thin, moist, large, perfused surfaces with maintained gradients.
- Gills (countercurrent), tracheae (direct), book lungs, vertebrate lungs (alveoli; birds unidirectional).
- Mammals: negative-pressure tidal breathing; birds: air-sac unidirectional flow.

Exam Pointers

- ★ Explain countercurrent exchange and why concurrent flow is inferior.
- ★ Compare insect tracheae with mammalian lungs (4 points).
- ★ How does the bird respiratory system support flight?

Unit 7: Circulatory System: Transport

Lectures 23–26

Learning Objectives

- Compare open and closed circulatory systems
- Trace vertebrate heart evolution: 2→3→4 chambers
- Explain double circulation and its advantage
- Describe blood composition and hemodynamics basics

Open vs Closed

Open — arthropods, most molluscs: hemolymph pumped into sinuses bathing tissues directly; low pressure, slow, fine for small/slow animals.

Closed — annelids, cephalopods, vertebrates: blood confined to vessels; high pressure, fast, directed — supports large active bodies.

Vertebrate Heart Evolution

- **Fish:** 2 chambers (1 atrium, 1 ventricle), single circulation: heart → gills → body → heart; blood pressure drops at gills.
- **Amphibians:** 3 chambers (2 atria, 1 ventricle); partial septation + differential shunting reduce mixing; double circulation begins.
- **Reptiles:** 3 chambers with partial ventricular septum (crocodilians: 4 chambers with shunts).
- **Birds/mammals:** 4 chambers, complete separation — high-pressure systemic circuit independent of pulmonary circuit; the engine of endothermy.

Blood and Flow

- **Components:** erythrocytes (O■ via hemoglobin), leukocytes (defense), platelets/thrombocytes (clotting), plasma (water, proteins, nutrients, hormones).
- **Hemodynamics:** pressure highest in arteries, drops across arterioles; exchange at capillaries (thin walls, slow flow); veins return via valves + skeletal-muscle pump. Cardiac output = heart rate × stroke volume.

> *Why did endothermy need 4 chambers? Maintaining high body temperature demands huge O■ delivery → high systemic pressure; mixing oxygenated with deoxygenated blood (as in 3-chamber hearts) would cripple delivery. Complete separation lets one pump run each circuit at its ideal pressure.*

Unit Summary

- Open (sinuses, low pressure) vs closed (vessels, high pressure) systems.
- Heart: fish 2-chamber single → amphibian/reptile 3-chamber → bird/mammal 4-chamber double circulation.

- Double circulation separates pulmonary and systemic pressures — prerequisite for endothermy.

Exam Pointers

★ Trace blood flow through a fish vs a mammal; explain the pressure consequence.

★ Why is complete ventricular septation linked to endothermy?

★ List blood components and one function each.

Unit 8: Excretory System and Osmoregulation

Lectures 27–30

Learning Objectives

- Distinguish osmoregulation from excretion
- Compare contractile vacuoles, nephridia, Malpighian tubules, kidneys
- Explain the mammalian nephron and urine formation
- Relate nitrogenous waste type to habitat

Two Problems, One System

Osmoregulation: balancing water and salts against the environment. **Excretion:** removing nitrogenous waste (from protein breakdown) and other metabolites. Freshwater animals fight water **gain**; marine/desert animals fight water **loss**.

Comparative Excretory Organs

Contractile vacuoles — freshwater protists/sponges: pump out excess water.

Protonephridia (flame cells) — flatworms: filter-like, mainly osmoregulation.

Metanephridia — annelids: ciliated funnels draining coelomic fluid.

Malpighian tubules — insects: secrete wastes into gut; water reabsorbed in rectum — brilliant water conservation.

Kidneys — vertebrates: millions of nephrons filtering blood.

The Nephron

Glomerulus → Bowman's capsule: pressure filtration of plasma (cells/proteins stay). **PCT:** reabsorb ~65% of filtrate (glucose fully, Na■, water). **Loop of Henle:** countercurrent multiplier builds medullary salt gradient (longer loop = more concentrated urine — desert mammals). **DCT + collecting duct:** fine-tuning under **ADH** (water) and **aldosterone** (Na■) control.

Nitrogenous Wastes

Ammonia — very toxic, very soluble: aquatic animals flush it directly (bony fish).

Urea — less toxic, needs water: mammals, amphibians (ureotelic).

Uric acid — non-toxic paste, minimal water: birds, reptiles, insects (uricotelic) — the key to the shelled egg and desert life.

Desert-rat case: long loops of Henle (steep medullary gradient), uricotelic-ish water economy, nocturnal behavior, dry feces, Malpighian-like rectal reabsorption analogues. Every arid adaptation is water conservation — organize answers around that single theme.

Unit Summary

- Osmoregulation (water/salt balance) + excretion (nitrogenous waste) = the excretory system's job.
- Organs escalate: vacuoles → nephridia → Malpighian tubules → kidneys.

- Nephron: filter (glomerulus) → reclaim (PCT) → concentrate (loop) → fine-tune (ADH/aldosterone). Waste type follows water availability.

Exam Pointers

★ Trace filtrate through the nephron with what happens in each segment.

★ Relate ammonia/urea/uric acid to habitat with examples.

★ How do Malpighian tubules conserve water?

Unit 9: Nervous and Endocrine Coordination

Lectures 31–34

Learning Objectives

- Compare nervous vs endocrine signaling
- Explain the neuron, action potential and synapse
- Describe vertebrate brain regions and functions
- Outline major endocrine glands and hormones

Two Control Systems

Nervous — fast, brief, targeted (neuron → specific cell); reflexes, movement, sensation.

Endocrine — slow, sustained, broadcast (hormone via blood); growth, metabolism, reproduction, homeostasis.

- They interlock: the **hypothalamus–pituitary axis** is the neuroendocrine bridge.

Neuron Signaling

Resting potential (~–70 mV, Na■/K■ pump). Stimulus opens Na■ channels → **depolarization** spike (+30 mV) → K■ efflux repolarizes → refractory period. The **all-or-none** action potential propagates without fading; **myelin + nodes of Ranvier** enable fast saltatory conduction (vertebrates). At the **synapse**, Ca²■ triggers neurotransmitter release (acetylcholine, etc.) onto the next cell.

Brains and Glands

- **Hindbrain:** medulla/pons (breathing, heart rate), cerebellum (coordination). **Midbrain:** visual/auditory relay. **Forebrain:** thalamus (relay), hypothalamus (homeostasis), cerebrum (cortex — cognition; hugely expanded in mammals, especially primates).
- **Pituitary** (master gland: GH, TSH, ACTH, gonadotropins), **thyroid** (thyroxine — metabolic rate), **adrenals** (adrenaline — fight-or-flight; cortisol — stress), **pancreas** (insulin/glucagon — blood glucose), **gonads** (sex steroids).
- **Feedback:** mostly negative (high thyroxine suppresses TSH) — the universal endocrine logic.

Diabetes case: insulin deficiency → cells starve amid plenty (glucose can't enter), liver pours out more glucose, blood sugar soars, kidneys spill glucose (osmotic diuresis — the classic excessive thirst/urination). One hormone's absence cascades through every system — ideal for 'integrate across units' exam questions.

Unit Summary

- Nervous: fast, precise; endocrine: slow, sustained; hypothalamus–pituitary links them.
- Action potential: Na■ in → K■ out, all-or-none, saltatory in myelinated fibers; synapses are chemical.

- Brain: hindbrain (vital functions), cerebellum (coordination), forebrain (homeostasis, cognition); endocrine control is negative-feedback loops.

Exam Pointers

★ Describe the action potential sequence and the role of myelin.

★ Name four endocrine glands, one hormone each, and its effect.

★ Explain negative feedback with the thyroid axis.

Unit 10: Integration: Homeostasis and Review

Lectures 35–36

Learning Objectives

- Explain homeostasis with feedback loops
- Compare thermoregulation strategies
- Integrate organ systems in a stress response
- Review the comparative method for exams

Homeostasis

Homeostasis (Cannon): maintaining stable internal conditions via **negative feedback** — sensor → control center → effector. Example: blood glucose (pancreas), body temperature (hypothalamus), blood Ca²■ (parathyroid/calcitonin), osmolarity (ADH/thirst). Positive feedback is rare (blood clotting, childbirth) — it amplifies rather than stabilizes.

Thermoregulation

Ectotherms — heat from environment; behavior (basking), low metabolic cost; performance varies with temperature.

Endotherms — metabolic heat; high, stable temperature; expensive (most food becomes heat).

- **Adaptations:** insulation (fur, feathers, blubber), countercurrent heat exchangers (dolphin flukes, bird legs), evaporative cooling, torpor/hibernation (controlled hypothermia to save energy).

Integrated Stress Response

A gazelle spotting a lion: **senses** (eyes) → **brain** assesses → **sympathetic + adrenaline**: heart rate up (circulatory), bronchioles dilate (respiratory), glucose mobilized (liver/endocrine), blood shunted to muscles (vascular), digestion paused. Every system from this course fires in one coordinated survival program — homeostasis under threat.

Comparative Method — Exam Strategy

For any 'compare X across groups' question: 1) state the functional problem, 2) describe each group's structural solution, 3) explain the mechanism, 4) state the adaptive significance / trade-off. Problem → structure → mechanism → significance. Apply relentlessly.

Final drill: pick any system (e.g., gas exchange) and run the four-step comparative answer for an aquatic invertebrate, a fish, and a mammal — in under 10 minutes. If you can do that for all systems, the final paper is yours.

Unit Summary

- Homeostasis = negative-feedback stability of the internal environment.
- Ectothermy (cheap, variable) vs endothermy (expensive, stable); insulation, exchangers, torpor manage heat.

- Stress responses integrate all systems; answer comparisons via problem → structure → mechanism → significance.

Exam Pointers

★ Explain homeostasis with the thermoregulation feedback loop.

★ Compare ectotherms and endotherms (costs and benefits).

★ Trace the organ-system responses to a predator encounter.

Key Terms Glossary

All key terms from this handout in one place — use for quick revision.

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