Unit 20 · Excretory System

STUDY NOTES

WHAT NEB'S GRADE 12 EXAM ASKS

- **CDC's grid (2078):** Human Biology (Units 17–24 together): 16 of 75 marks; 4 MCQs (knowledge, understanding, application, higher ability), 1 short question (4 marks: knowledge 1, application 2, higher ability 1) and 1 long question (8 marks: understanding 2, application 2, higher ability 4)
- **The paper:** Botany 37 + Zoology 38; each part: MCQs × 1 (5 Botany, 6 Zoology) · 4 short × 4 · 2 long × 8; one OR in each short and long group; 3 hours; 1 mark per expected point
- **Our model papers:** Paper 1 MCQ (share of filtrate reabsorbed: 125 mL/min filtered, 1 mL/min urine → 99.2%); Paper 2's long OR question (how filtrate forms; net filtration pressure from given pressures; glucose in urine, much urine and thirst in diabetes)
- **MCQ (1 mark)**
  - most toxic: ammonia; starfish: amino acids
  - tadpole ammonotelic; insects uricotelic
  - kidney retroperitoneal; afferent **arteriole**, not venule
  - ducts of Bellini → renal pelvis; obligatory water: PCT
  - urochrome colors urine; glucose most completely reabsorbed
  - juxtamedullary: long loops deep in the medulla; detrusor contracts
- **Short and long (in parts)**
  - excretion; types by nitrogenous waste; classify 22 animals
  - labeled kidney diagram; structure of the kidney
  - ultrafiltration; tubular secretion (who benefits)
  - urine; micturition
  - label kidney L.S. (A–D): cortex vs medulla; jobs of calyx, pelvis
  - label Malpighian body (A–G): afferent vs efferent; why glomerular pressure high
  - excretory organs with a diagram (long); nephron, urine formation (long); cortical vs juxtamedullary (long)

Key terms

Excretion: removal of **metabolic wastes** made by the body's own cells.

Egestion: passing out undigested food (feces); not excretion.

Homeostasis: keeping body fluids' water, salts, pH steady.

Deamination: $-NH_2$ removed from amino acids → **ammonia**.

Ammonotelism, **ureotelism**, **uricotelism**, **aminotelism**: nitrogen out mainly as ammonia, urea, uric acid, amino acids.

Retroperitoneal: behind the peritoneum, on the back wall of the abdomen.

Metanephros: the third, most advanced embryonic kidney (reptiles, birds, mammals).

Nephron (uriniferous tubule): **structural and functional unit** of the kidney.

Podocytes: foot cells of Bowman's capsule's inner layer; gaps = **filtration slits**.

Glomerular filtration rate (GFR): filtrate made by both kidneys per minute, ~125 mL.

Obligatory reabsorption: water taken back in the PCT whatever the need; **facultative**: in DCT and CD, with ADH.

Counter-current multiplier: the loop of Henle building the medulla's saltiness.

Micturition: passing urine; the **micturition reflex**.

Nitrogenous wastes

- wastes: **ammonia, urea, uric acid, creatinine**; excess water; salts; CO_2; used hormones, drugs
- proteins (and nucleic acids) → deamination → **ammonia**; form depends on **water** to spare

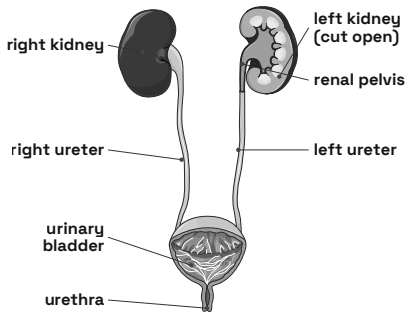
	Ammonia	Urea	Uric acid
toxicity	**highest**	less	**least**
solubility	very high	high	almost insoluble
water to pass out	a great deal	moderate	very little (paste)
made in	—	**liver** (NH_3 + CO_2)	—
animals	*Amoeba*, sponges, *Hydra*, tapeworms, leeches, crabs, prawns, aquatic mollusks, **bony fishes**, **tadpoles**, newts	**mammals**, humans, **adult frogs**, toads, **sharks, rays** (urea kept for the sea's saltiness), turtles	**insects**, land snails, **lizards, snakes, birds** (white of droppings)

- uric acid: dry places; young in a hard-shelled egg (no toxic ammonia builds up)
- **aminotelic**: *Unio*, *Limnaea*, starfish (*Asterias*): amino acids lost to the water

- **dual excretion**:
  - **earthworm**: ammonia (fed, wet) / urea (short of water, food)
  - **lungfish**: ammonia in water / urea in dried mud
  - *Xenopus*: ammonotelic in water, ureotelic out
  - **crocodile**: ammonia + uric acid
- marine **bony** fishes: mainly **ammonia** (sharks are the ureotelic ones); woodlice: **ammonia gas**

The urinary system

- **kidneys** (make urine) → **ureters** → **urinary bladder** (stores) → **urethra** (out)



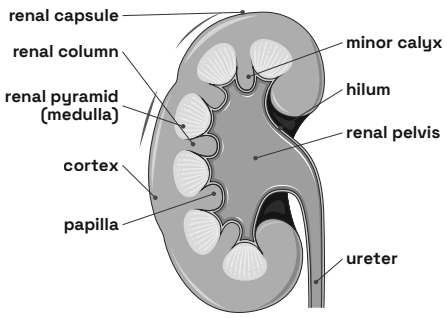
The human urinary system from the front.

Kidneys: outside

- dark red, **bean-shaped**; back wall of the abdomen, either side of the backbone, **T12–L3**
- **retroperitoneal**; **right lower** (pushed down by the liver)
- **~11 × 5.5 × 3 cm**; ~150 g (man), 135 g (woman)
- three coats: **renal capsule** (inner, fibrous) · **adipose capsule** (fat, cushions) · **renal fascia** (outer, anchors)
- outer convex border; inner concave border with the **hilum**: ureter, renal artery, renal vein, lymph vessels, nerves

Kidneys: L.S.

- **cortex**: outer, darker, ~⅓; Malpighian bodies, PCT, DCT
- **medulla**: inner, lighter, **striped**, ~⅔; **8–18 renal pyramids**; loops of Henle, collecting ducts, ducts of Bellini
- **renal columns** (columns of **Bertini**): cortex between pyramids
- **renal papilla** (pyramid tip) → **minor calyx** → 2–3 **major calyces** → **renal pelvis** → ureter
- **~1 million nephrons** each



A kidney cut lengthwise.

Ureters

- **25–30 cm**; whitish, muscular; open separately into the back of the bladder
- wall: fibrous · **smooth muscle** · mucosa with **transitional epithelium**
- **peristalsis** pushes urine in spurts (even upside down)
- slant through the bladder wall + mucosal fold = **valve**: no backflow

Urinary bladder

- hollow, **pear-shaped** muscular bag on the pelvic floor; stores urine
- wall: fibrous · thick smooth muscle (**detrusor**) · **transitional epithelium**
- **rugae**: folds when empty
- sympathetic and parasympathetic nerves
- **trigone**: smooth triangle, **3 openings** (2 ureters, urethra)
- holds **~500 mL** comfortably, up to ~1000; urge at **~300 mL**

Urethra

- **woman**: **~4 cm**; between clitoris and vagina; urine only; short → more urinary infections
- **man**: **~18–20 cm**; **prostatic** (~3) · **membranous** (1–2; shortest, narrowest) · **spongy (penile)** (~15); urine and semen: **urinogenital**
- **internal sphincter**: **smooth**, involuntary, bladder neck
- **external sphincter**: **striated**, voluntary

The nephron

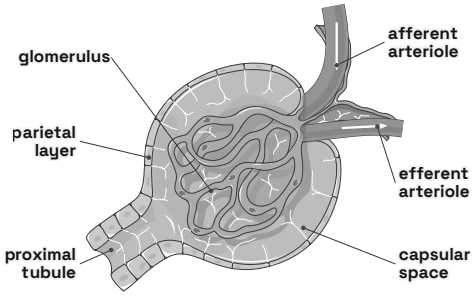
- ~1 million per kidney, **3–5.5 cm** long each
- **Malpighian body** (renal corpuscle, ~0.2 mm; the filter) + **renal tubule**

Bowman's capsule (Sir William Bowman)

- double-walled cup
- **outer (parietal) layer**: squamous epithelium
- **inner (visceral) layer**: **podocytes**, foot branches (**pedicels**) interlocking; **filtration slits** between
- **capsular (urinary) space** between the layers → tubule

Glomerulus

- tuft of capillaries pushing into the capsule
- **wide afferent arteriole** in → capillaries → **narrow efferent arteriole** out
- between two **arterioles** (not arteriole and venule)
- endothelium with **fenestrae** ~0.07–0.1 μm
- filtration under pressure

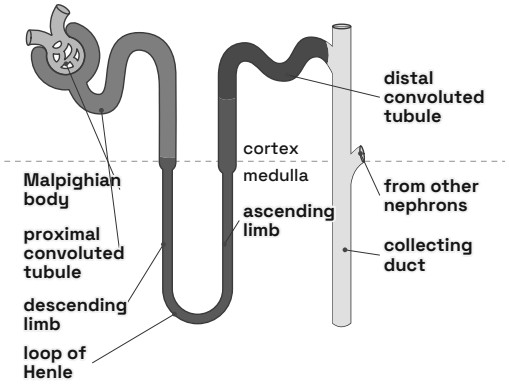


A Malpighian body cut open.

Renal tubule

- **PCT** (cortex): **cuboidal** cells with **brush border** (microvilli: area) and many **mitochondria** (ATP); **main site of reabsorption**

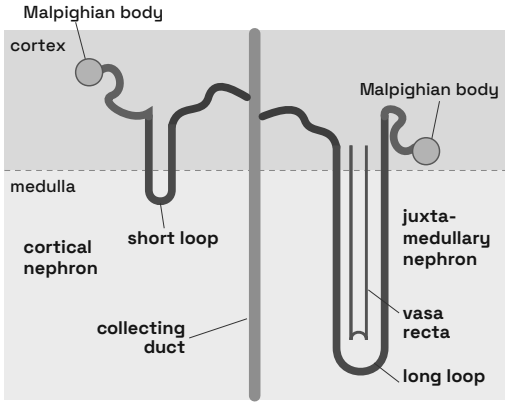
- **loop of Henle** (mostly medulla; U-shaped):
  - **descending limb**: thick part cuboidal, thin part squamous; **permeable to water**
  - **ascending limb**: thin (squamous; NaCl out **passively**), thick (cuboidal; NaCl **pumped out actively**); **impermeable to water**
- **DCT** (cortex): cuboidal, **no brush border**; Na^+, water back, K^+ secreted, under hormones; ends in a **connecting tubule**
- **collecting duct**: cuboidal and columnar; many DCTs; through the medulla → **ducts of Bellini** → renal papillae → calyces → pelvis
- urine's way: collecting duct → duct of Bellini → calyx → renal pelvis → ureter



One nephron and its collecting duct, straightened out.

	Cortical	Juxtamedullary
position	almost all in **cortex**; Malpighian body outer cortex	Malpighian body next to the **medulla**
share	**~80–85%**	**~15–20%**
size	smaller	larger
loop of Henle	**short**	**long**, deep in medulla
vasa recta	absent (peritubular capillaries only)	**present**
role	plasma volume at normal water intake	**concentrated urine** when water is short

- desert kangaroo rat: many juxtamedullary nephrons, longest loops, very concentrated urine



A cortical nephron and a juxtamedullary nephron.

Urine formation

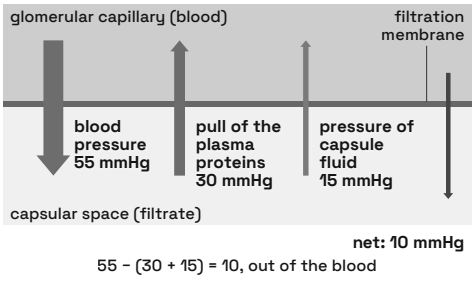
- **ultrafiltration** (Malpighian body) → **selective reabsorption** (tubules) → **tubular secretion**

1. Ultrafiltration

- purely **physical**; blood filtered under high pressure
- **filtration membrane**: capillary **endothelium** (pores) · **basement membrane** · **podocytes** (slits)
- passes: everything in plasma except **blood cells** and most **proteins**
- pressure high because the **afferent arteriole is wider than the efferent** (pinched hose)
- **glomerular hydrostatic ~55 mmHg**: out
- **colloid osmotic** (plasma proteins, albumin) **~30 mmHg**: back in
- **capsular hydrostatic ~15 mmHg**: against

$\mathrm{NFP} = P_G - (\pi + P_C)$	NFP net filtration pressure; P_G glomerular hydrostatic; π blood colloid osmotic; P_C capsular hydrostatic (mmHg) **Use:** $55 - (30 + 15)$ = **10 mmHg** ($7.3 - (4.0 + 2.0) = 1.3$ kPa); range ~8–15
$\text{reabsorbed} = \frac{\text{filtrate} - \text{urine}}{\text{filtrate}} \times 100\%$	per minute or per day **Use:** $(125 - 1)/125$ = 99.2%; 180 L, 1.5 L → ~99%

- e.g. vomiting, diarrhea: $45 - (32 + 15) = -2$ → **no filtration**, no urine
- **glomerular filtrate**: plasma without its proteins: glucose, amino acids, vitamins, salts + urea, uric acid, creatinine, a little ammonia
- **GFR ~125 mL/min ≈ 180 L/day**; plasma ~3 L → filtered ~60 × a day



The three pressures across a glomerular capillary wall.

2. Selective reabsorption (active with ATP, or passive) into the peritubular capillaries

Part	Taken back	Filtrate
PCT (~65–70% of filtrate)	~65% **Na^+** actively; **all glucose, amino acids**, water-soluble vitamins, lactic acid, HCO_3^- actively; 65–70% **water** by osmosis (**obligatory**); K^+, Cl^-, Ca^{2+}, Mg^{2+} by diffusion; ~50% **urea**	isotonic in, **isotonic** out
descending limb	**water** out into salty medulla (→ vasa recta)	more and more **hypertonic**
ascending limb	Na^+, K^+, Cl^- out (passive thin, **active** thick); no water	more and more **hypotonic**
DCT	Na^+ (**aldosterone**); Ca^{2+} (**parathormone**); water only with **ADH** (**facultative**)	hypotonic → isotonic with ADH
collecting duct	water (**ADH**); Na^+ (aldosterone); some urea, Cl^-, HCO_3^-	concentrated (ADH) or dilute (no ADH)

- loop = **counter-current multiplier**: salt out of the ascending limb makes the medulla salty → draws water from the descending limb and collecting duct; urea from the lower CD adds to it
- short of water: ADH → walls permeable → little, **concentrated** urine; drank a lot: no ADH → much **dilute** urine

3. Tubular secretion: blood → filtrate, mostly **active**; removes what was under-filtered; controls **pH** and **K^+**

- **PCT**: creatinine, hippuric acid, **H^+**, **NH_3**, drugs (**penicillin**), dyes, pigments
- **DCT, collecting duct**: **K^+**, **H^+**, **NH_4^+** (H^+ out + HCO_3^- back → blood not too acid)
- urea diffuses into the thin loop from the medulla
- main way in **aglomerular marine bony fishes** (toadfish, goosefish, pipefishes, seahorses): save water
- urine → ducts of Bellini → calyces → pelvis → ureter → bladder

Diabetes mellitus (paper question): blood glucose so high the PCT can't take it all back → **glucose in urine**; it holds water in the tubule → **much urine** → water lost → **thirst**

Urine and micturition

- **~95% water**, 5% solutes: mostly **urea**; creatinine, uric acid, Na^+, K^+, Cl^-, a little ammonia, hormone breakdown products, pigments
- no **glucose**, no protein normally; test strip: glucose → **diabetes mellitus**, protein → damaged glomerular filter
- **1.5–2 L/day**
- yellow: **urochrome** (urobilin), from hemoglobin breakdown
- fresh: faint aromatic smell; stale: bacteria turn urea → **ammonia**
- pH **~6** (4.5–8; acid on meat, alkaline on vegetables)
- specific gravity **1.005–1.030**

Micturition reflex

1. filling: **sympathetic** keeps detrusor relaxed, internal sphincter shut
2. **~300 mL**: **stretch receptors** → sensory nerves → **spinal cord**, brain → urge
3. **micturition center in the pons** allows it: **parasympathetic** → **detrusor contracts**, **internal sphincter relaxes**
4. **external sphincter** relaxed voluntarily → urine out

- baby: reflex alone; toilet training = voluntary control of the external sphincter

Other excretory organs

- **skin**: **sweat glands** (water, NaCl, a little urea, lactic acid, amino acids; mainly cooling) · **sebaceous glands** (sebum: sterols, waxes, fats)
- **lungs**: **CO_2**, water vapor
- **liver**: **urea** from ammonia; **bilirubin**, **biliverdin** (old RBCs), cholesterol, steroid hormones, vitamins, drugs into **bile**
- **intestine**: excess **calcium, iron**, salts into the gut (indole, skatole and undigested food leave by **egestion**)

COMMON MISTAKES

✗ Passing feces is excretion
✓ it is **egestion**; excretion removes wastes of the body's own metabolism.

✗ Urea is more toxic than ammonia
✓ **ammonia** most toxic, uric acid least.

✗ Marine bony fishes are ureotelic
✓ mainly **ammonotelic**; **sharks** are ureotelic.

✗ Blood enters the glomerulus by an afferent venule
✓ by the **afferent arteriole**, leaves by the efferent **arteriole**.

✗ The efferent arteriole is wider
✓ the **afferent** is wider; that keeps glomerular pressure high.

✗ All of the glomerular pressure drives filtration
✓ only the **net** pressure, ~10 mmHg.

✗ ADH controls water reabsorption in the PCT
✓ PCT water is **obligatory**; ADH acts on the **DCT and collecting duct**.

✗ The ascending limb lets water out
✓ it is **impermeable** to water; the **descending** limb lets water out.

✗ Ascending limb moves NaCl only actively
✓ **passively** in the thin part, **actively** in the thick part.

✗ Most nephrons are juxtamedullary
✓ ~80–85% are **cortical**.

✗ The internal sphincter is voluntary
✓ **internal** smooth, involuntary; **external** striated, voluntary.