Chapter 16: Excretory Products and Their Elimination

Exercises — Exercises

Q1 Define Glomerular Filtration Rate (GFR)

SOLUTION

Glomerular Filtration Rate (GFR) is the amount of glomerular filtrate formed in both kidneys per minute.

In a healthy adult, GFR is approximately 125 mL/minute, which amounts to about 180 litres of filtrate per day.

GFR is determined by the glomerular capillary blood pressure, which drives ultrafiltration of blood through the three-layered filtration barrier: the glomerular endothelium, the basement membrane, and the podocyte epithelium of Bowman's capsule.

Answer: GFR is the volume of glomerular filtrate formed per minute — approximately 125 mL/min (180 L/day) in a healthy adult.

Q2 Explain the autoregulatory mechanism of GFR.

SOLUTION

The kidneys have a built-in autoregulatory mechanism to maintain GFR, primarily through the Juxta Glomerular Apparatus (JGA).

JGA Mechanism:

The JGA is a specialised region formed by cellular modifications in the distal convoluted tubule (DCT) and the afferent arteriole at the point of their contact.

When GFR falls (due to reduced glomerular blood flow or blood pressure), the JG (juxtaglomerular) cells of the afferent arteriole are activated.

JG cells release the enzyme renin, which converts angiotensinogen (a plasma protein) to angiotensin I, which is further converted to angiotensin II.

Angiotensin II is a powerful vasoconstrictor — it constricts blood vessels, raising glomerular blood pressure and thereby restoring GFR to normal.

Angiotensin II also stimulates the adrenal cortex to secrete aldosterone, which causes reabsorption of Na+ and water from the distal tubule, increasing blood volume and pressure — further supporting GFR. This is the Renin-Angiotensin-Aldosterone mechanism.

ADH (Antidiuretic Hormone) role:

A fall in blood volume activates osmoreceptors in the hypothalamus, which stimulates release of ADH (vasopressin) from the neurohypophysis. ADH promotes water reabsorption from the distal tubule and collecting duct, restoring blood volume and indirectly supporting GFR.

ANF as a counter-check:
When blood pressure rises excessively, the heart atria release Atrial Natriuretic Factor (ANF), which causes vasodilation and lowers blood pressure, acting as a check on the renin-angiotensin mechanism.

Answer: GFR is autoregulated mainly by the JGA: a fall in GFR triggers renin release → angiotensin II (vasoconstriction + aldosterone) → raises blood pressure and GFR. ADH restores blood volume; ANF prevents over-correction.

Q3 Indicate whether the following statements are true or false :
(a) Micturition is carried out by a reflex.
(b) ADH helps in water elimination, making the urine hypotonic.
(c) Protein-free fluid is filtered from blood plasma into the Bowman's capsule.
(d) Henle's loop plays an important role in concentrating the urine.
(e) Glucose is actively reabsorbed in the proximal convoluted tubule.

SOLUTION

(a) TRUE. Micturition is a reflex (micturition reflex). Stretch receptors in the urinary bladder wall send signals to the CNS when the bladder is full; the CNS sends motor signals causing contraction of bladder smooth muscles and relaxation of the urethral sphincter.

(b) FALSE. ADH (antidiuretic hormone / vasopressin) promotes water reabsorption from the distal parts of the renal tubule and collecting duct, thereby reducing water loss and making the urine hypertonic (more concentrated), not hypotonic.

(c) TRUE. The filtration barrier (glomerular endothelium, basement membrane, and podocyte slit pores) allows all plasma components except proteins to pass into the Bowman's capsule. The filtrate is therefore protein-free (ultrafiltrate).

(d) TRUE. Henle's loop is critical for urine concentration. The descending limb is permeable to water (concentrating the filtrate), and the ascending limb transports electrolytes into the medullary interstitium, maintaining the osmotic gradient. The counter-current mechanism between the two limbs of Henle's loop and vasa recta

builds the high osmolarity gradient (up to 1200 mOsmol L-1) in the medulla, which drives water reabsorption from the collecting duct to produce concentrated urine.

(e) TRUE. Glucose is completely and actively reabsorbed (against concentration gradient, requiring energy) in the proximal convoluted tubule (PCT). Under normal blood glucose levels, no glucose appears in the final urine.

Answer: (a) True (b) False — ADH makes urine hypertonic (c) True (d) True (e) True

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Q4 Give a brief account of the counter current mechanism.

SOLUTION

The counter current mechanism is a process that maintains a high osmolarity gradient in the medullary interstitium of the kidney, enabling concentration of urine.

Structures involved:
1. Henle's loop — the descending and ascending limbs carry filtrate in opposite (counter current) directions.
2. Vasa recta — the capillary network running parallel to Henle's loop also carries blood in a counter current pattern (downward in the descending limb, upward in the ascending limb).

How the gradient is built:
- The descending limb of Henle's loop is freely permeable to water but almost impermeable to electrolytes. As filtrate descends, water moves out by osmosis into the increasingly concentrated interstitium, concentrating the filtrate.
- The ascending limb is impermeable to water but actively/passively transports NaCl out into the medullary interstitium. This dilutes the filtrate as it ascends while adding solutes to the interstitium.
- NaCl transported out by the ascending limb exchanges with the descending limb of vasa recta; the ascending vasa recta then returns NaCl to the interstitium, trapping it in the medulla.
- Small amounts of urea also enter the thin segment of the ascending limb of Henle's loop from the collecting duct and are recycled back to the interstitium, further raising osmolarity.

Resulting gradient and effect:
This counter current arrangement maintains an increasing osmolarity from cortex

(300 mOsmol L-1) to inner medulla (~1200 mOsmol L-1). When the hypotonic filtrate in the collecting duct passes through this gradient (in the presence of ADH), water moves out by osmosis, producing concentrated urine — up to four times the osmolarity of the initial filtrate.

Answer: Counter current mechanism: opposite flow in Henle's loop limbs and vasa recta builds an osmolarity gradient (300–1200 mOsmol/L, cortex to inner medulla) via NaCl/urea cycling; collecting duct filtrate loses water into this gradient (ADH-dependent) to yield concentrated urine.

Q5 Describe the role of liver, lungs and skin in excretion.

SOLUTION

Role of Liver:

- The liver is the largest gland in the body and plays a significant excretory role.
- It secretes bile, which contains bilirubin and biliverdin (breakdown products of haemoglobin from destroyed red blood cells), cholesterol, degraded steroid hormones, vitamins and drugs.
- These substances are passed into the bile and ultimately eliminated along with faeces (digestive wastes).
- The liver also converts ammonia (produced by amino acid catabolism) into urea via the ornithine cycle (urea cycle) for excretion by kidneys.

Role of Lungs:

- Lungs are the primary organs for excretion of carbon dioxide (CO_2), which is a major metabolic waste product of cellular respiration.
- Approximately 200 mL of CO_2 is eliminated per minute through expired air.
- Lungs also eliminate significant quantities of water vapour during exhalation.

Role of Skin:

- The skin has two types of glands involved in excretion: sweat glands and sebaceous glands.
- Sweat glands produce sweat, which is a watery fluid containing NaCl, small amounts of urea, lactic acid and other substances. Although the primary function of sweating is thermoregulation (cooling the body), it also serves as a minor excretory route for these substances.
- Sebaceous glands secrete sebum, which contains sterols, hydrocarbons and waxes. Sebum provides a protective oily covering for the skin and eliminates

these substances.
- Small amounts of nitrogenous wastes can also be excreted through saliva.

Answer: Liver: excretes bilirubin/biliverdin, cholesterol, steroid hormones, drugs via bile/faeces. Lungs: eliminate CO_2 (~200 mL/min) and water vapour. Skin: sweat glands excrete NaCl, urea, lactic acid; sebaceous glands excrete sterols, waxes via sebum.

Q6 Explain micturition.

SOLUTION

Micturition is the process of release (voiding) of urine from the urinary bladder through the urethra.

Process:
1. Urine formed by the nephrons is carried via the ureters to the urinary bladder, where it is stored.
2. As the bladder fills with urine, its wall stretches. Stretch receptors on the bladder wall are activated and send afferent nerve impulses to the central nervous system (CNS).
3. The CNS processes these signals and, when appropriate (voluntary control), sends efferent motor signals back to the bladder.
4. These motor signals cause: (a) contraction of the smooth muscles of the urinary bladder wall, and (b) simultaneous relaxation of the urethral sphincter.
5. This results in the expulsion of urine through the urethra.

The neural mechanism that controls micturition is called the micturition reflex.

Normal output:
- An adult human excretes on average 1 to 1.5 litres of urine per day.
- Urine is a light yellow, slightly acidic (pH ~6.0) watery fluid with a characteristic odour.
- About 25–30 g of urea is excreted per day.
- Presence of glucose (glycosuria) or ketone bodies (ketonuria) in urine indicates metabolic disorders such as diabetes mellitus.

Answer: Micturition is the reflex voiding of urine: bladder stretch receptors signal CNS → motor response causes bladder wall contraction + urethral sphincter relaxation → urine expelled. Adults void ~1–1.5 L/day of slightly acidic (pH ~6), light yellow urine.

Q7 Match the items of column I with those of column II :

Column I	Column II
(a) Ammonotelism	(i) Birds
(b) Bowman's capsule	(ii) Water reabsorption
(c) Micturition	(iii) Bony fish
(d) Uricotelism	(iv) Urinary bladder
(d) ADH	(v) Renal tubule

SOLUTION

(a) Ammonotelism — (iii) Bony fish

Bony fishes (many teleosts) excrete nitrogenous waste primarily as ammonia (ammonotelism). Ammonia is highly soluble and readily diffuses out across gill surfaces in the aquatic environment.

(b) Bowman's capsule — (v) Renal tubule

The Bowman's capsule is the double-walled cup-like beginning of the renal tubule that encloses the glomerulus and collects the glomerular filtrate.

(c) Micturition — (iv) Urinary bladder

Micturition involves the controlled emptying of the urinary bladder through the urethra in response to stretch receptor signals and CNS motor commands.

(d) Uricotelism — (i) Birds

Birds (and reptiles) excrete nitrogenous waste as uric acid (uricotelism), which is non-toxic, insoluble and can be excreted as a paste with minimal water loss.

(e) ADH — (ii) Water reabsorption

Antidiuretic hormone (ADH / vasopressin) facilitates water reabsorption from the distal parts of the renal tubule and collecting duct, reducing water loss in urine.

Answer: (a)–(iii) Bony fish; (b)–(v) Renal tubule; (c)–(iv) Urinary bladder; (d)–(i) Birds; (e) ADH–(ii) Water reabsorption

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Q8 What is meant by the term osmoregulation?

SOLUTION

Osmoregulation is the process by which an organism actively regulates and maintains the osmotic concentration (water and ion balance) of its body fluids within a narrow, physiologically acceptable range, despite fluctuations in the external environment or intake.

In animals, osmoregulation involves controlling the concentration of water, salts (Na+, K+, Cl-, etc.) and other solutes in blood and body fluids.

In humans, the kidneys are the primary organs of osmoregulation. They adjust the volume and concentration of urine to maintain blood osmolarity at ~300 mOsmol L-1. Hormones such as ADH (which promotes water retention) and aldosterone (which promotes Na+ reabsorption) are key regulators.

Osmoregulation is essential for proper cell function — cells swell or shrink if surrounding fluid osmolarity changes significantly, disrupting normal metabolism.

Answer: Osmoregulation is the active regulation of water and ionic (osmotic) balance of body fluids. Kidneys are the primary osmoregulatory organs in humans; ADH and aldosterone are key hormones maintaining blood osmolarity at ~300 mOsmol/L.

Q9 Terrestrial animals are generally either ureotelic or uricotelic, not ammonotelic, why ?

SOLUTION

Ammonia is the most toxic form of nitrogenous waste. It is highly soluble but extremely poisonous even at low concentrations. To excrete ammonia safely, large amounts of water are required to dilute it.

Aquatic animals (ammonotelic), such as bony fishes and aquatic amphibians, can afford ammonotelism because they live in water and can continuously dilute and eliminate ammonia across their body/gill surfaces.

Terrestrial animals, however, do not have access to abundant external water. Excreting ammonia would require them to lose large quantities of body water, leading to dehydration — which is fatal in a terrestrial environment.

Therefore, terrestrial animals have evolved to convert ammonia into less toxic forms that can be stored or excreted with minimal water loss:
- Ureotelic animals (mammals, terrestrial amphibians, marine fishes): convert ammonia to urea in the liver (ornithine/urea cycle). Urea is much less toxic and moderately soluble; it can be excreted in relatively small volumes of water.
- Uricotelic animals (reptiles, birds, insects): convert ammonia to uric acid. Uric acid is the least toxic nitrogenous waste, nearly insoluble, and can be excreted as a semi-solid paste with minimal water loss — ideal for fully terrestrial life and also for animals that lay eggs (prevents toxic build-up inside the egg shell).

In summary, terrestrial adaptation drove the evolution from ammonotelism to ureotelism or uricotelism as a strategy for conserving water.

Answer: Ammonia is highly toxic and requires large amounts of water for excretion — incompatible with water-scarce terrestrial life. Terrestrial animals evolved to excrete urea (less toxic, moderate water needed) or uric acid (least toxic, excreted as semi-solid paste, minimal water loss) to conserve body water.

Q10 What is the significance of juxta glomerular apparatus (JGA) in kidney function?

SOLUTION

The Juxta Glomerular Apparatus (JGA) is a specialised sensor and regulatory structure located at the junction of the distal convoluted tubule (DCT) and the afferent arteriole of the glomerulus.

Significance:

1. Regulation of GFR: JGA is the primary autoregulatory mechanism for GFR. When GFR or glomerular blood pressure falls, JG (juxtaglomerular) cells in the afferent arteriole wall respond by releasing the enzyme renin.

2. Renin-Angiotensin-Aldosterone cascade: Renin converts angiotensinogen (a plasma protein) to angiotensin I, which is then converted to angiotensin II. Angiotensin II:

- Acts as a powerful vasoconstrictor, raising glomerular blood pressure and restoring GFR.
- Stimulates the adrenal cortex to release aldosterone, which promotes Na+ and water reabsorption from the distal tubule — raising blood volume and blood pressure.

3. Macula densa feedback: The macula densa cells of the DCT detect changes in the NaCl concentration of the tubular fluid and send paracrine signals to the JG cells, linking tubular flow composition to GFR regulation.

4. Overall homeostasis: Through the renin-angiotensin mechanism, JGA helps maintain systemic blood pressure, blood volume, and electrolyte balance in addition to GFR.

In summary, JGA is a critical sensor-effector unit that ensures stable kidney filtration and systemic cardiovascular homeostasis.

Answer: JGA regulates GFR: a fall in GFR/blood pressure activates JG cells to release renin, triggering the renin-angiotensin-aldosterone cascade — raising blood pressure and GFR. It also maintains systemic blood volume and electrolyte balance.

Q11 Name the following:
(a) A chordate animal having flame cells as excretory structures
(b) Cortical portions projecting between the medullary pyramids in the human kidney
(c) A loop of capillary running parallel to the Henle's loop.

SOLUTION

(a) Amphioxus (Branchiostoma)
Amphioxus is a cephalochordate (the simplest chordate). Its excretory structures are protonephridia (flame cells). Among chordates, this is a characteristic feature. (Platyhelminthes and some annelids also have flame cells but are non-chordates.)

(b) Columns of Bertini (Renal columns)
The cortex of the kidney extends inward between the medullary pyramids as renal columns called Columns of Bertini.

(c) Vasa recta
Vasa recta is a hairpin-shaped capillary loop that runs parallel to the Henle's loop. It is formed from the efferent arteriole (after the glomerulus) as part of the peritubular capillary network. Vasa recta plays a key role in the counter current mechanism for urine concentration.

Answer: (a) Amphioxus (cephalochordate); (b) Columns of Bertini (renal columns); (c) Vasa recta

Q12 Fill in the gaps :
(a) Ascending limb of Henle's loop is _____ to water whereas the descending limb is _____ to it.
(b) Reabsorption of water from distal parts of the tubules is facilitated by hormone _____.
(c) Dialysis fluid contain all the constituents as in plasma except _____.
(d) A healthy adult human excretes (on an average) _____ gm of urea/day.

SOLUTION

(a) Ascending limb of Henle's loop is impermeable to water whereas the

descending limb is permeable to it.
Explanation: The ascending limb allows active/passive transport of electrolytes (NaCl) out but is impermeable to water, which dilutes the filtrate as it moves upward. The descending limb is freely permeable to water (but not electrolytes), so water leaves by osmosis, concentrating the filtrate as it descends.

(b) Reabsorption of water from distal parts of the tubules is facilitated by hormone ADH (Antidiuretic Hormone / vasopressin).
ADH is released from the neurohypophysis (posterior pituitary) in response to low blood volume or high osmolarity. It acts on the DCT and collecting duct to increase water permeability and promote reabsorption.

(c) Dialysis fluid contains all the constituents as in plasma except nitrogenous wastes (urea and other nitrogenous compounds).
In haemodialysis, blood passes through a cellophane tube surrounded by dialysing fluid. Since the dialysing fluid has no nitrogenous wastes, these substances diffuse out of the blood by concentration gradient, cleaning the blood.

(d) A healthy adult human excretes (on an average) 25–30 gm of urea per day.

Answer: (a) impermeable; permeable (b) ADH (antidiuretic hormone / vasopressin) (c) nitrogenous wastes (urea) (d) 25–30 gm