THE URINARY SYSTEM

I. Excretion:
- Excretory systems regulate the chemical composition of body fluids by removing metabolic wastes and retaining the proper amounts of water, salts, and nutrients.
- Components of this system in vertebrates include the kidneys, liver, lungs, and skin.
  a) Skin: sweat with water, salts, heat and some urea
  b) Lungs: carbon dioxide, water, and heat
  c) Liver: breakdown products of hemoglobin (bilirubin added to bile)
  d) Intestines: certain heavy metals (as opposed to defecation)
  e) Kidneys: the main excretory organ

II. Nitrogen Wastes
- Nitrogen wastes (usually ammonia- NH₃) are a byproduct of protein metabolism.
- Ammonia is very toxic and is converted to urea, a compound the body can tolerate at higher concentrations than ammonia. The urea is then transported via the circulatory system to the kidneys, where it is concentrated and excreted out of the body as urine.

III. Water and Salt Balance
- The kidneys perform a number of homeostatic functions, as they are the chief regulators of our internal environment:
  1. Regulate blood volume + osmotic balance by excreting or conserving water as the situation demands.
  2. Regulate the ions of the blood by controlling the excretion of inorganic salts (especially potassium, sodium, calcium, and magnesium).
  3. Regulate blood pH + indirectly tissue pH by excreting excess acids (H⁺) or base (HCO₃⁻)
  4. Excrete toxic metabolic by-products such as urea, ammonia, uric acid, and creatine (a product of muscle activity).

Humans will die if they lose about 12% of their body water. The threat of desiccation is the most important problem confronting terrestrial life. How do we control our loss of water?
- Multiple layers of dead, keratinized skin cells
- Drink and eat moist foods
- Nervous and hormonal mechanisms control thirst
- Behaviour: (ie: stay out of intense heat)
- Kidneys and other excretory organs help conserve water.

Water loss can be considerable: a person in a 38°C temperature will lose 1 litre of H₂O/hour.
We acquire most of our water in our food and drink, and obtain a smaller amount by oxidative metabolism (dehydration synthesis) and as a by-product of cellular respiration.
We lose water by urinating, defecating, sweating, and breathing.
Recall that osmosis is the movement of water across a selectively permeable membrane. This movement occurs whenever two solutions separated by a membrane differ in total solute concentration or osmolarity.
Structures of the Urinary System

**Kidneys**: a pair of bean-shaped organs about 10 cm long located in the lower, dorsal part of the abdomen.

Blood enters the kidney via the renal artery, is cleaned, and leaves the kidney in the renal vein.

Although the kidneys account for less than 1% of the weight of the human body, they receive about 20% of the blood pumped with each heartbeat.

Urine, the waste fluid formed within the kidney, exits the organ through a duct called a ureter.

- The ureter of each kidney conducts urine by peristalsis into a common urinary bladder, which is periodically emptied into the bladder.

**Bladder**: An average can hold a maximum of 2 cups of urine. When the bladder is full, the urinated response is triggered and sphincter muscles control the release of urine from the bladder as it is emptied from the body through a tube called the urethra.

1. Outer granulated region called the renal cortex

2. Striated or lined layer called the renal medulla
   The medulla has high concentrations of the solutes NaCl and urea.

3. Inner cavity called the renal pelvis where urine collects
The Nephron:
- The functional unit of the kidney is the **Nephron**, which consists of a renal tubule and its associated blood vessels.
- Each kidney contains approximately 1 million nephrons, which represents approximately 80 km of tubules.
- Water, urea, salts, and other small molecules present in the blood flow from the capillaries into the renal tubules, where the fluid is now called **filtrate**.
- The epithelium that lines the renal tubule processes the filtrate to eventually form **urine**.
- From the 1100 to 2000L of blood that flows through the human kidneys each day, the nephron processes about 180L of filtrate, but excretes only ~1.5L of urine. The rest of the filtrate, including ~99% of the water, is reabsorbed into the blood.

The Structure of the Nephron:
- The blind end of the renal tubule, which receives filtrate from the blood, is expanded to form a cup-shaped receptacle, the **Bowman's capsule**.
- This capsule encloses a ball of capillaries called the **glomerulus**.
- From the capsule, the filtrate passes successively through three main regions of the renal tubule:
  1. The **proximal convoluted tubule** (PCT)
  2. The **loop of Henle**: ascending and descending
  3. The **distal convoluted tubule** (DCT)
The last portion of the renal tubule empties its filtrate into a collecting duct, which receives filtrate from many other renal tubules.

The many collecting ducts of the kidney pass the filtrate (now called urine) into the renal pelvis, a chamber that in turn drains into the ureter.

Each nephron is supplied with blood by an afferent arteriole, a branch of the renal artery that subdivides to form the capillaries of the glomerulus.

The capillaries converge as they leave the capsule to form an efferent arteriole, but then this vessel subdivides again into a second network of capillaries, the peritubular capillaries, which intermingle with the proximal and distal convoluted tubules. Additional capillaries extend downward to form the capillary system that serves the loop of Henle.

**General physiology of the nephron:**

The nephron has three main functions:

1. **Pressure Filtration:**
   - forces water and solutes from the glomerulus into the Bowman’s capsule.
   - The capillaries of the glomerulus are specialized in that they are porous and function as a filter.
   - They are permeable to water and small solutes, but not to blood cells or large molecules like blood proteins.
   - The filtrate contains a mixture of solutes such as salts, glucose, water soluble vitamins, penicillin, histamines, nitrogenous wastes and other small molecules.

2. **Tubular Reabsorption:**
   - since filtration is nonselective, it is important that small molecules essential to the body be returned to the blood plasma.
   - Nearly all of the sugar, vitamins, and other organic nutrients (potassium ions, bicarbonate ions) present in the initial filtrate are reabsorbed.
   - Most of the water and salt is also reabsorbed.
   - This is a very selective process in which passive and active transport are involved.

3. **Tubular Secretion:** if the blood still needs to rid itself of other ions and waste products (hydrogen ions, ammonia, potassium ions), it will secrete them into the renal tubule.
   - This is a very selective process that involves both active and passive transport.
Urine Production
1. The filtrate formed by pressure filtration as the fluids move from the Glomerulus into the Bowman’s capsule.
   - The filtrate becomes urine as a result of the serial processing of the fluid as it flows along the tubule and collecting duct.

2. The Proximal Convoluted Tubule (PCT): This part of the renal tubule alters the volume and composition of the filtrate by reabsorption
   a) It reabsorbs: 75% of the salts, glucose, amino acids (active transaport), and potassium ions & 70% of the water back into the blood (passive transport)

3. The Descending Loop of Henle: This part of the renal tubule continues the reabsorption of water as the filtrate moves from the cortex and down into the concentrated medulla.
   a) It reabsorbs: water. This is a passive process and the water diffuses down its concentration gradient.

4. The Ascending Loop of Henle: As the renal tubule heads back towards the cortex again, the epithelium of the ascending loop is permeable to salt and not to water.
   a) It reabsorbs: NaCl. This is a passive process in the thin segment and an active process in the thick segment.

5. The Distal Convoluted Tubule (DCT): This part of the renal tubule is another important site of selective secretion and absorption.
   a) It reabsorbs: sodium ions, water, and bicarbonate ions.
      o The positive sodium ions are actively transported into the interstitial fluid, and water follows by osmosis.
      o The bicarbonate ions are actively transported back into the blood, as this is an important buffer needed in the blood to transport of carbon dioxide.
   b) It secretes: hydrogen ions, potassium ions, ammonia and certain drugs and poisons from the blood into the filtrate.
      o The hydrogen ions are actively transported into the filtrate. This helps to maintain the pH of the blood.
      o The potassium ions are also actively transported into the filtrate.

6. The Collecting Duct: this duct now carries the filtrate back in the direction of the medulla and into the renal pelvis.
The permeability of the distal convoluted tubule and collecting duct are regulated by 2 hormones

**Hormone Control of the Reabsorption of Water and Salt**

- If you are dehydrated, the kidneys can excrete a small, concentrated volume of urine and reabsorb the majority of water from the filtrate.
- If you have consumed an excessive amount of fluid, the kidneys can excrete a large, dilute volume of urine, with very little water being reabsorbed from the filtrate.

A. Water reabsorption is controlled by the ANTIDIURETIC HORMONE (ADH) in a negative feedback cycle.

- The hypothalamus makes ADH and it is stored and released from the **posterior pituitary gland**.
- It is released in response to an increase in the osmolarity (solute concentration) of the blood when you are dehydrated (inadequate intake of water).
  - When you have **low blood volume** (high osmolarity), the osmoreceptor cells in the hypothalamus trigger the posterior pituitary to **release ADH**.
  - ADH acts to increase water absorption in the kidneys, by increasing the permeability of the distal convoluted tubules and collecting ducts to water.
  - This amplifies water reabsorption and ultimately increases blood volume. At the same time, the removal of water from the filtrate increases the concentration of the urine, and the less urine is excreted.
  - When you have **high blood volume and low osmolarity**, sensors in the heart signal the hypothalamus to cause a **reduction of the amounts of ADH** in the blood.
  - This decreases the amount of water that is reabsorbed into the blood, and large quantities of a more dilute urine are produced.

This is a negative feedback cycle, because as the osmolarity of the blood is reduced (blood volume increases) less ADH will be secreted.

Alcohol can perturb water balance by inhibiting the release of ADH, causing excessive loss of water in the urine and dehydrating the body. This leads to the symptoms of a hangover.
Aldosterone:

- A second system regulating kidney function involves a specialized tissue called the juxtaglomerular apparatus (JGA), which is located in the vicinity of the afferent arteriole.
- When the blood pressure in the afferent arteriole drops, or if the sodium concentration of the blood is too low (due to excessive loss of salt and body fluids: an injury or severe diarrhea), the JGA releases an enzyme called RENIN.
- In the blood, renin activates the plasma protein called ANGIOTENSIN, which in its active form (angiotensin II) functions as a hormone. The ANGIOTENSIN II does two things:

1. It stimulates the adrenal gland to release the hormone ALDOSTERONE, which acts on the distal convoluted tubule of the nephrons, stimulating the reabsorption of sodium. Because water follows the sodium by osmosis, the aldosterone also increases the blood volume and blood pressure.

2. It also causes a generalized VASOCONTRICION of arterioles, which raises blood pressure and therefore increases the filtration rate.

3. Finally, the hormone ATRIAL NATRIURETIC PROTEIN (ANP) opposes the rennin-angiotensin-aldosterone system. The wall of the atrium of the heart releases ANP in response to an increase in blood volume and pressure, and ANP inhibits the release of renin from the juxtaglomerular apparatus and also directly reduces the release of aldosterone from the adrenal glands. This action decreases the amount of sodium (and therefore water) reabsorption and thus, lowers blood volume and pressure.