Excretion and Water Balance

1. Osmoregulation (water balance)
    a. Most marine invertebrates are **osmoconformers** in which the concentration of solutes in their body fluid is equal to that of their environment. As a result, they do not gain or lose water.
        i. Osmoconformers usually live in water that has a very stable composition (*i.e.*, the ocean) and so their internal environment changes very little.
    b. Most vertebrates are **osmoregulators**, meaning they maintain a concentration of solutes in their body fluid different from that of the environment.
    c. Problems faced by osmoregulators
        i. Marine vertebrates
            (1) Maintain a lower salt concentration in the body than in the environment.
            (2) Having body fluids hypotonic to the environment means water tends to leave the body.
            (3) They must retain water to prevent dehydration
            (4) Marine fishes solve this problem by
                (a) Drinking large amounts of seawater.
                (b) They then excrete excess ions from the blood through the gills or skin. They produce very little urine.
        ii. Freshwater vertebrates
            (1) Maintain body fluids hypertonic to the environment, meaning they are constantly gaining water by osmosis and losing solutes by diffusion.
            (2) Freshwater fishes solve this problem by
                (a) Not drinking water and excreting a large volume of dilute urine.
                (b) They replace lost ions by active transport across the gills from the water into the blood.
        iii. Terrestrial vertebrates
            (1) Have bodies with a higher concentration of water than the surrounding air so they tend to lose water by evaporation from the skin and lungs.
                (a) The body covering helps prevent water loss.
            (2) Efficient kidneys allow the excretion of concentrated urine to get rid of waste.

2. Excretion of nitrogenous wastes
    a. When animals metabolize amino acids (which contain nitrogen), the toxic byproduct ammonia is produced and must be excreted.
    b. Animals that excrete this waste as ammonia need access to lots of water because the very toxic chemical must be diluted.
        i. For freshwater fish this is not a problem because they can just produce a large volume of dilute urine.
        ii. Marine fish and terrestrial vertebrates must conserve water so they cannot excrete the waste in the form of ammonia.
            (1) Instead, in these animals, the ammonia is converted to **urea** in the liver.
            (2) Urea is much less toxic (about 100,000 times less than ammonia) and is excreted as a concentrated solution of urea rather than a dilute solution of ammonia.

iii. Land snails, insects, birds, and many reptiles excrete **uric acid** as the main nitrogenous waste. It is also relatively nontoxic.
(1) Uric acid does not dissolve very well in water so it crystallizes and is excreted as a semi-solid paste with very little water loss.

3. The organization of the vertebrate kidney
   a. In humans, the kidneys are located in the lower back
   b. Urine exits each kidney through a duct called the **ureter,** and both ureters drain to a common **urinary bladder.**
      i. During urination, urine is expelled from the urinary bladder through a tube called the **urethra,** which empties to the outside near the vagina in females or through the penis in males.
   c. The mammalian kidney has an outer **renal cortex** and an inner **renal medulla.**
      i. Both regions are packed with microscopic tubules called **nephrons**.
      ii. Each human kidney contains about a million nephrons, with a total tubule length of 80 km.
      iii. Each nephron consists of a single long tubule and a ball of capillaries, called the **glomerulus.**
      iv. The closed end of the tubule forms a cup, called **Bowman's capsule,** that surrounds the glomerulus.
      v. From Bowman's capsule, the filtrate (*i.e.*, the fluid that will become urine) passes through three regions of the nephron: the **proximal tubule;** the **loop of Henle,** a hairpin turn with a descending limb and an ascending limb; and the **distal tubule.**
      vi. The distal tubule empties into a **collecting duct,** which receives processed filtrate from many nephrons.
      vii. The many collecting ducts empty into the **renal pelvis,** which is drained by the ureter.
   d. Blood flow to the kidney
      i. The kidneys are about 1% of body weight but gets about 20% of resting cardiac output.
      ii. Blood enters the kidney through a branch of the aorta called the **renal artery** which then branches into the smaller **afferent arterioles** which bring blood to the capillaries of the glomerulus.
      iii. Blood leaves the capillaries of the glomerulus through an **efferent arteriole** and enters capillaries in the medulla, where they collect much of the water that was lost through the glomerulus.
      iv. Venules from these capillaries lead to the **renal vein**, which exits the kidney and returns blood to the inferior vena cava.

4. The kidney functions produces removes waste remove waste from the blood
   a. **Filtration**
      i. As blood passes into the capillaries of the glomerulus, blood pressure forces water and small molecules out of the blood into Bowman's capsule.
      ii. Proteins and large molecules cannot pass through the walls. Water and small solutes do pass through.
      iii. The filtrate in Bowman's capsule contains salt, glucose, amino acids, vitamins, nitrogenous wastes such as urea, and other small molecules.

b. **Reabsorption** is necessary because filtration is nonselective and useful molecules must be recovered from the urine into the blood.
   i. Fluid flows from the capsule to the **proximal tubule** in the renal cortex where most of the salt (NaCl) and water filtered into the capsule are reabsorbed immediately.
   ii. This occurs by active transport of Na^+ out of the filtrate into the blood.
   iii. Water follows both because of osmosis
   iv. Most of the water and dissolved solutes that enter the glomerulus are returned to the blood.
      (1) In humans, between 1000 and 2000 L of blood passes through the kidneys per day. About 180 L of water leaves the blood but most is reabsorbed, and only about 1.5 L of urine is produced.
   v. The nephrons and collecting ducts reabsorb nearly all of the sugar, vitamins, and other organic nutrients from the initial filtrate and about 99% of the water.
   vi. Reabsorption of water continues as the filtrate moves into the **descending limb of the loop of Henle**.
      (1) The loop of Henle is permeable to water but not very permeable to salt and other small solutes.
      (2) The concentration of salt increases as we move further into the medulla, so the loop of Henle continues to lose water.
   vii. In contrast to the descending limb, the **ascending limb of the loop of Henle** is permeable to salt, but not water.
      (1) As filtrate ascends the ascending limb, NaCl diffuses out of the permeable tubule, increasing the salt concentration of the medulla.
      (2) In the upper part of the ascending limb salt is actively transported out of the filtrate.
      (3) By losing salt without giving up water, the filtrate becomes more dilute as it moves up to the cortex in the ascending limb of the loop.
   viii. When the concentration of some substances in the blood reaches a certain level, the substance is not reabsorbed; it remains in the urine. This regulates the levels of several nutrients in the blood.
   ix. In the **distal tubule** several different ions are actively transported into and out of the filtrate.

c. **Secretion**
   i. Because filtration is not selective, some things must be deliberately removed from the blood after filtration.
   ii. Certain ions, drugs and organic molecules not removed by filtration are actively transported from the blood to the filtrate.
   iii. This is similar to reabsorption but in the opposite direction.

d. **Excretion**
   i. By actively reabsorbing NaCl, the **collecting duct** plays a large role in determining how much salt is actually excreted in the urine.
      (1) The duct is permeable to water but not to salt and the permeability is under hormonal control.
      (2) As the filtrate travels through the collecting duct into the medulla, it encounters an increasing salt concentration. Water is lost by osmosis, making the filtrate more concentrated.
   ii. Potentially harmful substances are eliminated by the kidney
   iii. Urine also contains nitrogenous wastes from the metabolism of protein.

iv. It may also contain excess K^+, H^+ and other ions. Eliminating excess H^+, helps maintain the pH of the blood.
v. Excretion of excess water maintains the blood volume and pressure.

5. The kidneys control the concentration of urine to maintain water balance.
   a. By changing the amount of water eliminated or conserved, blood volume and blood pressure can also be maintained by the kidneys.
      i. The kidneys excrete hypertonic urine when the body needs to conserve water.
      ii. The kidneys excretes hypotonic urine when too much water has been ingested.
      iii. One hormone important in regulating water balance is **antidiuretic hormone (ADH).**
      iv. The hypothalamus in the brain produces ADH and it is stored in and secreted by the pituitary gland.
      v. Sensor cells in the hypothalamus monitor the concentration of the blood.
         (1) If the body loses water, the concentration of the blood increases (*i.e.*, becomes more salty). The sensors detect this and trigger the release of ADH.
            (a) ADH makes the distal tubules and collecting ducts become more permeable to water so that water is reabsorbed from the filtrate, decreasing the volume of urine.
               (i) Note that ADH can only reduce water loss. Lost water can only be replaced by eating or drinking.
         (2) If a large intake of water has reduced the blood concentration (*i.e.*, becomes less salty) very little ADH is released.
            (a) This decreases the permeability of the distal tubules and collecting ducts, so water reabsorption is reduced, resulting in the production of more dilute urine.
         (3) Alcohol inhibits the secretion of ADH, increasing water loss. The resulting dehydration causes some symptoms of a hangover. It is important, therefore to always drink plenty of water if you are consuming alcohol.

6. Kidney disorders
   a. Kidney disease
      i. The kidneys can be damaged by physical trauma or by infection.
      ii. If they fail, dialysis or a transplant is necessary.
   b. Diabetes
      i. Mellitus
         (1) Type 1
            (a) Formerly called insulin dependent, juvenile or early onset diabetes.
            (b) Approximately 10 % of people with diabetes have type 1 diabetes.
            (c) The immune system attacks the part of the pancreas that produces insulin. Without insulin, blood sugar is abnormally high.
         (2) Type 2
            (a) Formerly called insulin independent, adult, or late onset diabetes.
            (b) About 90 % have type 2 diabetes, which occurs when the pancreas does not produce enough insulin or when the body does not effectively use the insulin that is produced. Type 2 diabetes usually develops in adulthood, although increasing numbers of children are

being diagnosed.

(c) A diet high in sugar can cause the body to become less sensitive to insulin. This causes a chronic, high blood sugar.

(3) High blood sugar causes increased sugar in the urine. This in turn causes more water to enter the urine by osmosis. The end result is increased urine production (and resulting water loss).

ii. Diabetes facts

(1) Approximately 80% of people with diabetes will die as a result of heart disease or stroke.

(2) The onset of type 2 diabetes may be prevented or delayed, through increased physical activity, healthy eating, weight loss, not smoking and stress reduction.

(3) If left untreated or improperly managed, diabetes can result in a variety of complications, including complications of the heart, kidney, and eyes, as well as erectile dysfunction, and nerve damage

(4) Risk factors

(a) Being:

(i) A member of a high-risk group (Aboriginal, Hispanic, Asian, South Asian or African descent)

(ii) Overweight (especially if you carry most of your weight around your middle)

(b) Having:

(i) A parent, brother or sister with diabetes

(ii) Health complications that are associated with diabetes

(iii) Given birth to a baby that weighed more than 4 kg (9 lb)

(iv) Had gestational diabetes (diabetes during pregnancy)

(v) Impaired glucose tolerance or impaired fasting glucose

(vi) High blood pressure

(vii) High cholesterol or other fats in the blood

(5) Signs and symptoms of diabetes include the following:

(a) Unusual thirst

(b) Frequent urination

(c) Weight change (gain or loss)

(d) Extreme fatigue or lack of energy

(e) Blurred vision

(f) Frequent or recurring infections

(g) Cuts and bruises that are slow to heal

(h) Tingling or numbness in the hands or feet

(i) Trouble getting or maintaining an erection

(6) How is diabetes treated?

(a) Physical Activity: Regular physical activity helps your body lower blood glucose levels, promotes weight loss, reduces stress and enhances overall fitness.

(b) Nutrition: What, when and how much you eat all play an important role in regulating blood glucose levels.

(c) Weight Management: Maintaining a healthy weight is especially important in the management of type 2 diabetes.

(d) Medication: Type 1 diabetes is always treated with insulin. Type 2 diabetes is managed through physical activity and meal planning and may require medications and/or insulin to assist your body in making or using insulin more effectively.

(e) Lifestyle Management: Learning to reduce stress levels in day-to-day life can help people with diabetes better manage their disease.

(f) Blood Pressure: High blood pressure can lead to eye disease, heart disease, stroke and kidney disease, so people with diabetes should try to maintain a blood pressure level at or below 130/80.

c. Diabetes insipidus
   i. In this disorder, the hypothalamus is damaged and is unable to control water balance in the body.
   ii. The result is production of large volumes of very dilute urine.
   iii. Extreme cases can mean 20 L of urine per day.

d. Kidney stones
   i. Minerals crystallize from the blood and form tiny stones.
   ii. If the stones become large enough they can block the ureter and/or urethra.