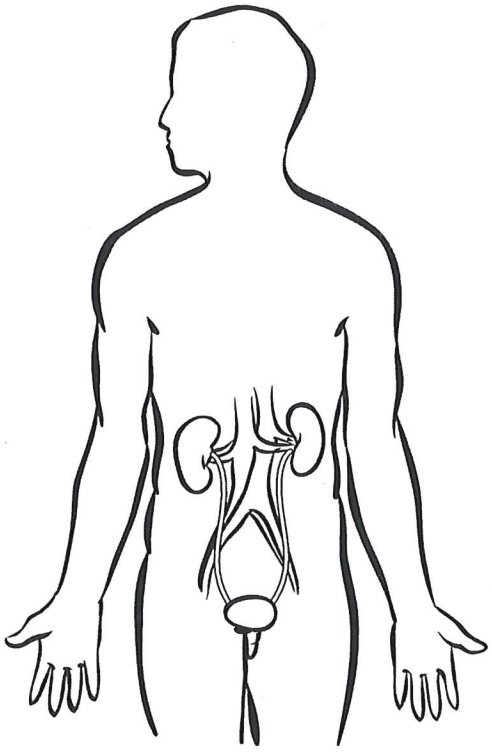
Section 4.2
Urinary System

Section Overview

Your body takes nutrients from food and uses them to maintain all bodily functions including energy and self-repair. After your body has taken what it needs from the food, waste products are left behind in the blood and in the bowel. The urinary system works with the lungs, skin, and intestines—all of which also excrete wastes—to keep the chemicals and water in your body balanced.

Simply put, the urinary system is the organ system that produces, stores, and eliminates urine. In humans it includes two kidneys, two ureters, the bladder, and the urethra.

Did you know adults eliminate about a quart and a half of urine each day. The amount depends on many factors, especially the amounts of fluid and food a person consumes and how much fluid is lost through sweat and breathing.



Resource List

- *Inquiry Into Life*
- *Biology 12 Web site*
  http://www.openschool.bc.ca/courses/biology/bi12/mod4.html

Lesson 4.2A
Urinary System Anatomy

Overview

The kidney is the main organ of **excretion**, which is the process of removing nitrogen wastes from the body. Nitrogen compounds, mainly ammonia, are produced during the breakdown of proteins. Ammonia is very toxic, so it is quickly combined with carbon dioxide to produce urea. If left to accumulate, the body would be overwhelmed within days and the major organs would stop functioning. As a result, the kidney is one of the body's essential organs. People whose kidneys fail must submit to artificial removal of wastes by **dialysis**, or have their kidneys replaced with a donated kidney.

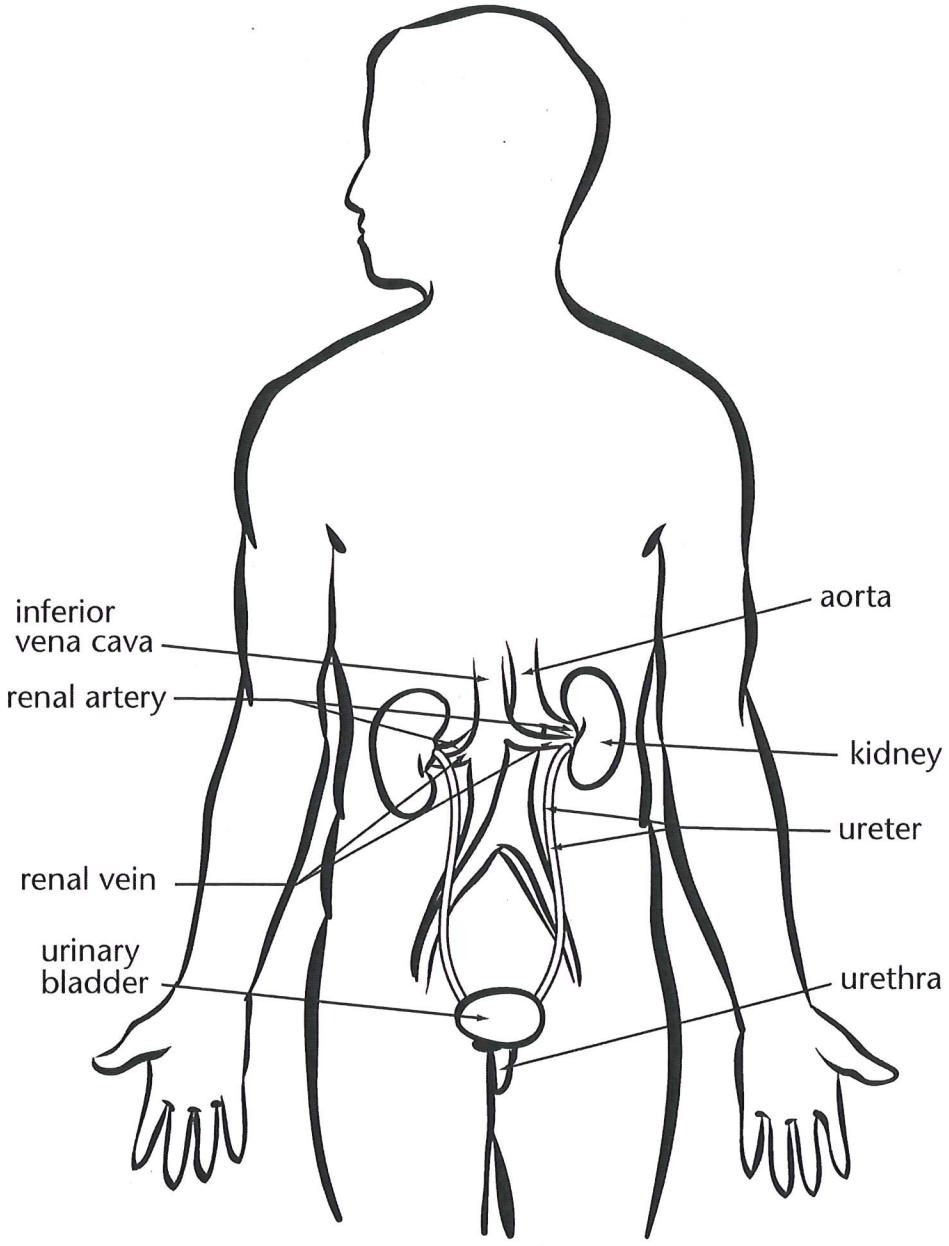
As well as excretion, the kidneys regulate water concentration and pH (acid/base balance.) Additionally, the kidneys also release hormones important in Na^+ regulation (**renin**) and red blood cell production (**erythropoietin**).

Resource List

- *Inquiry Into Life*
- *Biology 12 Provincial Exam Preparation package*

The Urinary System

The urinary system consists of two kidneys (flattened fist-sized organs), the ureters that carry urine to the bladder (stores urine), and a single urethra, (carries urine out of the body). Study the provided diagram of the urinary system. You may want to cover the labels and practice naming the parts.



Notice how the blood vessels that service the kidneys are directly connected to the two major blood vessels of the abdomen. About 20 percent of the blood flowing through these vessels is diverted through the kidneys. As a result, all the blood in the body is filtered two or three times every minute. This filtration produces about 1 to 2 millilitres of urine in this time. Of course, this volume depends on the body's level of hydration (how much fluid has been consumed). With more water in the blood, the volume of urine output increases and its concentration of urea decreases.

Guided Practice 4.2A 1
Study Flash Cards

Using the information in your lessons, the *Inquiry Into Life* textbook, and the *Biology 12 PEP*, make a study flash card for each of the following vocabulary terms. Be sure the information is in your words, as that will be more meaningful to you.

Vocabulary terms to know for this lesson:

- dialysis
- erythropoietin
- excretion
- kidneys
- renal artery
- renal cortex
- renal medulla
- renal pelvis
- renal pyramid
- renal vein
- renin
- ureter
- urinary bladder
- urethra

Guided Practice 4.2A 2
Urinary System

Select the best answer to each question.

1. The primary structure of excretion in the body is the:
   A. kidney
   B. intestine
   C. lung
   D. bladder

2. The structure that carries urine out of the kidney is the:
   A. urethra
   B. ureter
   C. renal vein
   D. renal artery

3. How important are the kidneys to survival?
   A. We can live without them.
   B. They would be missed but we could survive without them.
   C. They are essential.
   D. We would die immediately without them.

4. The structure carrying wastes to the kidney, so that they can be removed, is the:
   A. ureter
   B. urethra
   C. renal artery
   D. renal vein

5. We have two kidneys. The best explanation for this is:

   A. We need two functioning kidneys.

   B. We have a spare kidney in case something goes wrong with one.

   C. We are bilaterally symmetrical, and our body design includes two of most organs.

   D. We did have many kidneys, but we have lost most of them over time.

Summary

There is no section assignment for this lesson.

Completing this lesson has helped you to:

- identify the parts of the kidney
- explain the functions of the kidney and each of its parts

Lesson 4.2B
Kidney Anatomy and Urine Formation

Overview

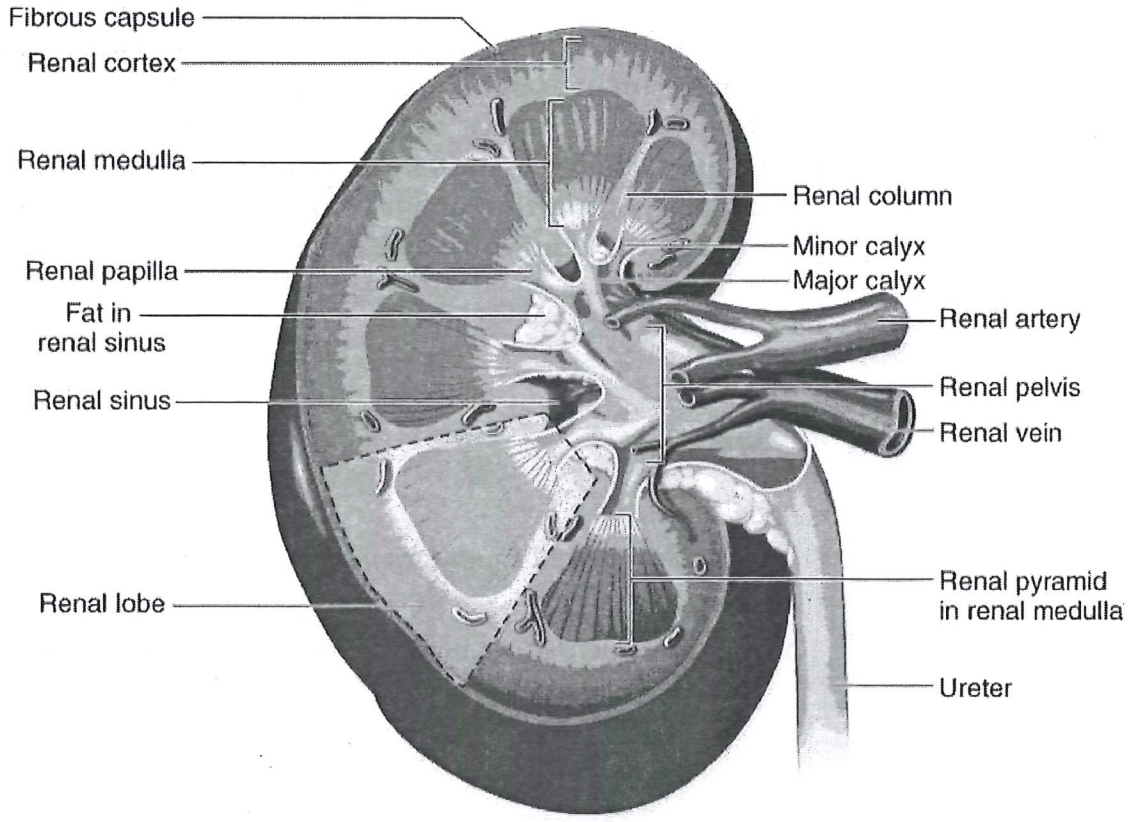
Every day your body filters about 180 litres of water in the blood, which is the equivalent of a large oil drum. Obviously the fluids in the blood are filtered more than once, since the body's total volume of blood is about 5 litres. From these 180 litres, about 2 litres of urine (approximately 1% of the volume being filtered) is produced each day. This varies as the kidneys balance water concentration, pH, and salt concentration.

Resource List

- *Inquiry Into Life*
- *Biology 12 Provincial Exam Preparation package*
- *Biology 12 Web site*
  http://www.openschool.bc.ca/courses/biology/bi12/mod4.html

Kidney Anatomy

Study the following diagram of the anatomy of the kidney. You will be responsible for knowing these structures.



Right kidney, coronal section

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The functions of these structures are provided in the following table.

Structure	Function
kidneys	main organ of excretion, water balance and Na^+ ion regulation; also involved in secretion of the hormones renin and erythropoietin
renal pyramid	region of the kidney which contains nephrons, the urine-forming structures of the kidney
renal cortex	outer region of the kidney that contains most of nephrons, excluding the collecting ducts
renal medulla	central region of the kidney that contains the collecting ducts
renal pelvis	receives urine from the collecting ducts
renal artery	carries arterial blood to kidney
renal vein	carries venous blood away from kidney
ureter	carries urine to bladder from each kidney
urinary bladder	stores urine until released in urination
urethra	carries urine from bladder, out of the body

If you have access to the Internet, go to the *Biology 12 Web site* Lesson 4.2B Kidney Anatomy and Urine Formation:

- to find interactive media relating to a kidney dissection.
- to watch a video of a kidney dissection showing macroscopic anatomy.
- to see a dissected kidney.

Nephron Structure

The **nephron** is the unit of filtration in the kidney. Each kidney contains at least a million nephrons. A nephron is composed of a capsule into which fluids and dissolved molecules and ions are squeezed under pressure. This fluid then passes through a series of tubules that selectively reabsorb molecules needed by the body, leaving the wastes in the fluid. Eventually the remaining fluid is expelled from the kidney in the form of urine. To fully understand this process, it is first necessary that you learn about the parts of the nephron.

In your *Inquiry Into Life* textbook, study Figure 16.4 on page 307. Take note of the location of the nephron in the kidney. Locate the glomerular capsule, also known as Bowman's capsule. Trace the path of blood flow into the glomerulus. Notice how it enters through the **afferent arteriole**, passes through the glomerulus, and exits through the **efferent arteriole**. (Hint: it's easy to remember the path of blood flow through these arterioles because they're in alphabetical order.)

Study the names of the various parts of the nephron. You must be able to identify them from memory. (Vocabulary note: convoluted means twisted; proximal means near; distal means far; in this case, near and far refer to Bowman's capsule).

Study Figure 16.4 on page 307 of the *Inquiry Into Life* textbook to see how the tubules are distributed within the renal medulla and cortex.

Redraw a nephron on a sheet of paper, label it, and keep it handy. You will need it later in the lesson. Label all the parts of the nephron on your diagram. Do not trace the diagram; draw it freehand. This will force your mind to remember the structures much better. Include the following: **Bowman's capsule**, **glomerulus**, **proximal convoluted tubule**, loop of Henle, **distal convoluted tubule**, collecting duct.

Urine Formation

Urine formation has three stages—pressure filtration (also known as glomerular filtration), tubular reabsorption, and tubular secretion.

Glomerular filtration — Blood entering the kidney is under pressure. Blood enters the Bowman's capsule and circulates through a loop of capillaries. Because it is under pressure, relatively small molecules, including water, salts, glucose, wastes, and amino acids, are filtered through the glomerular walls where the Bowman's capsule absorbs them. Large molecules, such as proteins and blood cells, are left in the blood and circulate out to the peritubular capillary network.

Tubular reabsorption — Glomerular filtrate passes out of Bowman's capsule and passes through the tubules of the nephron, beginning with the proximal tubule near the Bowman's capsule. Water from this dilute fluid moves by diffusion across the wall of the tubule and is reabsorbed by the peri-tubular capillary network. This diffusion is facilitated by the osmotic imbalance created by the highly concentrated blood emerging from the glomerulus.

This initial reabsorption increases the concentration of the urine in the tubule. Other small molecules in high concentration include glucose and amino acids. These are valuable resources, so they are actively reabsorbed, aided by carrier proteins in the cell in the membranes of the proximal tubule wall. The process is selective because the types of molecules reabsorbed are controlled by the specific carrier proteins.

Tubular secretion — Tubular secretion occurs as molecules too large to be filtered into the glomerulus are actively transported across the wall of the distal convoluted tubule and into the urine. Molecules left over from muscle metabolism, hormone breakdown, and drugs such as antibiotics are removed from the blood in this way.

One of the main functions of the kidney is to balance water concentration. To accomplish this, the kidney varies the amount of water reabsorbed at the descending loop of Henle and the collecting duct. This system is called **Water Reabsorption**. The ascending loop actively pumps Na^+ ions out of the tubule and into the peritubular space. Chloride ions (Cl^-) move by attraction to the Na^+, resulting in a salty environment surrounding the loop of Henle and the collecting duct. This hypertonic environment draws water out of the tubule. The peritubular capillary network picks up water, leaving relatively concentrated urine. Reabsorption accounts for about 98% of the glomerular filtrate. Of the 100 millilitres of filtrate, only 2 millilitres finds its way into urine.

The Product of Nephron Function: Urine

Urine is the ultimate product of nephron filtration and reabsorption. Urine is mostly water. The actual concentration of urine is determined by the relative concentration of water, which is varied under control according to the osmolarity (water balance) of the blood. You will have noticed the variation in colour of your own urine, which can be attributed to the amount of water you consume and the amount you lose due to evaporation. As well as water, urine contains:

- dissolved salts such as NaCl
- metabolic wastes, including nitrogenous wastes (i.e., urea and ammonia). These wastes are the result of protein breakdown that releases nitrogen compounds (i.e., ammonia). Ammonia is toxic, so is quickly converted to urea in the liver.
- small molecules resulting from the breakdown of hormones. This is the basis for urine testing of athletes. If irregular quantities of the products resulting from hormone breakdown are found in the urine, this may indicate the athlete has been taking supplements of these hormones, which are banned by most athletic regulatory bodies.
- Occasionally there will be unusual amounts of other products, such as protein or blood in the urine. These are not normal and usually signal something is not working properly. For example, high blood pressure may force proteins across the glomerular walls.

In the next lesson you will learn more about the mechanisms that regulate water reabsorption.

On the drawing you made earlier in this lesson:

- Indicate the direction of flow of fluids, beginning with glomerular filtration into Bowman's capsule and ending with urine leaving the collecting duct.
- Indicate with arrows where each of the processes of urine formation occurs. Label the arrows.

Guided Practice 4.2B 1
Study Flash Cards

Using the information in your lessons, the *Inquiry Into Life* textbook, and the *Biology 12 PEP*, make a study flash card for each of the following vocabulary terms. Be sure the information is in your words, as that will be more meaningful to you.

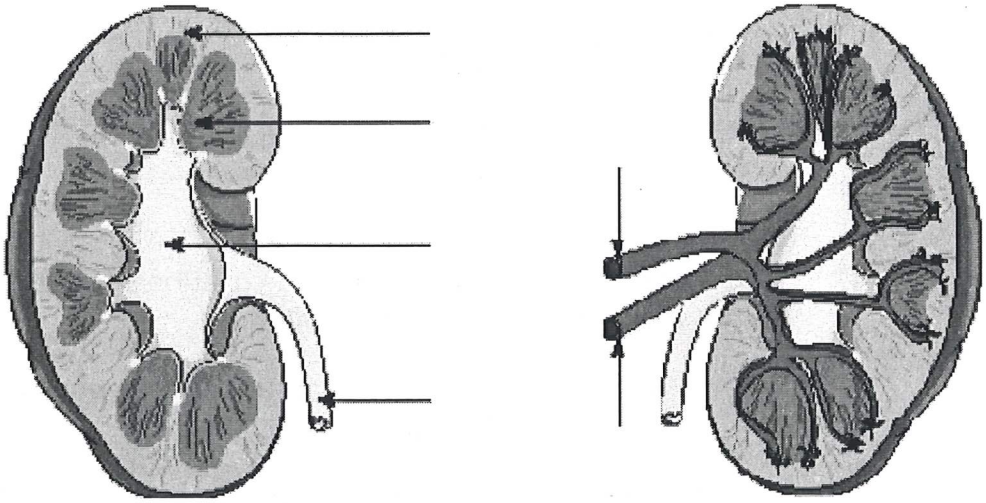
Vocabulary terms to know for this lesson:

- afferent arteriole
- bowman's capsule
- collecting duct
- distal convoluted tubule
- efferent arteriole
- glomerular filtration
- glomerulus
- loop of Henle
- nephron
- peritubular capillary network
- proximal convoluted tubule
- selective reabsorption
- tubular secretion
- water reabsorption

Guided Practice 4.2B 2
Kidney Anatomy

Use the terms from the following list to label the diagram of the kidney.

- renal cortex
- renal medulla
- ureter
- renal vein
- renal artery
- renal pelvis



Guided Practice 4.2B 3
Nephron Structure and Function

1. Complete the following table, showing various molecules and whether they are filtered into Bowman's capsule. The first one is done for you to demonstrate how to proceed.

Blood component	Found in filtrate	Not filtered	Reabsorbed
Water	X		some
Formed elements (cells)			
Nitrogen wastes			
Nutrients			
Salts			
Proteins			

2. Generally speaking, what is the relationship between particle size and whether it is filterable?

3. What is the general rule about whether or not something is reabsorbed or excreted?

4. Consider the blood flowing through the afferent and efferent arterioles. Considering what is filtered, fill in the following table.

Blood component	Afferent Arteriole	Efferent arteriole
Water	Has more	Has less
Formed elements		
Nitrogen wastes		
Nutrients		
Salts		
Proteins		
Oxygen		

Note:

Hint for oxygen and nutrients: Think about whether the processes in the nephron are active or passive.

Summary

Now do Section Assignment 4.2 Part A: Case Studies in Renal Function.

Completing this lesson has helped you to:

- identify the structures of the kidney and explain their functions
- describe the production of urine, using appropriate terminology

Lesson 4.2C
Renal Artery vs. Renal Vein

Overview

This lesson consists of an assignment that you will send in at the end of this section.

Resource List

- *Inquiry Into Life*
- *Biology 12 Web site*
  http://www.openschool.bc.ca/courses/biology/bi12/mod4.html

Renal Artery vs. Renal Vein

You have learned about the functions of the kidney, the processes that occur there, and the hormones that are important in kidney function. Blood that flows into via the renal artery has a different composition than the blood flowing out of the kidney via the renal vein.

For this lesson you will complete a section assignment in which you will play the role of a new lab assistant in a lab where a mistake with patient records has been made. Your job is to resolve the problem accurately. The office manager, who risks being fired if the problem isn't solved, has given you several documents and asked you to find a solution. Keep hard copies of these documents available while doing the assignment. Good luck!

There is no guided practice activity or glossary for this lesson.

Summary

Now do Section Assignment 4.2 Part B: Renal Artery vs. Renal Vein.

Completing this lesson has helped you to:

- use new knowledge to analyze complex situations
- understand the importance of ethical problem solving and decision making

Lesson 4.2D
ADH and Aldosterone

Overview

All organs modify the blood that flows through them. The lungs replace CO_2 with O_2, the heart pressurizes the blood, the gonads add sex hormones, etc. The kidneys modify the blood by regulating water concentration, removing nitrogenous wastes (i.e., urea and ammonia), and regulating blood pH and concentrations of ions, such as Na^+, K^+, Mg^{2+}, and HCO_3^-. This lesson focuses on the regulation of water by the kidney and the hormones responsible for it.

Resource List

- *Inquiry Into Life*
- *Biology 12 Provincial Exam Preparation package*
- *Biology 12 Media CD*

Solute Gradients in the Nephron

To understand how the kidney regulates water, you need to understand the processes involved in the reabsorption of water by the nephron. As you work through this lesson, keep in mind the following information on passive and active transport:

- A solution moves from areas of high concentration to areas of low concentration (diffusion).
- Water easily moves across living membranes, following diffusion gradients (osmosis).
- By changing the solute concentration (e.g., salt), water concentration is affected.
- Raising the solute concentration lowers the water concentration, even if the quantity of water is unchanged.

- Membranes are differentially permeable (i.e., membranes can control the type of molecule transported and the direction of that transport).
- Active transport requires an input of energy. In the case of salt reabsorption in the kidney, the amount of energy consumed is considerable—about one-third of all non-muscular activity of the body.

Hormonal Regulation of Water Balance

Several hormones are involved in controlling water balance. You are responsible for knowing about two of them: **anti-diuretic hormone** (ADH) and **aldosterone**.

Anti-diuretic Hormone (ADH)

This hormone is produced in the posterior pituitary gland, which is located in the brain. Some chemicals, such as caffeine and alcohol, are diuretics. They cause a reduction in water reabsorption, so urine becomes less concentrated and more dilute. ADH is an anti-diuretic. It does the opposite of a diuretic, causing an increase in urine concentration by stimulating the reabsorption of water.

The release of ADH is controlled by the hypothalamus, which detects variations in the osmolarity of the blood. As concentrations of water in the blood change, the amount of water diffusing in or out of the cells of the hypothalamus stimulate it to vary the amount of releasing hormone sent to the posterior pituitary.

ADH's target cells are in the collecting duct and distal convoluted tubule. These cells become more permeable to water in the presence of ADH. Since the peri-tubular environment is salty, any increase in water permeability causes water to leak through the membrane and into the peri-tubular capillary network.

When the water concentration in the blood falls, the body becomes dehydrated and the hypothalamus stimulates the posterior pituitary to release more ADH. The increase in ADH is sensed by the cells of the distal tubule and collecting duct, making them more permeable to water. As more water is reabsorbed, its concentration in the blood increases, reducing stimulation of the hypothalamus. The hypothalamus responds by slowing the secretion of releasing hormone, and balance is restored. This is a negative feedback system because the decrease in the water concentration in the blood stimulates a series of events that reverse the imbalance.

ADH is primarily released at night, which explains why the urine is more concentrated in the morning.

Aldosterone

Unlike ADH, which affects only water reabsorption, aldosterone affects both salt and water reabsorption. As a result its presence causes an increase in both blood pressure and volume without changing its tonicity (concentration).

Secretions of **renin** from the **juxtaglomerular apparatus** promote the release of aldosterone. These cells are located just outside of the glomerulus and are sensitive to changes in blood pressure. When pressure drops, glomerular filtration slows, stimulating secretion of renin. Renin is circulated in the blood to the **adrenal cortex** where it stimulates the release of aldosterone. In turn, aldosterone affects the distal convoluted tubule, which excretes more K^+ and reabsorbs more Na^+. As more Na^+ is reabsorbed, more water is absorbed. This increase in water and salt results in an increase in blood volume (without a change in tonicity) resulting in an increase in blood pressure.

Recall that the reabsorption of water is driven by Na^+ concentration. More salt in the peritubular space means the tonicity of the space increases, drawing water along, which is reabsorbed. This is also a negative feedback system.

Aldosterone's control of blood pressure is a complex process involving many steps.

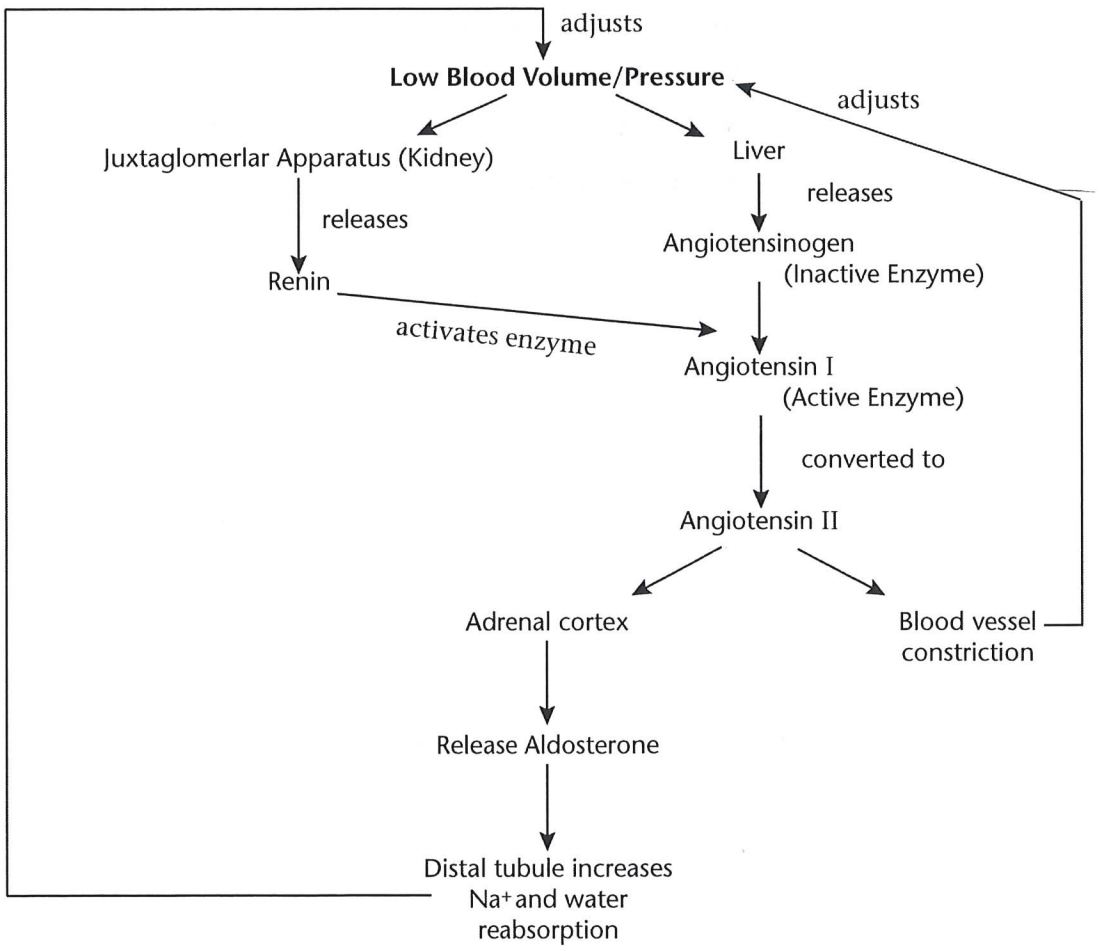
If you have access to a computer and the *Biology 12 Media CD*, go to *Regulating the Body's Water Balance* now.

Go to your:

Biology 12 Media CD > Module 4 > **Regulating the Body's Water Balance.**

The following diagram summarizes the homeostatic control of blood volume and pressure by Aldosterone.

Homeostatic Control of Blood Volume (Pressure) by Aldosterone



Guided Practice 4.2D 1
Study Flash Cards

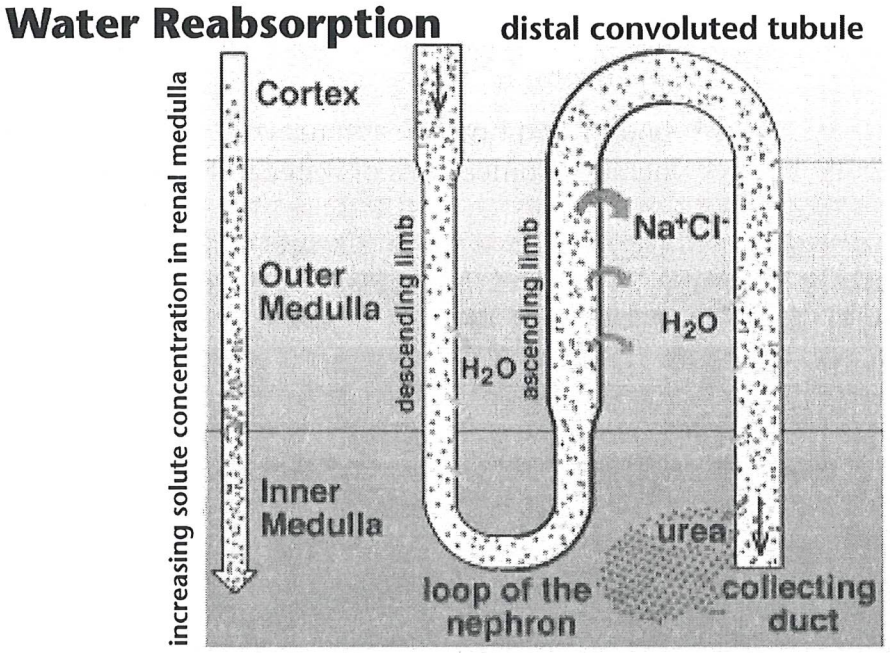
Using the information in your lessons, the *Inquiry Into Life* textbook, and the *Biology 12 PEP*, make a study flash card for each of the following vocabulary terms. Be sure the information is in your words, as that will be more meaningful to you.

Vocabulary terms to know for this lesson:

- adrenal cortex
- aldosterone
- aldosterone
- anti-diuresis
- antidiuretic hormone
- anti-diuretic hormone
- diuresis
- juxtaglomerular apparatus
- osmotic imbalance
- renin

Guided Practice 4.2D 2
Water Reabsorption in the Nephron

Use the information in your lessons, the *Inquiry Into Life* textbook, and the following diagram to answer these questions.



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1. Which limb of the loop of Henle is more permeable to water?
2. Which limb of the loop of Henle is more permeable to salt?
3. Is the collecting duct more permeable to water or salt?
4. How does the concentration of water change as the filtrate in the tubules moves closer to the inner medulla?
5. If you were designing a mechanism for regulating the amount of water reabsorbed from the filtrate, which two factors could you vary?

Summary

Now do Section Assignment 4.2 Part C: Regulation of Water and the Kidney.

Completing this lesson has helped you to:

- identify the source glands for antidiuretic hormone (ADH) and aldosterone
- understand how the hypothalamus, posterior pituitary, ADH, and the nephron achieve homeostasis of water levels in the blood
- understand how the adrenal cortex, aldosterone, and the nephron achieve homeostasis of water and sodium levels in the blood