Name of Unit	Nervous system
Subject/Course Name	Human Anatomy and Physiology-II
Subject/Course ID	BP201T
Class: B. Pharm. Semester	II
Course coordinator	Dr. Rahul Kumar Sharma
Mobile No.	9461551680
Email id	Buntyrahul177@gmail.com

Learning Outcome of Module 03

LO	Learning Outcome	Course Outcome Code
LO 1	To understand structural and functional aspects of organs of respiratory system	BP201.3
LO 2	To understand physiology of respiration	BP201.3
LO 3	To study of the lungs capacities.	BP201.3
LO 4	To understand anatomy urinary system.	BP201.3
LO 5	To understand anatomy kidney.	BP201.3
LO 6	To understand anatomy nephron and urine formation	BP201.3

Content Table

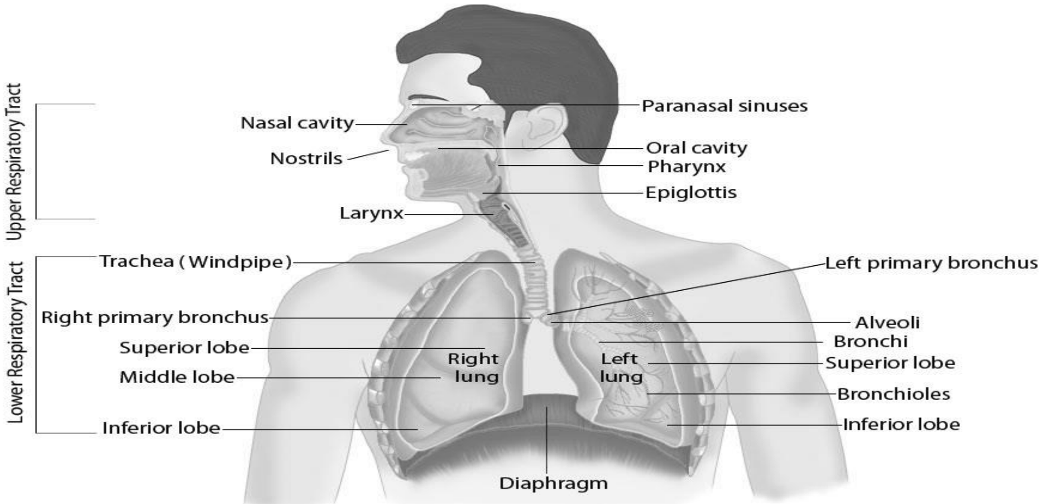
Topic
• Anatomy of respiratory system with special reference to anatomy of lungs, • Mechanism of respiration, regulation of respiration • Lung Volumes and capacities transport of respiratory gases, artificial respiration, and resuscitation methods. • Anatomy of kidney and nephron, functions of kidney and urinary tract. • Physiology of urine formation, micturition reflex and role of kidneys in acid base balance • Role of RAS in kidney and disorders of kidney.

RESPIRATORY SYSTEM

The respiratory system plays role in exchange of oxygen and carbon dioxide between the atmospheric air, blood and tissue cells. Metabolic reactions in human body use oxygen (O_2) to produce energy from nutrients in form of ATP. At the same time, these reactions release carbon dioxide (CO_2) which must be eliminated quickly to prevent acidity due to CO_2. The respiratory and cardiovascular systems cooperate to supply O_2 and eliminate CO_2. The respiratory system provides for gas exchange *i.e.* intake of O_2 and elimination of CO_2. The cardiovascular system transports these gases through blood between the lungs and body cells. The respiratory system also participates in regulating blood pH, contains receptors for the sense of smell, filters inspired air, produces sounds, and rids the body of some water and heat in exhaled air.

Parts of Respiratory System:

The respiratory system consists of the nose, pharynx (throat), larynx (voice box), trachea (Windpipe), bronchi and lungs.



Parts of Respiratory System

Nose:

It is only externally visible organ of respiratory system.

Nose can be divided into 2 parts:

1. External nose: The external nose consists of a framework of bones and hyaline cartilage covered with muscle and skin and lined by a mucous membrane. The frontal bone, nasal bones and maxillae form the bony framework of the external nose. On the undersurface of the external nose are two openings called the **external nares** or **nostrils**. Interior to external nostrils is a portion called nasal vestibule which has coarse hairs that filter out dust particles.

2. Internal nose: Internal nose is larger cavity and is present inferior to nasal bone and superior to mouth. Anteriorly it merges with external nose and posteriorly joins with pharynx through 2 openings called **internal nares**. Space within internal nose is called **nasal cavity**. A vertical partition called the **nasal septum** divides the nasal cavity into right and left sides. The superior surface of nasal cavity contains olfactory epithelium which provides sense of smell. Nasal cavity is lined internally with mucous membrane which contains goblet cells and cilia. Goblet cells produce mucous which moistens the nasal cavity and entraps dust particles. Cilia cells move mucous and dust particles toward oral cavity so that they can be swallowed or spit out. Thus nose have three functions:

a) Warming, moistening, and filtering incoming air
b) Detecting olfactory stimuli
c) Modifying speech vibrations

Pharynx:

The pharynx or throat is a funnel-shaped tube that starts at the internal nares and extends to the larynx (voice box). Pharynx lies posterior to the nasal and oral cavities, superior to the larynx and anterior to the cervical vertebrae. The pharynx functions as a passageway for air and food, provides a resonating chamber for speech sounds, and houses the tonsils, which participate in immunological reactions against foreign invaders.

The pharynx can be divided into three anatomical regions:

1. Nasopharynx: It is the superior portion of pharynx which extends from internal nares to soft palate. It has respiratory function only.

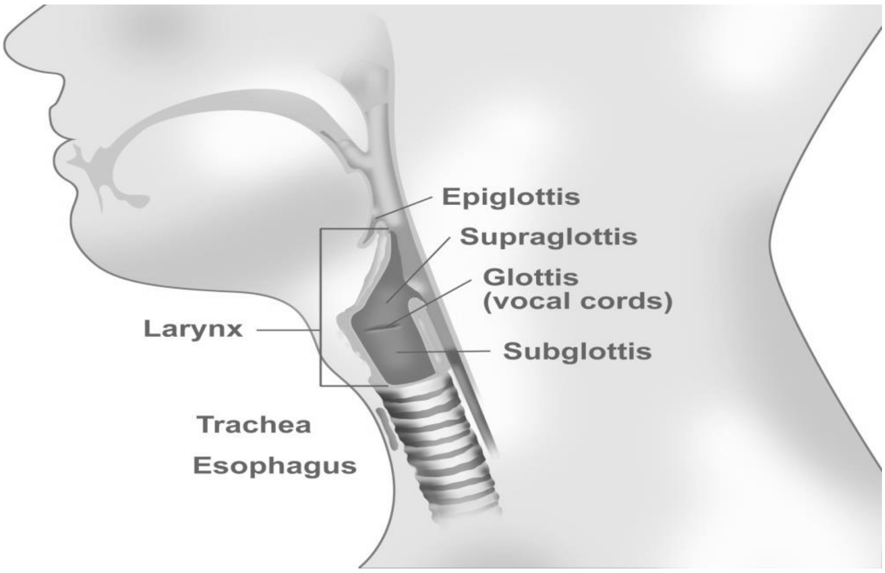
2. Oropharynx: It is middle part of pharynx which extends from soft palate to hyoid bone. It has both respiratory and digestive function as air, food and liquid pass through it.

3. Laryngopharynx: It is inferior portion of pharynx. It starts from hyoid bone and connects with esophagus and larynx. It has both respiratory and digestive function.

Larynx:

The larynx or voice box is a short passageway that connects the laryngopharynx with the trachea. It lies in the midline of the neck anterior to the esophagus. It is made up of 9 cartilages. One of the cartilages, called epiglottis extends superiorly and forms a lid over trachea during swallowing so that liquid and food do not enter into wind pipe.

Larynx acts as a passageway and produces sound by modifying air vibrations



Structure of larynx

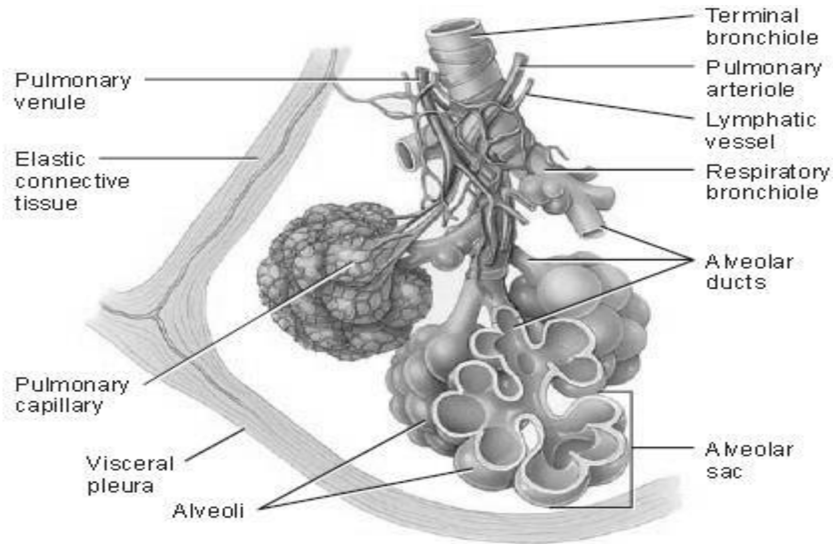
Trachea:

The trachea or windpipe is a tubular passageway for air that is about 12 cm (5 in.) long an2.5 cm (1 in.) in diameter. It is located anterior to the esophagus and extends from the larynx to the superior border of the fifth thoracic vertebra (T5), where it divides into right and left primary bronchi.The mucosa of the trachea consists of ciliated columnar cells and goblet cells which provide protection against dust. Trachea consists of 16–20 incomplete horizontal rings of hyaline cartilage (resemble the letter C), which are stacked one above another and are connected together by dense connective tissue. The open part of each-shaped cartilage ring faces posteriorly toward the esophagus and is spanned by a fibro muscular membrane. The trachealis muscles allow the diameter of the trachea to change subtly during inhalation and exhalation, which is important in maintaining efficient airflow. The solid C-shaped cartilage rings provide a semi-rigid support so that the tracheal wall does not collapse inward (especially during inhalation) and obstruct the air passageway.

Bronchi:

At the superior border of the fifth thoracic vertebra, the trachea divides into a right primary bronchus which goes into the right lung and a left primary bronchus which goes into the left lung. Like the trachea, the primary bronchi contain incomplete rings of cartilage and are lined by pseudostratified ciliated columnar epithelium. On entering the lungs, the primary bronchi divide to form smaller bronchi—the secondary (lobar) bronchi, one for each lobe of the lung. (The right lung has three lobes; the left lung has two.) The secondary bronchi continue to branch, forming still smaller bronchi, called tertiary (segmental) bronchi, that divide into bronchioles. Bronchioles in turn branch repeatedly, and the smallest ones branch into even smaller tubes called **terminal bronchioles**. This extensive branching from the trachea resembles an inverted tree and is commonly referred to as the bronchial tree. Terminal bronchioles subdivide into microscopic branches called respiratory bronchioles. Respiratory bronchioles in turn subdivide into several alveolar ducts.

Around the alveolar ducts are numerous alveoli and alveolar sacs. On the outer surface of the alveoli, there is a network of blood capillaries called pulmonary capillaries. The exchange of O_2 and CO_2 between the air spaces in the lungs and the blood takes place by diffusion across the alveolar and capillary walls.



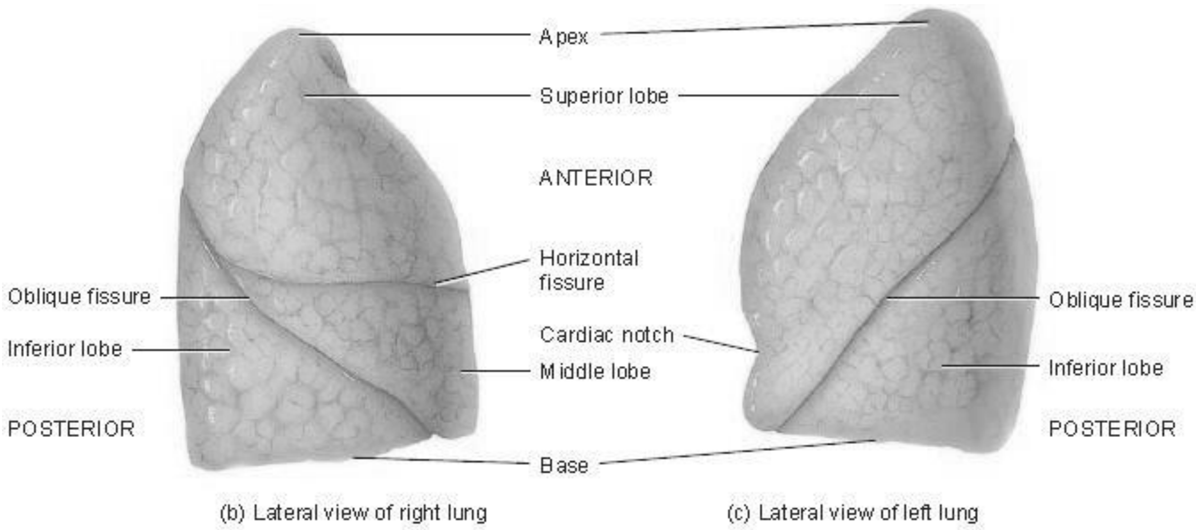
Structure of Bronchi

Lungs:

The lungs are paired cone-shaped organs in the thoracic cavity. They are separated from each other by the heart and other structures in the mediastinum. Each lung is enclosed and protected by a double-layered membrane called the pleural membrane. Between the both layers of pleural membrane a small space is present which is called the pleural cavity. Pleural cavity contains a small amount of lubricating fluid. This pleural fluid reduces friction between the membranes, allowing them to slide easily over one another during breathing.

The lungs extend from the diaphragm to just slightly superior to the clavicles and lie against the ribs anteriorly and posteriorly. The broad inferior portion of the lung is called the base and is present over the diaphragm. The narrow superior portion of the lung is called apex. The medial surface of each lung contains a region called the hilum through which bronchi, pulmonary blood vessels, lymphatic vessels, and nerves enter and exit. Medially the left lung also contains a concavity called the **cardiac notch** in which the heart lies.

Each lung is divided further into lobes by the fissures. Right lung is divided into 3 lobes (Superior lobe, Middle lobe and Inferior lobe) by horizontal and oblique fissure. The left lung is divided into 2 lobes (Superior lobe and Inferior lobe) by oblique fissure. Each lobe is further divided into number of small lobules.



Structure of lungs

Respiration:

The process of gas exchange in the body is called respiration. It has three basic steps:

1. Pulmonary ventilation or **breathing:** It is the inhalation (inflow) and exhalation (outflow) of air and involves the exchange of air between the atmosphere and the alveoli of the lungs.

2. External (pulmonary) respiration: It is the exchange of gases between the alveoli of the lungs and the blood in pulmonary capillaries across the respiratory membrane. In this process, pulmonary capillary blood gains O_2 and loses CO_2.

3. Internal (tissue) respiration: It is the exchange of gases between blood in systemic capillaries and tissue cells. In this step the blood loses O_2 and gains CO_2.

Within cells, the metabolic reactions that consume O_2 and give off CO_2 during the production of ATP are termed cellular respiration.

Pulmonary Ventilation:

Air moves into the lungs when the air pressure inside the lungs is less than the air pressure in the atmosphere. Air moves out of the lungs when the air pressure inside the lungs is greater than the air pressure in the atmosphere. It involves 2 steps:

1. Inhalation: Breathing in is called inhalation (inspiration). Just before each inhalation, the air pressure inside the lungs is equal to the air pressure of the atmosphere, which at sea level is about 760 mmHg or 1 atmosphere (atm). For air to flow into the lungs, the pressure inside the alveoli must become lower than the atmospheric pressure. This condition is achieved by increasing the size of the lungs. For inhalation to occur, the lungs must expand which increases lung volume and thus decreases the pressure in the lungs to below atmospheric pressure (758 mmHg). The most important muscle of inhalation is the diaphragm, the dome-shaped skeletal muscle that forms the floor of the thoracic cavity. Contraction of the diaphragm causes it to flatten and lowering its dome. This increases the vertical diameter of the thoracic cavity. Contraction of the diaphragm is responsible for about 75% of the air that enters the lungs during quiet breathing. The other muscles of inhalation are the external intercostals.When these muscles contract, they elevate the ribs. As a result, there is an increase in the anteroposterior and lateral diameters of the chest cavity.

2. Exhalation: Breathing out, also called exhalation (expiration) is also due to pressure difference. During exhalation the pressure in the lungs is greater than the pressure of the atmosphere. Normal exhalation is a passive process because no muscular contractions are involved. Instead, exhalation results from elastic recoil of the fibers of chest wall and lungs, both of which have a natural tendency to spring back after they have been stretched. Exhalation starts when the inspiratory muscles relax. As the diaphragm relaxes, its dome moves superiorly owing to its elasticity. As the external intercostals relax, the ribs are depressed.These movement decrease the vertical, lateral, and anteroposterior diameters of the thoracic cavity, which decreases lung volume. In turn, the alveolar pressure increases to about 762 mmHg. Air then flows from the area of higher pressure in the alveoli to the area of lower pressure in the atmosphere.

Lung volumes and capacities:

While at rest, a healthy adult averages 12 breaths a minute. The apparatus used to measure the volume of air exchanged and respiration rate is called spirometer or respirometer. The record is called spirogram.

1. Tidal Volume (V_T): It is the volume of air that moves in and comes out with each inhalation and exhalation. It is approximately 500 ml.

2. Minute Ventilation (MV): It is the total volume of air inhaled and exhaled each minute. It is calculated as respiratory rate multiplied by tidal volume:

MV = 12 breaths/min X 500 mL/breath = 6 liters/min

3. Inspiratory Reserve Volume: This is additional amount of air other than 500 ml that can be inhaled with a deep breath. It is approximately 3100 ml in males and 1900 ml in females.

4. Expiratory Reserve Volume: This is volume of air in addition to 500 ml that can be expelled out by a forceful exhalation after a normal inhalation. It is approximately 1200 ml in males and 700 ml in females.

5. Forced expiratory volume in 1 second ($FEV_{1.0}$): It is volume of air that can be exhaled from lung in 1 second with maximal effort after a maximal inhalation.

6. Residual Volume: Even after a strong exhalation, some volume of air remains inside lungs which cannot be exhaled out. This is called residual volume and it cannot be measured with spirometer. It is approximately 1200 ml in male and 1100 ml in female.

7. Inspiratory capacity: It is sum of tidal volume + inspiratory reserve volume. It is 500 ml + 3100 ml = 3600 ml in males

500 ml + 1900 ml = 2400 ml in females.

8. Functional Residual Volume: It is sum of residual volume + expiratory reserve volume. It is 1200 ml + 1200 ml = 2400 ml in male

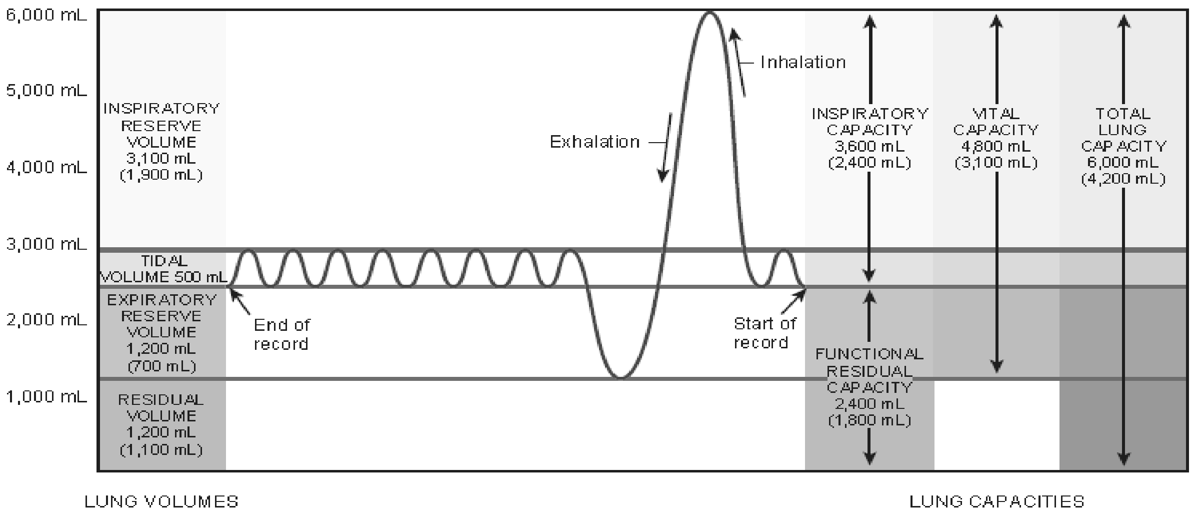
1100 ml + 700 ml = 1800 ml in female

9. Vital Capacity: It is sum of inspiratory reserve volume + tidal volume + expiratory reserve volume. It is approximately 4800 ml in male and 3100 ml in female.

10. Total Lung Capacity: It is sum of vital capacity + residual volume

4800 + 1200 = 6000 ml in male

3100 + 1100 = 4200 ml in female

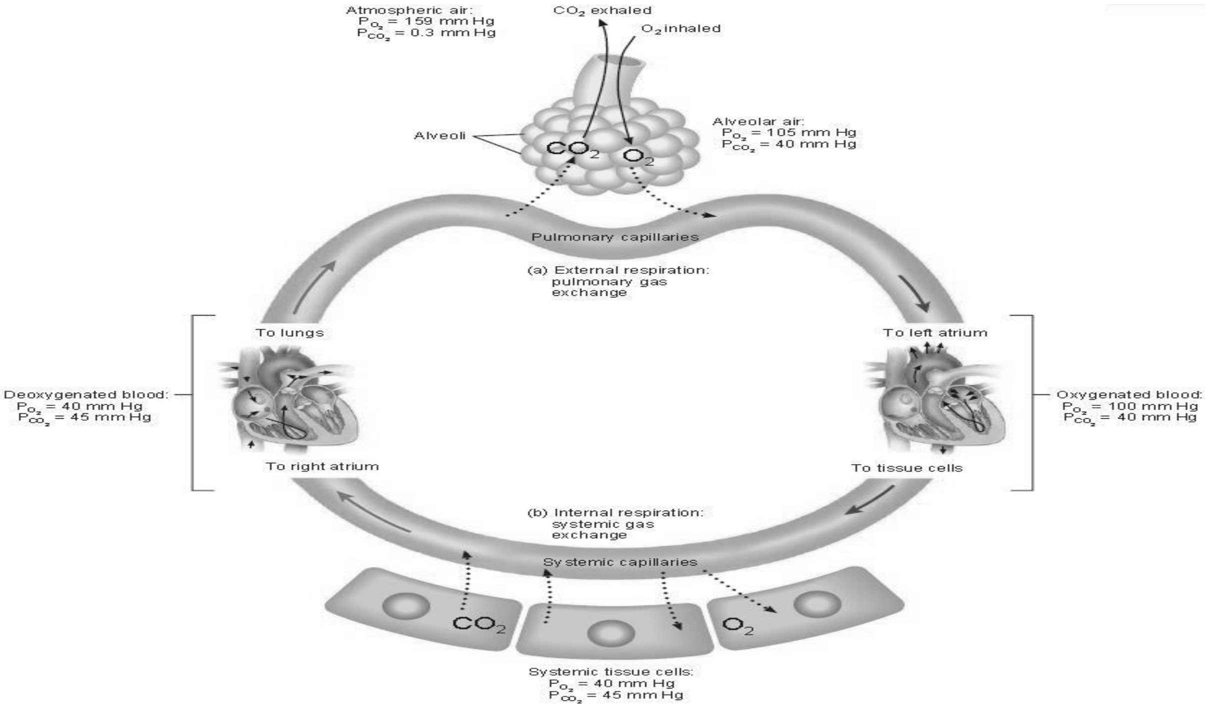


Lung volumes and capacities

External and Internal Respiration:

1. External respiration or pulmonary gas exchange: External respiration or pulmonary gas exchange is the diffusion of $O_2$from alveoli of the lungs to blood in pulmonary capillaries and the diffusion of CO_2 in the opposite direction i.e. from blood in pulmonary capillaries to alveoli of lungs. External respiration converts deoxygenated blood into oxygenated blood in the lungs. As blood flows through the pulmonary capillaries, it picks up O_2 from lungs and unloads CO2 into lungs. This exchange of gases depends upon the partial pressure of each gas. The gasses move from the area of higher partial pressure to the area where its partial pressure is low. In a resting person, the partial pressure of O_2 (PO_2) in alveoli of lungs is 105 mmHg whereas PO_2 in pulmonary capillaries is 40 mmHg. So the O_2 diffuses from alveoli into pulmonary capillaries. Diffusion continues until the PO_2in pulmonary capillary matches thePO_2in alveoli and becomes 100 mmHg. While O_2 is diffusing from alveoli into deoxygenated blood, CO_2 is diffusing in the opposite direction. The PCO_2 in deoxygenated blood in pulmonary capillaries is 45 mmHg in a resting person and thePCO_2 of alveolar air is 40 mmHg. Because of this difference inPCO_2, carbon dioxide diffuses from deoxygenated blood into the alveoli until the PCO_2 of the blood decreases to 40 mmHg. Oxygenated blood returning to the left side of the heart in the pulmonary veins thus has a PCO_2 of 40 mmHg. The left ventricle pumps oxygenated blood into the aorta and through the systemic arteries to systemic capillaries.

2. Internal respiration or systemic gas exchange: The exchange of O_2 and CO_2 between systemic capillaries and tissue cells is called internal respiration or systemic gas exchange. As O_2 leaves the bloodstream, oxygenated blood is converted into deoxygenated blood. Unlike external respiration, which occurs only in the lungs, internal respiration occurs in tissues throughout the body. The PO_2 of blood in systemic capillaries is higher(100 mmHg) than the PO_2 in tissue cells (40 mmHg at rest).Due to this pressure difference, oxygen diffuses out of the capillaries into tissue cells and blood PO_2 drops to 40 mmHg. While O_2 diffuses from the systemic capillaries into tissue cells, CO_2 diffuses in the opposite direction. Because tissue cells are constantly producing CO_2, the PCO_2 of cells (45 mmHg at rest) is higher than that of systemic capillary blood (40 mmHg). As a result, CO_2 diffuses from tissue cells into systemic capillaries until the PCO_2 in the blood increases to 45 mmHg. The deoxygenated blood then returns to the heart and is pumped to the lungs for another cycle of external respiration.



Cycle of respiration

The rate of pulmonary and systemic gas exchange depends on several factors:

1. Partial pressure difference of the gases: Alveolar PO_2 must be higher than blood PO_2 for oxygen to diffuse from alveolar air into the blood. The rate of diffusion is faster when the difference between PO_2 in alveolar air and pulmonary capillary blood is larger; diffusion is slower when the difference is smaller. The larger partial pressure differences accelerate the rates of gas diffusion.

2. Surface area available for gas exchange: Larger the surface area available, larger is the rate of diffusion. Any pulmonary disorder that decreases the functional surface area of the respiratory membranes decreases the rate of external respiration.

3. Diffusion distance: The respiratory membrane is very thin, so diffusion occurs quickly. Also, the capillaries are so narrow that the red blood cells must pass through them in single file, which minimizes the diffusion distance from an alveolar air space to hemoglobin inside red blood cells. Buildup of interstitial fluid between alveoli, as occurs in pulmonary edema slows the rate of gas exchange because it increases diffusion distance.

Control and Regulation of Respiration:

The rate and depth of respiration is controlled by **respiratory center** present in brain stem. The respiratory center is divided into 3 areas depending upon there functions.

(1) The **medullary rhythmicity area** in the medulla oblongata

(2) The **pneumotaxic area** in the pons

(3) The **apneustic area**, also in the pons

1. Medullary Rhythmicity Area: The function of the medullary rhythmicity area is to control the basic rhythm of respiration. Medullary rhythmicity area is divided into inspiratory area and expiratory area. During quiet breathing, inhalation lasts for about 2 seconds and exhalation lasts for about 3 seconds.

a) **Inspiratory area:** Inspiratory area establishes the basic rhythm of breathing. While the inspiratory area is active it generates nerve impulse which causes inhalation of air for about 2 seconds. At the end of 2 seconds, the inspiratory area becomes inactive and nerve impulses cease. With no impulses arriving, the diaphragm and external intercostal muscles relax for about 3 seconds, allowing passive elastic recoil of the lungs and thoracic wall. Then, the cycle repeats.

b) **Expiratory area:** Expiratory area remains inactive during quiet breathing. However, during forceful breathing, nerve impulses from the inspiratory area activate the expiratory area which causes forceful exhalation.

2. Pneumotaxic Area: It helps coordinate the transition between inhalation and exhalation by transmitting inhibitory impulses to the inspiratory area. The major effect of these nerve impulses is to help turn off the inspiratory area before the lungs become too full of air. In other words, the impulses shorten the duration of inhalation.

3. Apneustic Area: It also coordinates inhalation and exhalation. This area sends stimulatory impulses to the inspiratory area that activate it and prolong inhalation. It helps in a long, deep inhalation.

Regulation of the Respiratory Center:

Although the basic rhythm of respiration is maintained by respiratory center, but it can be modified or regulated by following factors:

1. Cortical Influences on Respiration: Because the cerebral cortex has connections with the respiratory center, we can voluntarily alter our pattern of breathing. We can even refuse to breathe at all for a short time. Voluntary control is protective because it enables us to prevent water or irritating gases from entering the lungs. The ability to not breathe, however, is limited by the buildup of CO_2 and H^+ in the body. When PCO_2 and H^+ concentrations increase to a certain level, the inspiratory area is strongly stimulated and breathing resumes, whether the person wants it to or not.

2. Chemoreceptor Regulation of Respiration: Chemoreceptors monitor levels of

CO_2, H^+ and O_2 and provide input to the respiratory center. Chemoreceptors are of two types:

○ Central chemoreceptors which are located in or near the medulla oblongata in the central nervous system. They respond to changes in H^+ concentration or PCO_2 in cerebrospinal fluid. When concentration of CO_2increases, these chemoreceptors stimulate respiratory center, increases ventilation and reduce PCO_2 to normal.

○ Peripheral chemoreceptors are located in blood vessels near the arch of aorta and carotid arteries. These chemoreceptors are part of the peripheral nervous system and are sensitive to changes in PO_2, H^+ and PCO_2 in the blood. Sensitive to change in PCO_2 and stimulate respiratory center to increase rate and depth of breathing.

3. Proprioceptor Stimulation of Respiration: As soon as you start exercising, your rate and depth of breathing increase even before changes in PO_2, PCO_2 or H^+ level occur. The main stimulus for these quick changes in respiratory effort is input from proprioceptors, which monitor movement of joints and muscles. Nerve impulses from the proprioceptors stimulate the inspiratory area of the medulla oblongata.

4. The Inflation Reflex: Stretch-sensitive receptors called baroreceptors or stretch receptors are located in the walls of bronchi and bronchioles. When these receptors become stretched during over inflation of the lungs, nerve impulses are sent to the inspiratory and apneustic areas. In response, the inspiratory area is inhibited directly and the apneustic area is inhibited from activating the inspiratory area. As a result, exhalation begins. As air leaves the lungs during exhalation, the lungs deflate and the stretch receptors are no longer stimulated.

5. Other Influences on Respiration: Other factors that contribute to regulation of respiration include the following:

a) **Limbic system stimulation:** Anticipation of activity or emotional anxiety may stimulate the limbic system, which activates the inspiratory area to increase the rate and depth of ventilation.

b) **Temperature:** An increase in body temperature (during a fever or vigorous muscular exercise), increases the rate of respiration. A decrease in body temperature decreases respiratory rate.

c) **Pain:** A sudden severe pain brings about brief apnea, but a prolonged somatic pain increases respiratory rate.

d) **Irritation of airways:** Physical or chemical irritation of the pharynx or larynx brings about an immediate stopping of breathing followed by coughing or sneezing.

e) **Blood pressure:** A sudden rise in blood pressure decreases the rate of respiration, and a drop in blood pressure increases the respiratory rate.

Very Short Answer Type Question (2Marks)

1.Write short on

a. Tidal Volume
b. Inspiratory Reserve Volume
c. Expiratory Reserve Volume
d. Forced expiratory volume
e. Residual Volume
f. Inspiratory capacity
g. Functional Residual Volume
h. Vital Capacity
i. Total Lung Capacity

Short Answer Type Question (5 Marks)

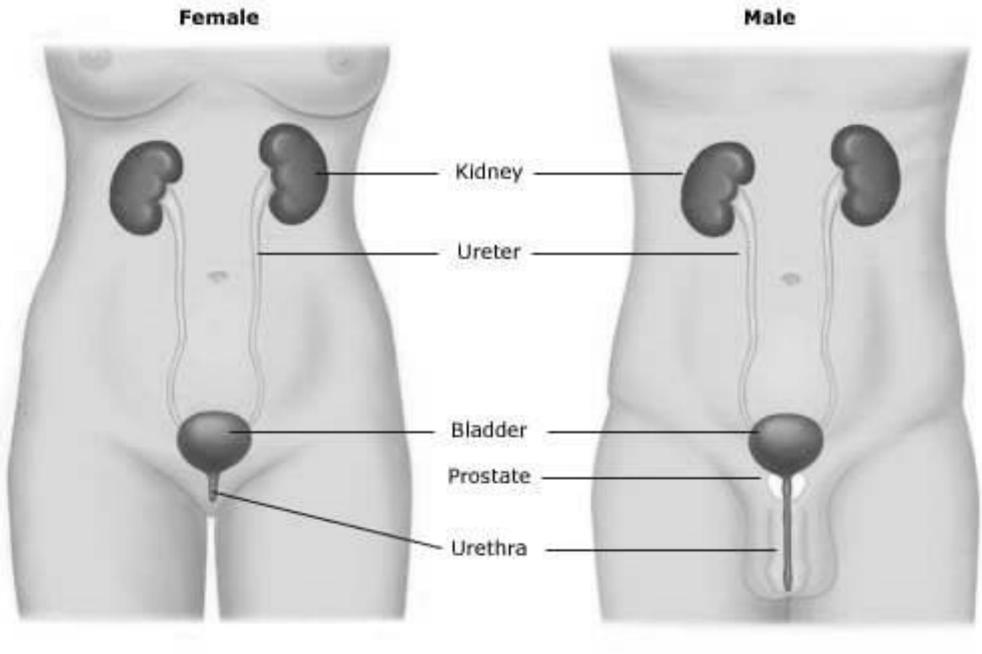
1. Draw diagram of lungs.
2. Write short note on pulmonary ventilation.
3. Explain the physiology of respiration.
4. Write brief note on control and regulation of respiration.

Short Answer Type Question (10 Marks)

1. Draw labelled diagram of respiratory tract.
2. Write the anatomy of bronchi with pictorial form.
3. Write structure of pharynx and its parts.

URINARY SYSTEM

The urinary system consists of two kidneys, two ureters, one urinary bladder and one urethra. Kidneys filter blood plasma to remove waste materials, solutes and water. They return most of the water and solutes to the bloodstream. The remaining water and solutes constitute urine, which passes through the ureters and is stored in the urinary bladder until it is excreted from the body through the urethra.



The urinary system

FUNCTIONS OF KIDNEYS

1. Regulation of blood ionic composition: The kidneys help regulate the blood levels of several ions *e.g.* sodium ions (Na^+), potassium ions (K^+), calcium ions ($Ca2^+$), chloride ions (Cl^-) and phosphate ions (HPO_4^{2-}).

2. Regulation of blood pH: The kidneys excrete a variable amount of hydrogen ions (H^+) and bicarbonate ions (HCO_3^-). Both of these help to regulate blood pH.

3. Regulation of blood volume: The kidneys adjust blood volume by conserving or eliminating water in the urine. An increase in blood volume increases blood pressure; a decrease in blood volume decreases blood pressure.

4. Regulation of blood pressure: The kidneys also help regulate blood pressure by secreting the enzyme renin, which activates the renin–angiotensin–aldosterone pathway. Increased renin causes an increase in blood pressure.

5. Maintenance of blood osmolarity: By separately regulating loss of water and loss of solutes in the urine, the kidneys maintain a relatively constant blood osmolarity close to 300 milliosmoles per liter (mOsm/liter).

6. Production of hormones: The kidneys produce two hormones.**Calcitriol** (the active form of vitamin D), which helps to regulate calcium levels and **erythropoietin** which stimulates the production of red blood cells.

7. Regulation of blood glucose level: Kidneys can use the amino acid glutamine in gluconeogenesis (synthesis of new glucose molecules). They can then release glucose into the blood to help maintain a normal blood glucose level.

8. Excretion of wastes and foreign substances: The kidneys help excrete wastes substances from the body. These include ammonia, urea, bilirubin, creatinine and uric acid. Other wastes excreted in urine are foreign substances from the diet, such as drugs and environmental toxins.

KIDNEY

The kidneys are two reddish, bean-shaped, retroperitoneal organs located just above the waist. The kidneys are located between the levels of the last thoracic and third lumbar vertebrae.

Anatomy of kidney

A typical adult kidney is 10–12 cm long; 5–7 cm wide and 3 cm. near the center of the concave border, an indentation is present called the renal hilum. Through renal hilum, the ureter, blood vessels, lymphatic vessels and nerves enter and exit the kidney. Three layers of tissue surround each kidney:

Renal capsule: It is the inner smooth, transparent sheet of dense irregular connective tissue. It protects from trauma and helps maintain the shape of the kidney.

Adipose capsule: It is the middle layer and is a mass of fatty tissue surrounding the renal capsule. It also protects the kidney from trauma and holds it firmly in place within the abdominal cavity.

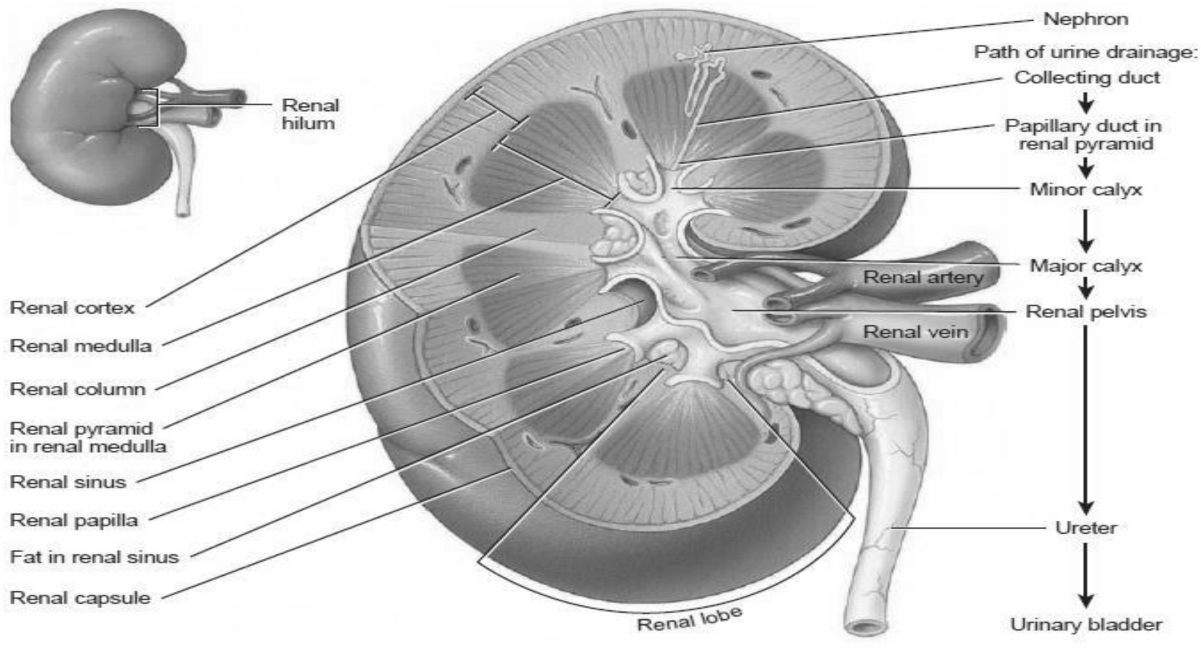
Renal fascia: It is the outermost layer of dense irregular connective tissue that anchors the kidney to the surrounding structures and to the abdominal wall.

Internal Anatomy of the Kidney: A kidney is divided into two distinct regions:

Renal medulla: It is inner region of kidney which appears dark reddish-brown. It consists of several cone-shaped regions called renal pyramids. The broad side of each pyramid (called base) faces the renal cortex and its apex (called renal papilla) points toward the renal hilum.

Renal cortex: It is outer region which is light red in color. The renal cortex is the smooth textured area extending from the renal capsule to the bases of the renal pyramids and into the spaces between them. It is further divided into an outer cortical zone and an inner juxtamedullary zone. The portions of the renal cortex present between renal pyramids are called **renal columns**.

Together, the renal cortex and renal pyramids constitute the parenchyma (functional portion) of the kidney. Within the parenchyma, the functional units of the kidney called nephrons are present. These nephrons are the actual site of urine formation. Urine formed by the nephrons drains into papillary ducts which further drain into minor and major calyces in the renal papillae area (calyces = cups; singular is calyx). From the major calyces, urine drains into the renal pelvis and then moves out through the ureter to the urinary bladder**.**



Structure of kidney

NEPHRON

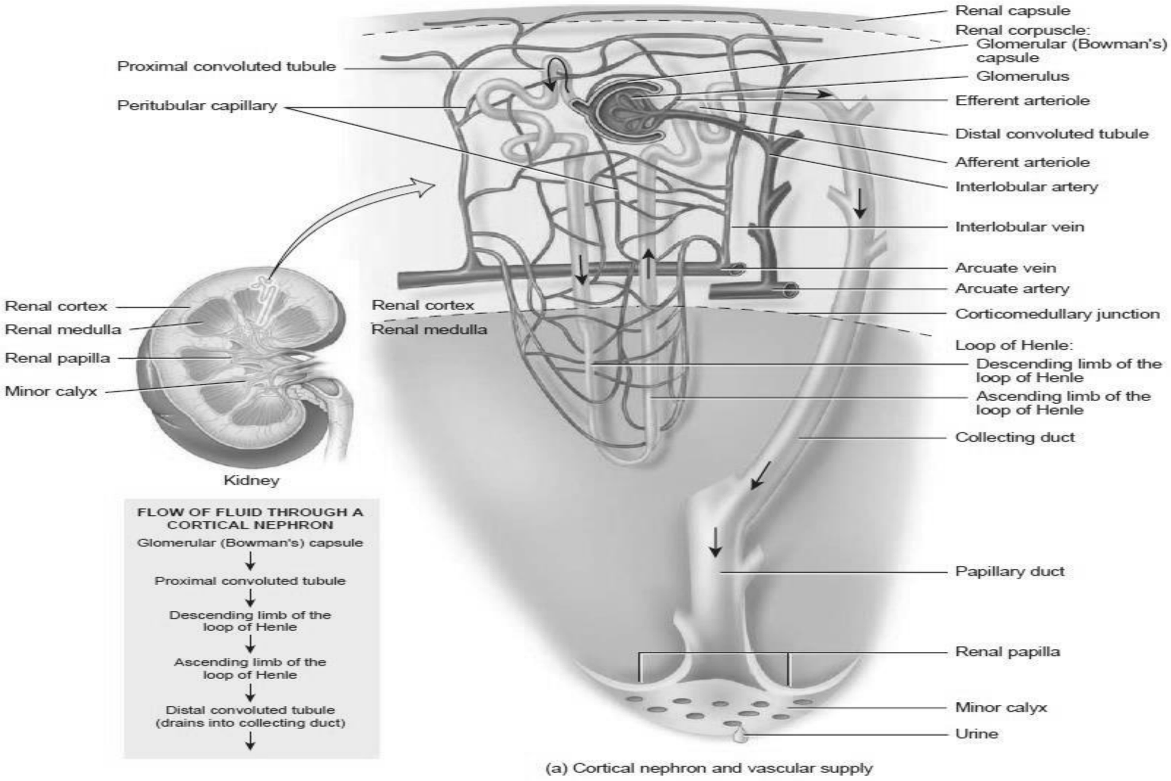
Nephrons are the functional units of the kidneys. Each kidney contains approximately 1 million nephrons. Each nephron consists of two parts:

Renal corpuscle: This is the part where blood plasma is filtered. It is further divided into two components: The **glomerulus** which is a network of blood capillaries and the **glomerular (Bowman's) capsule** which is a double-walled epithelial cup that surrounds the glomerular capillaries. Blood plasma is filtered in the glomerular capsule and then the filtered fluid passes into the renal tubule.

Renal tubule: This is the part into which the filtered fluid passes. It has three main sections: (i) Proximal convoluted tubule (ii) Loop of Henle (nephron loop) (iii) Distal convoluted tubule.

Proximal convoluted tubule (PCT): It is a convoluted (coiled) part of tubule which is attached to glomerular capsule.

Loop of Henle (nephron loop): The loop of Henle connects the proximal and distal convoluted tubules. It starts from PCT, dips into the renal medulla, makes a hairpin turn, returns to the renal cortex and ends at DCT. The first part of the loop of Henle which dips into the renal medulla is called the **descending limb of the loop of Henle**. It then makes that hairpin turn and returns to the renal cortex as the **ascending limb of the loop of Henle**.



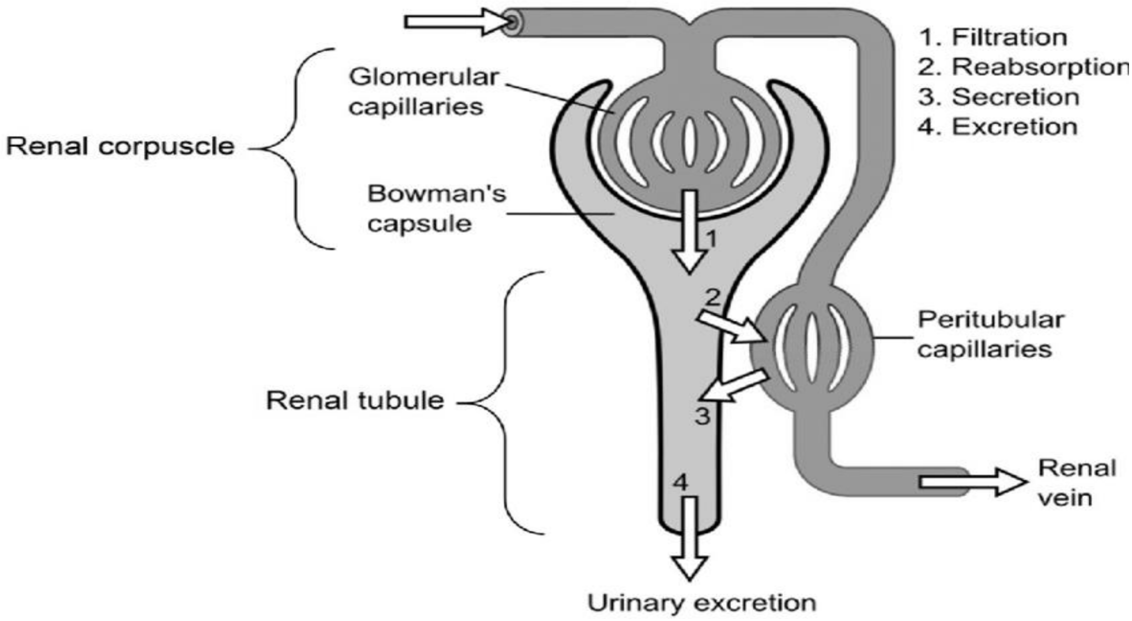
Structure of nephron

Distal convoluted tubule (DCT): It is convoluted part of tubule which is present away from glomerular capsule.The distal convoluted tubules of several nephrons empty into a single collecting duct. Collecting ducts then unite and converge into several hundred large papillary ducts, which drain into the minor calyces.

PHYSIOLOGY OF URINE FORMATION/KIDNEYS

Production of urine or physiology of kidney involves three basic processes (a) glomerular filtration (b) tubular reabsorption (c) tubular secretion.

1. Glomerular filtration: This is the first step of urine production. In this step, filtration takes place through the semipermeable walls of glomerulus and glomerular capsule. Water and most of the solutes present in blood plasma (water, mineral salts, amino acids, glucose, hormones, urea, uric acid, toxins and drugs *etc*.) move across the walls of glomerular capillaries and capsule into the renal tubule. Due to large size of blood cells (leucocytes, erythrocytes, platelets, blood proteins like globulin, albumin, prothormbin and fibrinogen) they do not filter through glomerular walls and remain in blood capillaries. The main factor which assists filtration is the difference in the pressure of blood in capillaries and pressure of filtrate in glomerular capsule. This pressure is called **Net filtration pressure** and its value is approximately 35mm Hg.



Physiology of urine formation

2 Selective or Tubular reabsorption: This is the process by which the composition and volume of glomerular filtrate changes during its passage through the convoluted tubules, the loop of Henle and the collecting duct. The general purpose of this process is to reabsorb those constituents which are essential to the body for maintenance of acid base balance, fluid balance and electrolyte balance. Some constituents like glucose, amino acids and vitamins are completely reabsorbed. Some substances are absorbed in varying amounts according to conditions within body *e.g.* water and mineral salts (Na^+, K^+, Ca^{2+}, HPO_4^{2-}, Cl^- *etc*.). Some substances (waste product) like urea and uric acid are absorbed only to a slight extent. The reabsorbed water and solutes return to the blood through the peritubular capillaries and vasa recta.

The maximum capacity of kidney for reabsorption of a substance is called **Transport maximum or renal threshold.** *E.g.* Glucose normally does not appear in urine because it is reabsorbed completely. But if its level rises above 160 mg/100 ml, it appears in urine. Several hormones also help in regulation of reabsorption. *E.g.* Parathyroid hormone and calcitonin help to regulate reabsorption of Ca^{2+} and HPO^{2-}. Antidiuretic hormone (ADH) increases water reabsorption. Aldosterone increases reabsorption of Na^+ and excretion of K^+. Atrial natriuretic peptide (ANP) decreases reabsorption of water and Na^+.

3 Tubular secretion: In this process, the substances which were not filtered in glomerulus and need long time for filtration (*e.g.* waste substances, drugs like penicillin and aspirin and H^+ ions) are secreted in convoluted tubules and are excreted from body in urine. Tubular secretion of H^+ is important to maintain normal blood pH.

Glomerular Filtration Rate (GFR)

The amount of filtrate formed by both kidneys each minute is called glomerular filtration rate (GFR). It is about 125 mL/min or 180 lit /day in healthy adult. GFR increases when blood flow into the glomerular capillaries increases.

Composition of urine

Urine is an amber coloured liquid which consist mainly of water (96%), urea (2%) and other solutes (2%). The solutes include uric acid, creatinin, ammonia, sodium, potassium, chloride, phosphate, sulphates and oxalates. The amber colour of urine is due to presence of bile pigment (urobilin). A healthy adult produces 1-1.5 lt of urine per day. The pH of urine varies from 4.5-6 and average value is 6. The colour and amount of urine secreted vary according to amount of fluid intake and fluid loss from body.

Regulation of water and electrolyte balance:

Even though fluid intake in our body can be highly variable but the total volume of fluid in our body normally maintained stable by our kidneys. Kidneys produce a large volume of dilute urine when fluid intake is high and a small volume of concentrated urine when fluid intake is low or fluid loss is large. ADH also controls whether dilute urine or concentrated urine is formed. In the absence of ADH, urine is very dilute and in presence of high level of ADH, concentrated urine is produced.

1. Formation of dilute urine:

Glomerular filtrate has the same ratio of water and solute particles as blood; its osmolarity is about 300 mOsm/liter. When dilute urine is being formed the osmolarity of the fluid in the tubular lumen increases as it flows down the descending limb of the loop of Henle, decreases as it flows up the ascending limb, and decreases still more as it flows through the rest of the nephron and collecting duct. These changes in osmolarity result from the following conditions along the path of tubular fluid:

Because the osmolarity of the interstitial fluid of the renal medulla becomes progressively greater, more and more water is reabsorbed by osmosis as tubular fluid flows along the descending limb toward the tip of the loop. As a result, the fluid in the lumen becomes more concentrated.

1. Cells lining the thick ascending limb of the loop of Henle actively reabsorb Na^+, K^+ and Cl^- from the tubular fluid and pass them to vasa recta.
2. Only solutes are reabsorbed in the thick ascending limb because it is very less permeable to the water. So osmolarity of tubular fluid drops to about 150 mOsm/liter.
3. While the fluid continues flowing along the distal convoluted tubule, additional solutes but only a few water molecules are reabsorbed.
4. Finally, the last part of distal convoluted tubules and collecting ducts are impermeable to water when the ADH level is very low. Thus, tubular fluid becomes progressively more dilute and its concentration can be as low as 65–70 mOsm/liter. This is four times more dilute than blood plasma or glomerular filtrate.

2. Formation of Concentrated Urine: When water intake is low or water loss is high (such as during heavy sweating), the kidneys conserve water while still eliminating wastes and excess ions. Under the influence of ADH, the kidneys produce a small volume of highly concentrated urine.

The ability of ADH to cause excretion of concentrated urine depends on the presence of an osmotic gradient of solutes in the interstitial fluid of the renal medulla. The solute concentration of the interstitial fluid in the kidney increases from about 300 mOsm/liter in the renal cortex to about 1200 mOsm/liter deep in the renal medulla. Countercurrent flow refers to the flow of fluid in opposite directions. Two types of countercurrent mechanisms exist in the kidneys: countercurrent multiplication and countercurrent exchange.

a) Countercurrent multiplication: Countercurrent multiplication is the process by which osmotic gradient is formed in the interstitial fluid of the renal medulla as a result of countercurrent flow. Since countercurrent flow through the descending and ascending limbs of the long loop of Henle establishes the osmotic gradient in the renal medulla, the long loop of Henle is said to function as a countercurrent multiplier. The kidneys use this osmotic gradient to excrete concentrated urine.

Production of concentrated urine by the kidneys occurs in the following way:

1. In the thick ascending limb of the loop of Henle, Na^+ and Cl^- are reabsorbed from the tubular fluid. Water is not reabsorbed in this segment because the cells are impermeable to water. As a result, there is a buildup of Na^+ and Cl^- ions in the interstitial fluid of the medulla.

2 .Since tubular fluid constantly moves from the descending limb to the thick ascending limb of the loop of Henle, the thick ascending limb constantly reabsorbs Na^+ and Cl^- which results in the formation of an osmotic gradient that ranges from 300 mOsm/liter to 1200 mOsm/liter. The descending limb of the loop of Henle is very permeable to water but impermeable to solutes except urea. Because the osmolarity of the interstitial fluid outside the descending limb is higher than the tubular fluid within it, water moves out of the descending limb via osmosis. This causes the osmolarity of the tubular fluid to increase. Because the ascending limb of the loop is impermeable to water, but reabsorb Na^+ and Cl^- from the tubular fluid into the interstitial fluid of the renal medulla, so the osmolarity of the tubular fluid decreases as it flows through the ascending limb. Overall, tubular fluid becomes progressively more concentrated as itflows along the descending limb and progressively more dilute as it moves along the ascending limb.

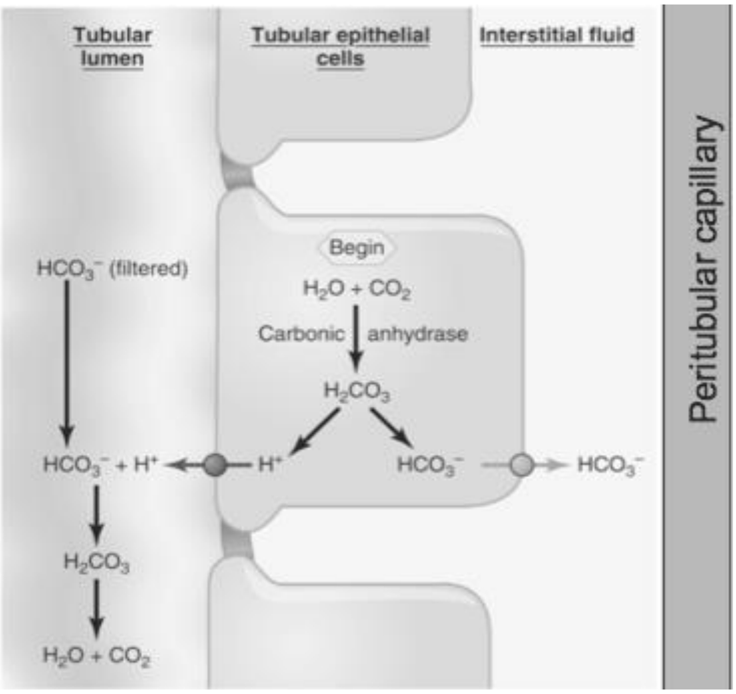
When ADH increases the water permeability of the principal cells, water along with urea quickly moves out of the collecting duct tubular fluid via osmosis and moves into interstitial fluid and then into the vasa recta.

4. As urea accumulates in the interstitial fluid, some of it diffuses into the tubular fluid in the descending and thin ascending limbs of the long loops of Henle. And along with the fluid, it flows back to collecting duct. Then water reabsorption occurs again which causes reabsorption of urea and the cycle repeats. The constant transfer of urea between segments of the renal tubule and the interstitial fluid of the medulla is termed urea recycling. In this way, reabsorption of water from the tubular fluid of the ducts promotes the buildup of urea in the interstitial fluid of the renal medulla, which in turn promotes water reabsorption. The solutes left behind in the lumen thus become very concentrated, and a small volume of concentrated urine is excreted.

b) Countercurrent exchange: Countercurrent exchange is the process by which solutes and water are passively exchanged between the blood of the vasa recta and interstitial fluid of the renal medulla as a result of countercurrent flow. The vasa recta also consist of descending and ascending limbs that are parallel to each other and to the loop of Henle. Just as tubular fluid flows in opposite directions in the loop of Henle, blood flows in opposite directions in the ascending and descending parts of the vasa recta. Thus countercurrent flow between the descending and ascending limbs of the vasa recta allows for exchange of solutes and water between the blood and interstitial fluid of the renal medulla and the vasa recta function as a countercurrent exchanger. When blood flows along the descending part into the renal medulla, where the interstitial fluid becomes increasingly concentrated, Na^+, Cl^- and urea diffuse from interstitial fluid into the blood and water diffuses from the blood into the interstitial fluid. When the blood flows into the ascending part of the vasa recta, the interstitial fluid becomes increasingly less concentrated. As a result Na^+, Cl^- and urea diffuse from the blood back into interstitial fluid, and water diffuses from interstitial fluid back into the vasa recta. Thus, the vasa recta provide oxygen and nutrients to the renal medulla without washing out or diminishing the osmotic gradient. The long loop of Henle establishes the osmotic gradient in the renal medulla by countercurrent multiplication, but the vasa rectum maintains the osmotic gradient in the renal medulla by countercurrent exchange.

Maintenance of Acid Base Balance

For the cells of body to function properly, blood pH must be maintained between 7.35-7.45. Whenever the pH of arterial blood rises above 7.45, it is called alkalosis. Drop in pH below 7.35 results in acidosis.Small amount of acidic substances enter our body through ingested food and large amount of acid or H^+ are produced like phosphoric acid, lactic acid and fatty acids *etc.* In addition CO_2 released during energy production forms carbonic acid. Ammonia and other basic substances are formed which go into blood. All these collectively play role in acid base balance of blood. Most of carbon dioxide is removed by lungs but main load is taken by kidneys to maintain acid base balance. Temporary balance is maintained by chemical buffers present in blood. Chemical buffers are systems of one or two molecules that act to prevent dramatic change in H^+ concentration when acid or base is added. They do this by binding to H^+ ions when pH drops and by releasing H^+ ions when pH rises. Three major chemical buffer systems of body are bicarbonate, phosphate and protein buffer systems, each of which helps to maintain pH in one or more fluid compartments. They all work together and maintain acid base balance.



Acid-base balance

Renal mechanism: Metabolic reactions produce nonvolatile acids such as sulfuric acid in body. The only way to eliminate this huge acid load is to excrete H^+ in the urine. Chemical buffers can neutralize excess acids or bases temporarily, but they cannot eliminate them form the body. Lungs can remove only carbonic acid by eliminating carbon dioxide. Only kidneys can remove other acids generated during metabolism. Kidneys can also regulate blood levels of alkaline substances. Cells in both the

proximal convoluted tubules (PCT) and the collecting ducts of the kidneys secrete hydrogen ions into the tubular fluid which is excreted out in urine. Two important means by which kidney maintains acid base balance of the blood are

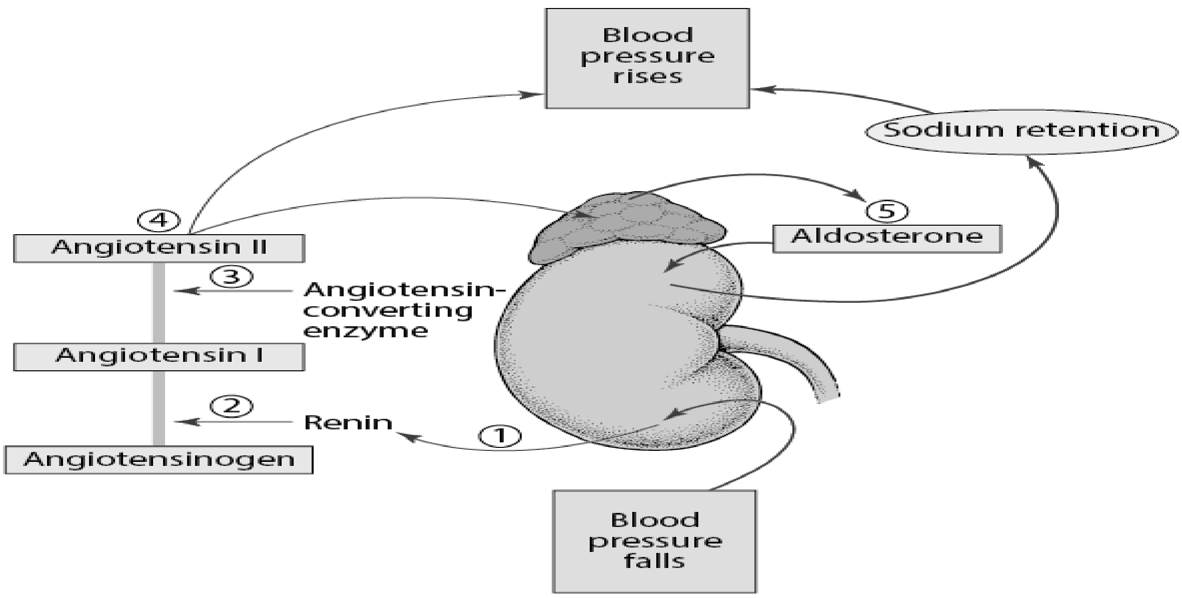
1) Excreting bicarbonate ion

2) Conserving, reabsorbing or generating new bicarbonate ions. As the pH rises, bicarbonate ions are excreted and H^+ ions are retained by tubular cells. When blood pH falls, bicarbonate ions are reabsorbed and H^+ ions are secreted out. Urine pH varies from 4.5-8 which shows ability of renal tubules to excrete basic or acidic ions to maintain blood pH.

REGULATION OF BLOOD PRESSURE

Renin-Angiotensin-Aldosterone System (RAAS)

The Renin-Angiotensin-Aldosterone System (RAAS) is a hormonal system within the body that is essential for the regulation of blood pressure and fluid balance. The system is mainly comprised of the three hormones **renin**, **angiotensin II** and **aldosterone**. Primarily it is regulated by the rate of renal **blood flow**.



Renin-Angiotensin-Aldosterone System

Ureters

The ureters are two 25–30 cm long, thick walled, retroperitoneal narrow tubes that vary in diameter from 1 mm to 10 mm. They extend from kidney to urinary bladder. The ureters transport urine from the kidneys to the urinary bladder. The transport occurs due to peristalsis, hydrostatic pressure and gravity. At the base of the urinary bladder, the ureters curve medially and pass obliquely through the wall of the posterior aspect of the urinary bladder. As the urinary bladder fills with urine, pressure within it compresses the oblique openings into the ureters and prevents the backflow of urine.

Three layers of tissue form the wall of the ureters. The deepest layer is mucosa which consists of mucous membrane with transitional epithelium and lamina propria. Transitional epithelium is able to stretch and mucus secreted by the goblet cells of the mucosa prevents the cells from coming in contact with urine. The middle layer is muscularis which is composed of inner longitudinal and outer circular layers of smooth muscle fibers. Peristalsis is the major function of the muscularis. The superficial coat of the ureters is the adventitia, a layer of areolar connective tissue containing blood vessels, lymphatic vessels and nerves. The adventitia helps to connect with surrounding connective tissue and anchors the ureters in place.

Questions Bank

1. Enlist the urinary organs of the body. Mention the functions of urinary system.
2. Draw well labled diagram of urinary system.
3. Give anatomical postion of kidney.
4. Draw well labled diagram of nephron.
5. Discuss the physiology of urine formation.
6. How kidney regulate electrolyte balance.
7. Write the physiology of micturition