Physiology of Excretion and Osmoregulation

Unit of excretion – Nephron (structural and functional unit of kidney)

Uriniferous tubules – [Secretory region or Nephron
Non-secretory region or collecting portion or Duct system.

Nephron: Types – (A) Cortical Nephrons : ~ 80% of total Nephron
- Confined mostly to the cortex of kidney.

(B) Juxtamedullary Nephron : ~ 20% of total Nephron.
→ Originate at the junction of cortex and medulla and penetrate deep into the medulla of kidney.

Nephron: structure – consists of 4 parts:
(a) Renal or Malpighian corpuscles
(b) PCT (Proximal Convoluted tubules)
(c) Loop of Henle
(d) Distal convoluted tubule

Renal Corpuscles – confined only to cortex of kidney having diameter of ~ 200 μ. It consists of two parts:

(i) Glomerulus : – It is Capillary tuft which invaginates Bowman's Capsule: The afferent arteriole breaks into about 50 Capillary loops and forms glomerular tuft which provides capillary bed for ultrafiltration.

(ii) Bowman's capsule: It is cup shaped structure with outer parietal layer and inner visceral layer. The parietal layer has typical squamous epithelium of flat polygonal cells while the visceral layer is made up of large cells known as podocyte cells.

Renal tubules

PCT
→ lined by single layer of cuboidal cell with striated or brush border
→ metabolically very active
→ absorbs ~2/3rd of water, all glucose, amino acid and most of Na^+, Cl^-, PO_4^{--} etc.

Loop of Henle
→ Descending limb
→ thin walled ascending limb
→ thick walled ascending limb.
→ mostly concerned with concentration of filtrate.

DCT
→ Smaller no. of microvilli.
→ Reabsorption from DCT is under the influence of ADH
→ Determines the volume of urinary output.

Juxtaglomerular Apparatus: Consists of following structure-
(a) Granular Juxtaglomerular cells in afferent arteriole
(b) Macula densa of DCT
(c) Agranular Polkissen cells or lacis cells in the angle created by entrance and exit of afferent and efferent arteriole of each glomerulus.

JG apparatus / complex acts an endocrine structure and secretes 3 important hormone :-
(i) Erythropoietin (ii) Erythrogenin (c) Renin

Urine Formation (Physiology) : Three steps ←
(a) Glomerular filtration or Ultrafiltration
(b) Selective Reabsorption
(c) Tubular secretion.

Glomerular filtration: This process depends on two factors: (i) pressure gradient from lumen of the capillary to the lumen of Bowman's capsule.

(ii) The sieve like properties of the three layered tissue separating two components.

The filtration takes place through 3 barriers that constitute the filtration membrane:
(a) Fenestrated endothelium of Capillary
(b) basement membrane
(c) Filtration slit.

→ The diameter of efferent arteriole is less than afferent, there develops a resistance of blood flow out through glomerule.

→ Effective filtration pressure = Glomerular hydrostatic pressure − (Blood colloid osmotic pressure + Capsular hydrostatic pressure)

→ EFP = GHP − (BCOP − CHP)
= 75 − (30 + 20) = 25 mm Hg (also called net filtration pressure)

→ Glomerular filtration Rate (GFR): 125 ml/minute out of which 0.8% goes as urine.

→ Glomerular filtrate = Blood − (Blood corpuscles + Plasma protein)
= Blood plasma − protein.

→ Regulation of GFR: through various factors:
(i) Effect of renal blood flow
ii) Effect of afferent arteriolar constriction
iii) Effect of efferent arteriolar constriction
iv) Effect of sympathetic stimulation
v) Effect of arterial blood pressure.

Tubular Reabsorption: The filtered plasma components are either completely absent from the urine or present in smaller quantities which proves that these substances undergo tubular reabsorption. Some substances are reabsorbed completely, known as high threshold substances such as water, glucose etc. while some substances are called low threshold substances which are partially

reabsorbed eg. Urea. Those substances which are not absorbed at all are the non-threshold or athreshold substances like uric acid.

→ For tubular reabsorption, PCT is structured for massive reabsorption of salt and water. The reabsorption fall under following categories.

(a) Reabsorption of substances of nutritional value: There are five important nutritional substances namely Glucose, amino acids, proteins, acetoacetate ions and vitamins. All these except proteins are absorbed completely by active process in PCT. The proteins are absorbed through pinocytosis.

(b) Reabsorption of metabolic end products: The metabolic end product like Urea, creatine, urates etc. show poor reabsorption. Urea is absorbed 40% from filtrate. The creatinine is not absorbed in renal tubules.

(c) PCT absorbs ~70% of Na^+, nearly 75% of K^+ and large amount of Ca^{2+} from glomerular filtrate.

(d) 75% of water from filtrate is also reabsorbed in PCT.

(e) About 5% of the water from filtrate is reabsorbed in descending limb of loop of Henle through osmosis

(f) Descending limb of loop of Henle is not permeable to Na^+ and other solutes.

(g) Ascending limb of loop of Henle actively reabsorbs the remaining 25% of the filtered K^+ and some amount of Cl^-. Some Na^+ is also reabsorbed by diffusion

(h) Ascending limb is impermeable to water

(i) The filtrate becomes dilute (hypotonic) than plasma as it flows through ascending limb.

(j) About 80% of water is reabsorbed in PCT and loop of Henle. This is called <u>obligatory water Reabsorption</u>.

(k) DCT, Collecting tubule and Collecting duct absorbs actively some sodium and in exchange secrete some K^+ in the urine

(l) About 19% of water is reabsorbed by the action of ADH (anti diuretic hormone) or Vasopressin.

(m) Absence of ADH reduces reabsorption of water in DCT causing dilute and increased urine, a condition called Diabetes insipidus

(n) Volume of urine is regulated by ADH and Aldosterone.

(o) Absorption of water in DCT mediated by ADH is called Facultative water Reabsorption.

Tubular secretion: This process adds materials to filtrate from blood. Tubular secretion plays minor role in the function of human kidney. In mammals, secreted substances are uric acid, K^+, H^+ ammonia, creatine and the drug penicillin and para-aminohippuric acid. Most of the K^+ eliminated in the mammalian urine is secreted by DCT and collecting duct in exchange of absorbed Na^+.

Composition of Human Urine:

Water - 95%, Salt - 2%, Urea - 2.6%, Uric acid - 0.3%.
pH - 4.5 to 8.2 (average pH 6.0; mild acidic)
Colour - Pale yellow due to pigment Urochrome produced due to breakdown of Haemoglobin.
Volume: 1-2 litre/day.

Micturition: act of passing/voiding urine. Act of micturition involves the coordinated contraction of the smooth muscle of the bladder wall (detrusor muscle), abdominal wall and muscles of pelvic floor with relaxation of internal and external urethral sphincter.

Regulation of Kidney Functions / Excretion

(A) Nervous control (B) Hormonal control.

Nervous control: Stimulation of sympathetic nerve and vasoconstriction of afferent arterioles results into the decreased blood flow to glomerulus which ultimately results into the decrease in the glomerular filtrate rate. But when vasoconstriction occurs in efferent arterioles, then it causes decreased out flow of blood through glomerulus and increases glomerular pressure, and hence GFR is also increased.

Hormonal control:

1. ADH: (Antidiuretic hormone): Increased secretion of ADH decreases discharge of urine because it promotes more water reabsorption through DCT. The hyposecretion of ADH causes more urine to discharge; a condition known as diuresis / (Diabetes insipidus) i.e., tasteless and more dilute urine.

(2) RAAS: ~~Renin Aldosterone~~ Renin - Angiotensin - Aldosterone system: This system get trigerred in respons to low Na⁺ / low B.P. and ultimately achieves the increased level of Na⁺ / B.P.

FIG.

(3) ANF (Atrial Natriuretic factor) / ANP (Atrial Natriuretic Peptide): The ANF / ANP is secreted by the atrial myocardium of heart in response to high Na⁺ / high B.P. The effects of ANF are opposite to those of aldosterone. ANF inhibits Na⁺ and water reabsorption i.e., ANF increases Urine and Na⁺ output and reduces blood volume and pressure.

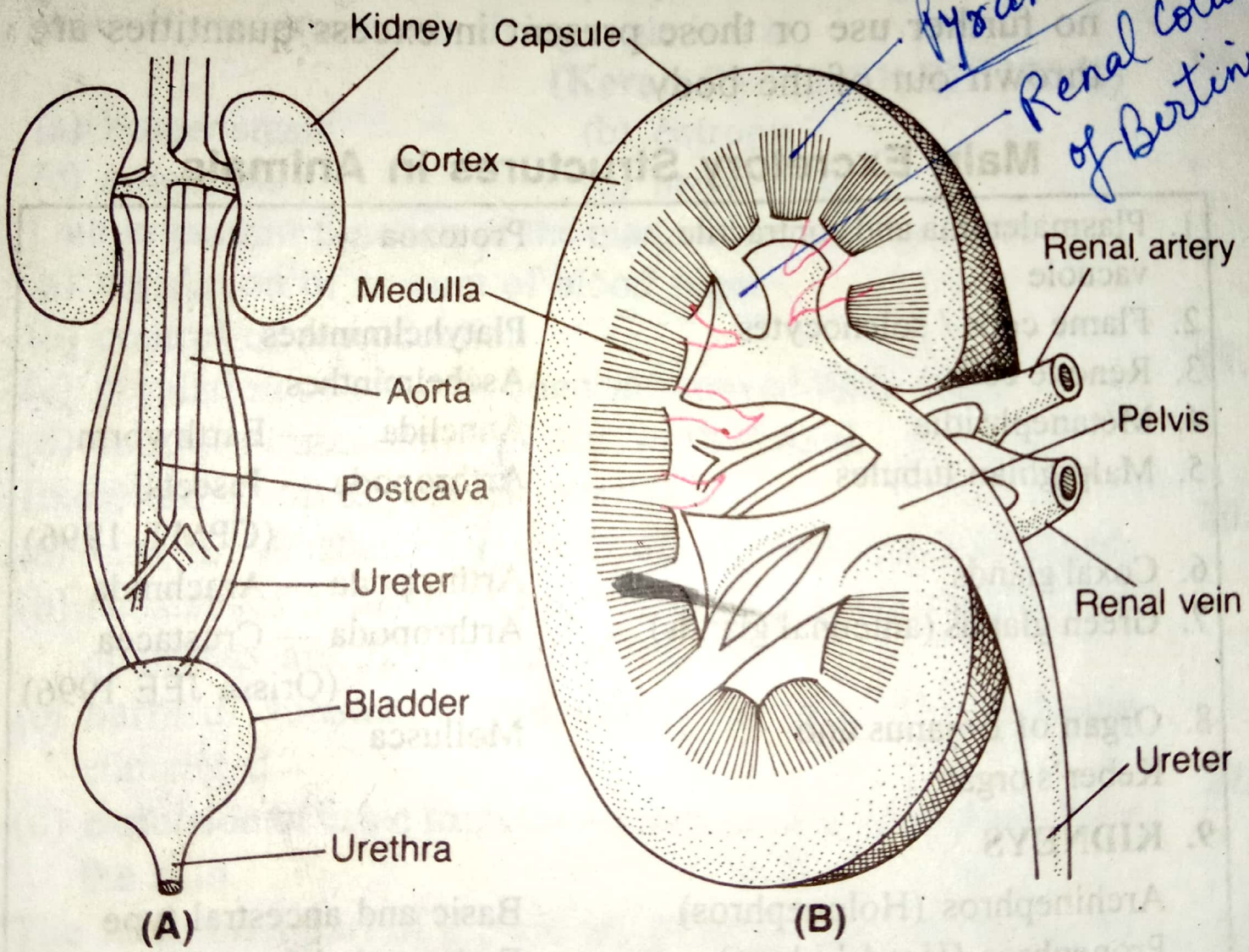
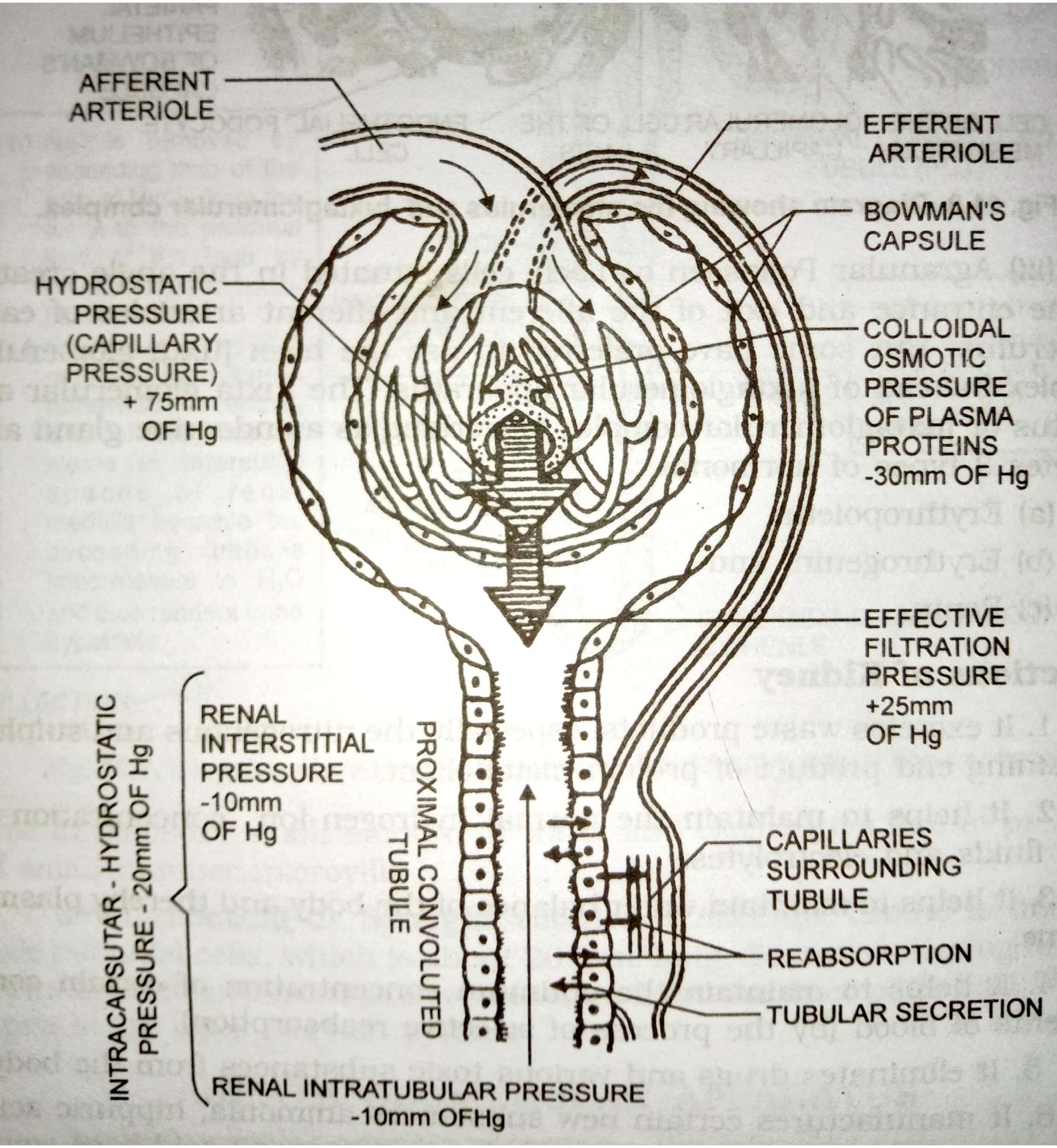


Fig.

A. Urinary system of man, B. Internal structure of kidney



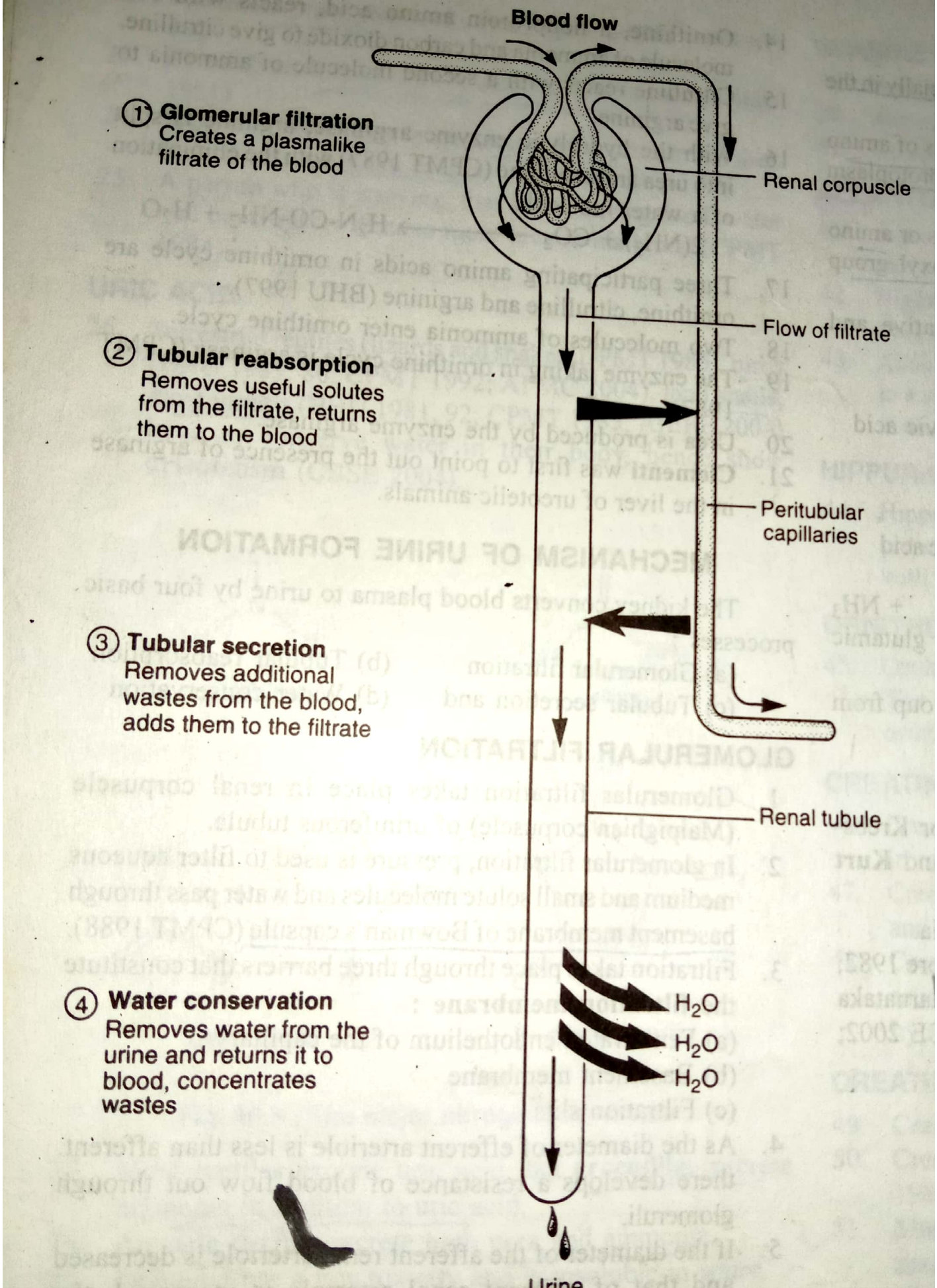


Fig. Basic steps in the formation of urine

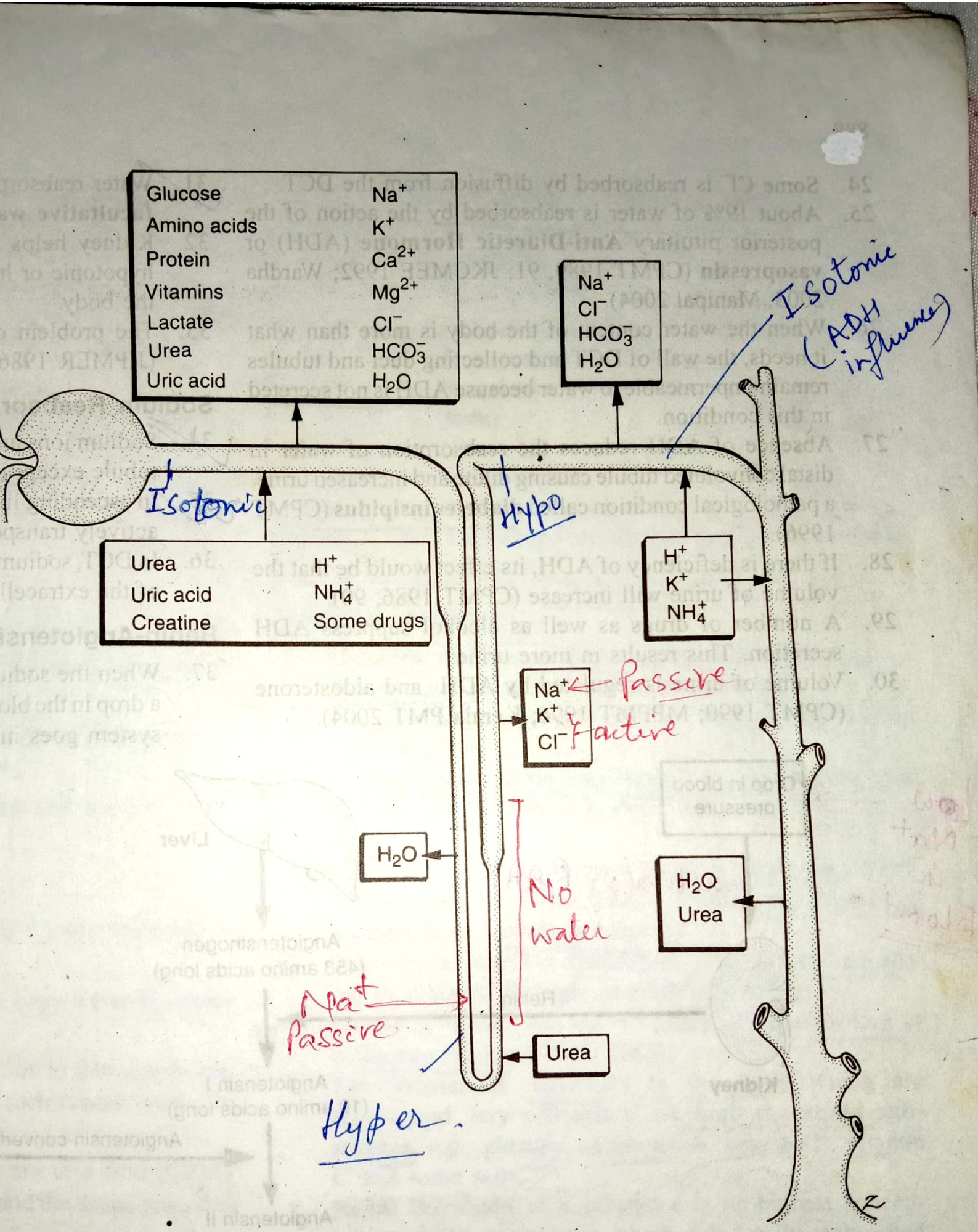


Fig. Solutes reabsorbed and secreted in different portions of the nephron

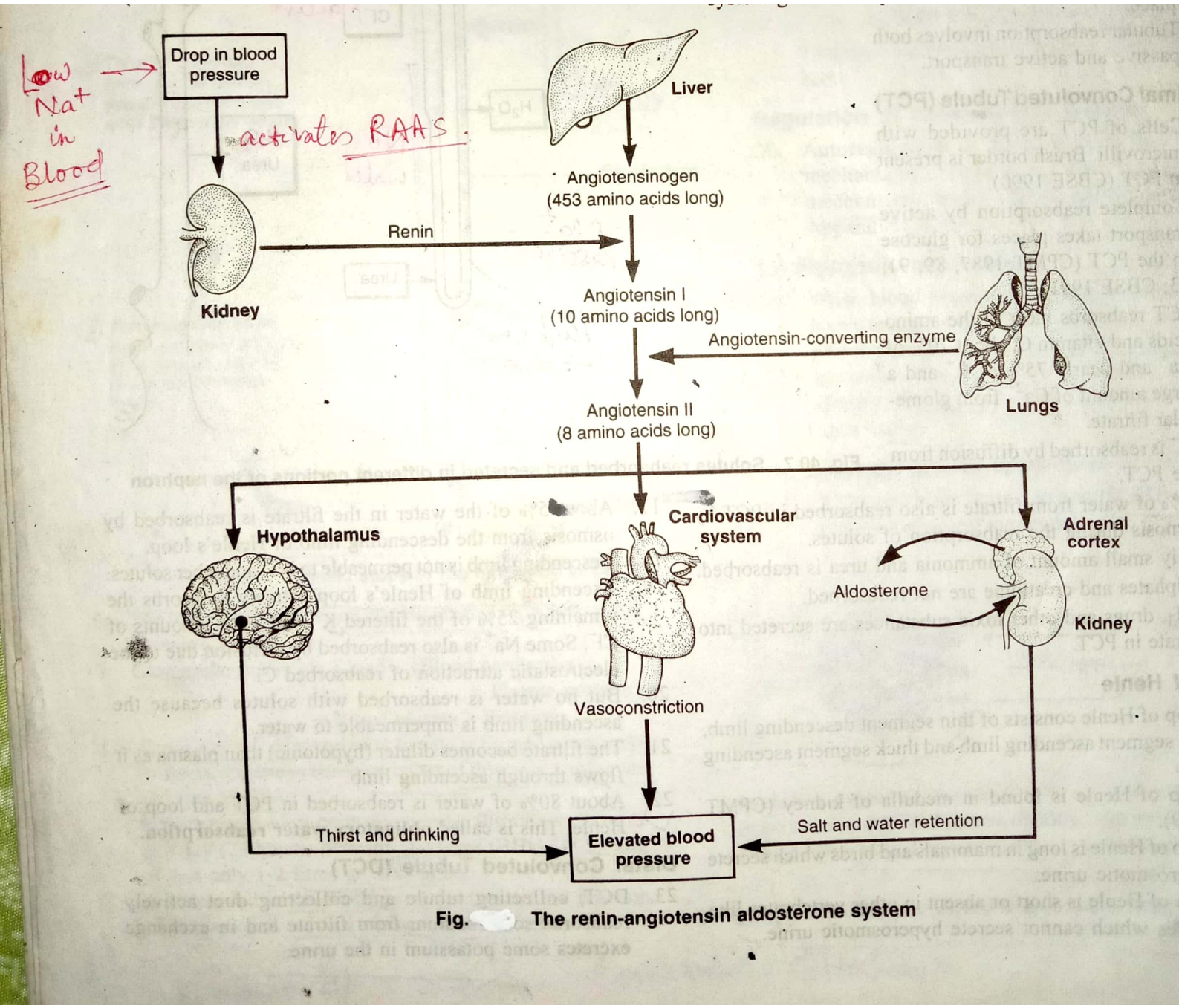


Fig. The renin-angiotensin aldosterone system