Osmoregulatory Systems in Fishes

Maintaining homeostasis with respect to solute concentrations and water content

Definitions

- Homeostasis = maintaining steady state equilibrium in the internal environment of an organisms
- Solute homeostasis = maintaining equilibrium with respect to solute (ionic and neutral solutes) concentrations
- Water homeostasis = maintaining equilibrium with respect to the amount of water retained in the body fluids and tissues

Definitions, continued

- Osmotic concentration - Total concentration of all solutes in an aqueous solution: measured in units of osmolals = 1 mole of solute/liter of water or milliosmolals = 1/1000th of one osmolal

Osmoregulation in different environments

- Challenge to homeostasis depends on
  - steady state concentration of solutes in the body fluids and tissues as well as
  - concentration of solutes in the external environment
    - marine systems: environment concentration = 34 - 36 parts per thousand salinity = 1000 mosm/l
    - freshwater systems: environment concentration < 3 ppt = 1 - 10 mosm/l

Osmoregulation in different environments

- Each species has a range of environmental osmotic conditions in which it can function:
  - stenohaline - tolerate a narrow range of salinities in external environment - either marine or freshwater ranges
  - euryhaline - tolerate a wide range of salinities in external environment - fresh to saline:
    - short term changes: estuarine - 10 - 32 ppt, intertidal - 25 - 40
    - long term changes: diadromous fishes

Four osmoregulatory strategies in fishes

- **Osmoregulators:** The animal who can maintain the internal osmolarity different from the medium which they live
- **Osmoconformers:** Osmoconformers cannot regulate the solutes in their body fluids at a concentration different from that of the external medium

1. Isosmotic (nearly isoionic, osmoconformers)
2. Isosmotic with regulation of specific ions
3. Hyperosmotic (freshwater fish)
4. Hyposmotic (Marine fish)

Osmotic regulation by marine teleosts…

- Marine teleost are hyposmotic and live in a medium having high salts concentration
- drink copiously to prevent osmotic dehydation
- Chloride cells eliminate Na^+ and Cl^-
- kidneys eliminate Mg^{++} and SO_4^{-2}

Osmoregulation by marine teleost

1. Oral ingestion:

2. Extrusion/secretion mechanism of salts/ions in gills

3. Absorption and secretion of salts/ions by kidney and urinary Bladder

Osmoregulation by marine teleost continued…….

1. Oral Ingestion

The hyperosmotic external environment withdraw water from the animal across the gill. To compensate this exosmosis marine teleost drinks sea water but this further increase salt content of body.

NaCl and water absorbed across the gut/intestine, Ca^{+2}, Mg^{+2} and SO_4^{-2} are also absorbed in intestine and some amount of Mg^{+2} and SO_4^{-2} excreted rectally.

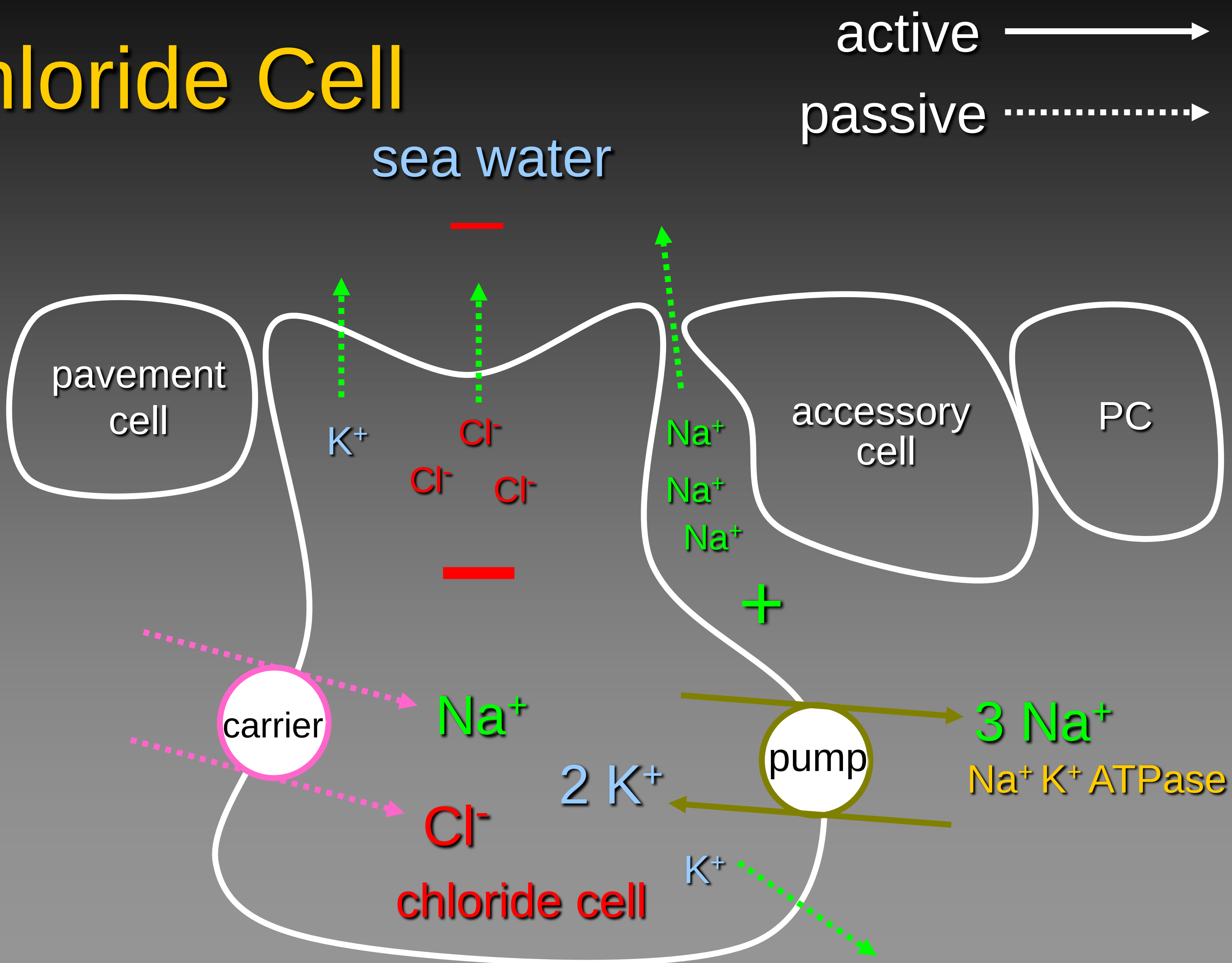
Ion transportation occurs in teleost intestine. Basolaetral membrane Na^+,K^+ ATPase at serosal side creates transmembrane electrochemical gradient for Na^+ and this drive movement of Na^+ through channels of mucosal side. Na^+ subsequently extruded by Basolaetral membrane Na^+,K^+ ATPase. Cl^- diffuse down its electrochemical gradient or is transported via Cl^-/HCO_3^- or K^+/Cl^- cotransporters.

Osmoregulation by marine teleost continued…….

2. Extrusion mechanism in gills

- Large acidophilic cells, the chloride secreting cells or chloride cella are found in the gills and oral membrane of marine and freshwater teleost
- Cl^- is co-transported by Na^+ ,K^+ / Cl^- co-transporters and secreted passively by these cells and rate of secretion is directly related to the number of chloride cells and Na+ also transported by active (Na^+ K^+ ATPase) and co transportation

Chloride Cell



Osmoregulation by marine teleost continued…

3. Absorption and secretion kidney and urinary Bladder

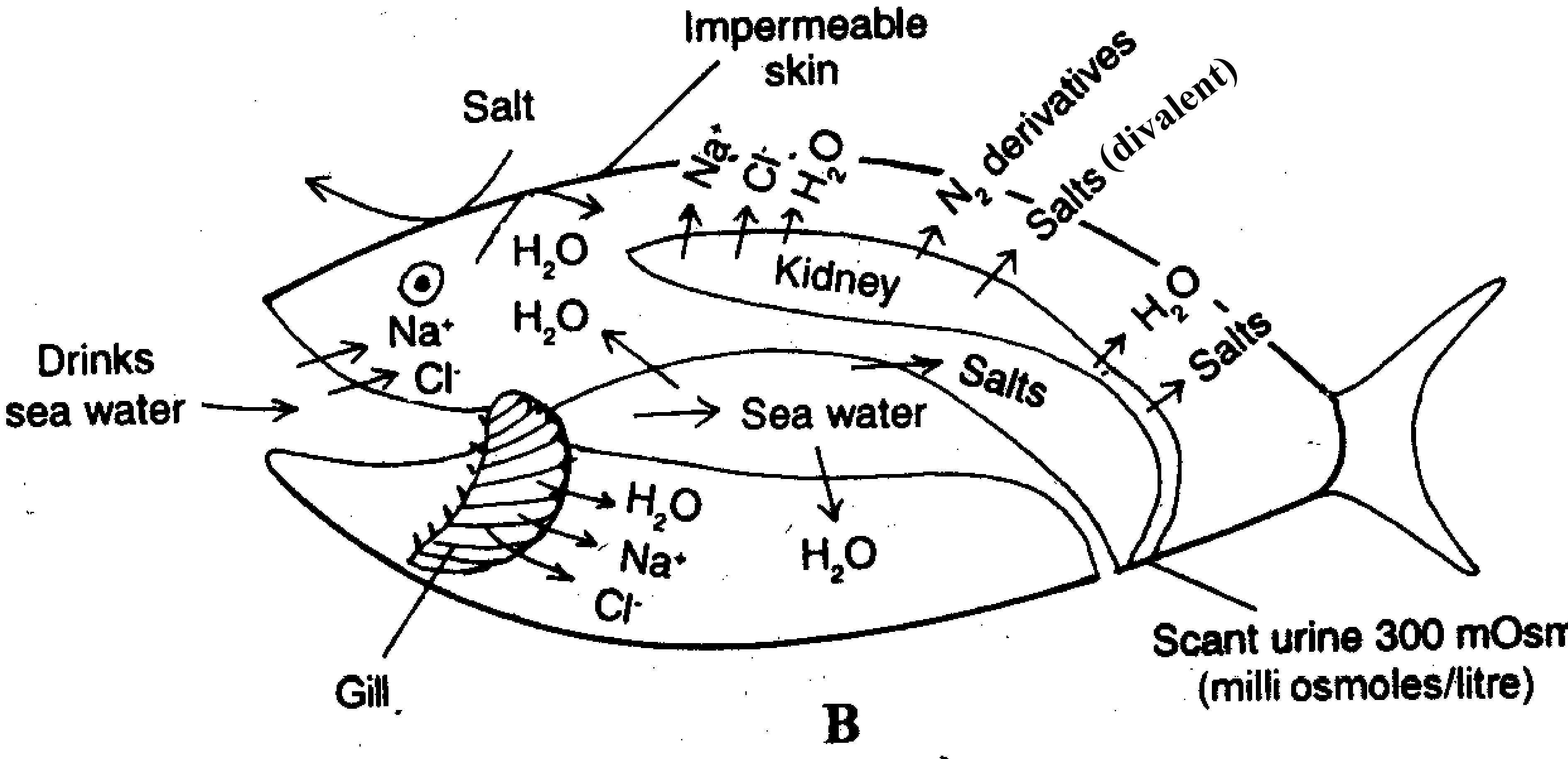
- ❖ Kidney of marine teleost have relatively low number of glomeruli, small in size and reduced rate of FGR and urine flow.

- ❖ Reabsorption of NaCl followed by water in renal tubules

- ❖Absorption or concenrtration of divalent ions like Mg+2 and SO4-2 in urine.

- ❖ Marine teteost excrete very low amount of concentrated urine (300 mOsm or 1% of body weight) in order to conserve water

Saltwater teleosts



Osmotic regulation by FW teleosts

- The hyperosmotic internal environment cause an influx of water, mainly across the gills
- To compensate endosmosis they Don't drink water
- Chloride cells work in reverse (Absorption of Na^+ and Cl^- ions)
- Ammonia & bicarbonate ion exchange mechanisms occurs in Chloride cells of freshwater gills
- Kidneys eliminate excess water and produced copious urine

Osmoregulation by Freshwater teleosts

1. **Uptake of salts/Ions mechanism by gills**

2. **Secretion and selective re-absorption in Kidney and urinary bladder**

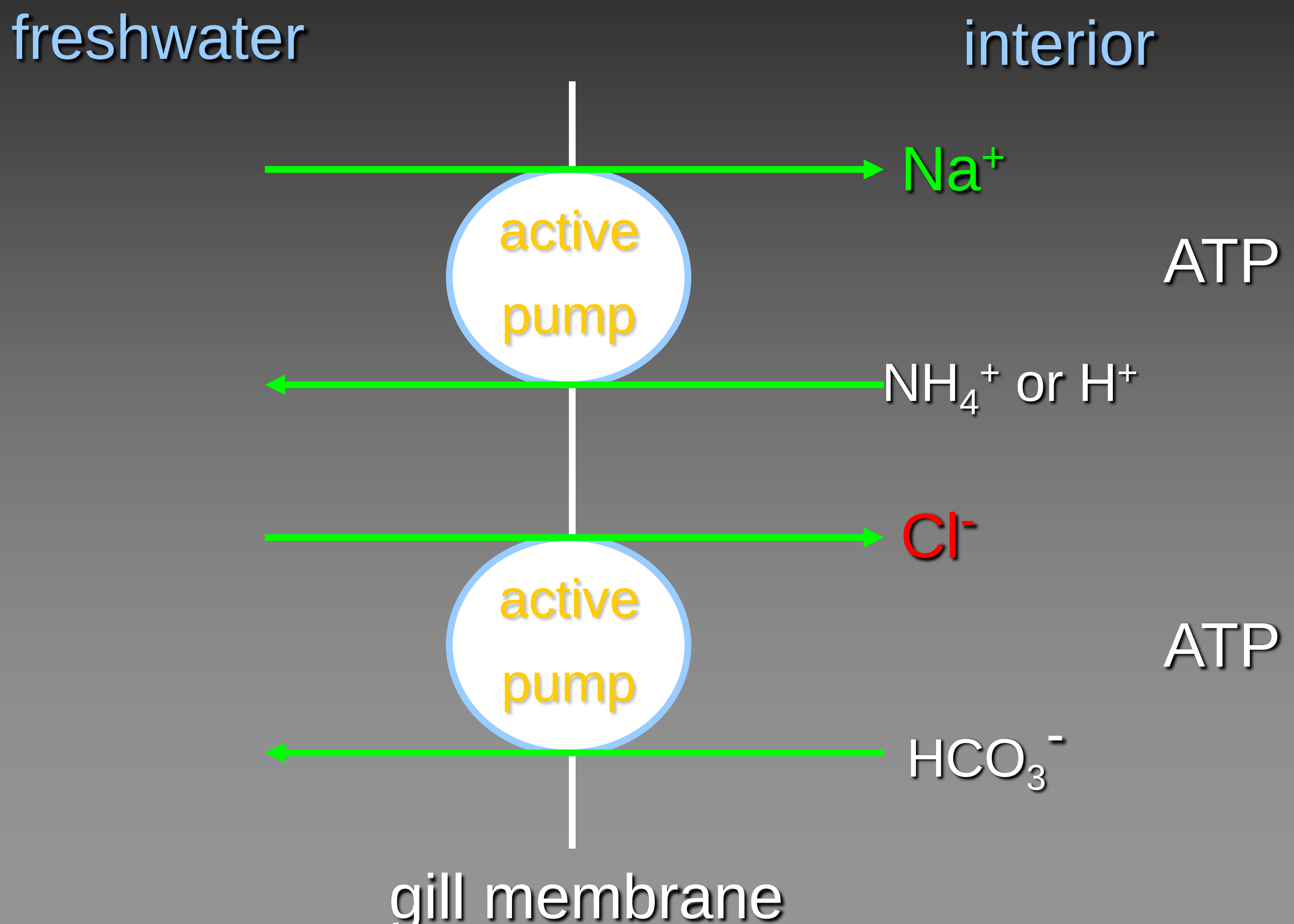
Osmoregulation by Freshwater teleosts continued........

1. Uptake mechanism by gills

Hyperosmotic freshwater fishes partially compensate the loss of salts through food and absorption salt ions from the surrounding water mainly by the chloride cells present in the gills and oral membrane

Absorption of Cl^- is effected by exchange of HCO_3^- and uptake of Na^+ is effected by NH_4^+ or H^+ by a mechanism present in the chloride cells of freshwater teleost.

Ion Exchange Mechanisms



Osmoregulation by Freshwater teleosts continued……

2. Secretion & selective re-absorption in Kidney and urinary bladder

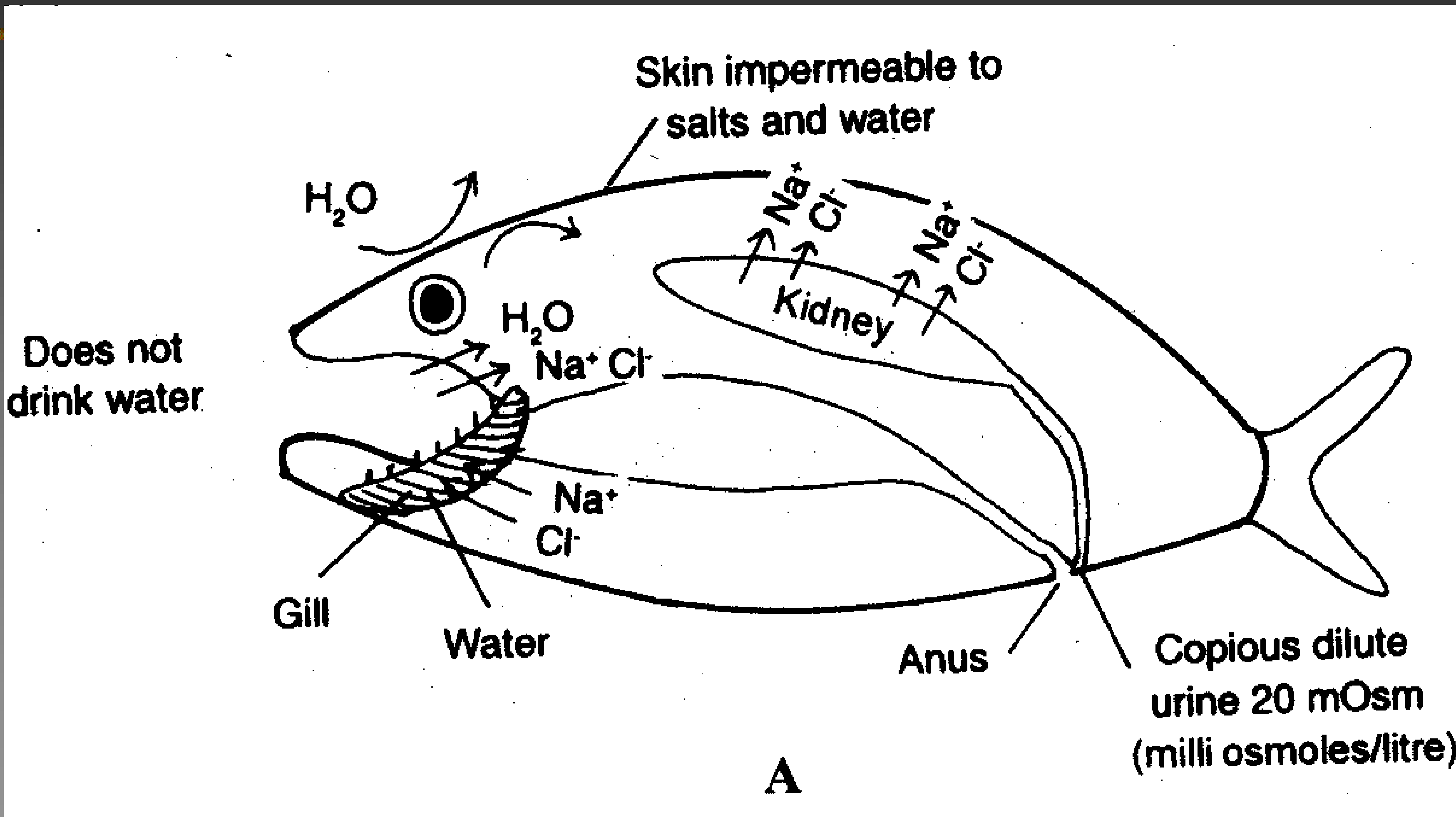
Kidney of these fishes have very large nuber of well developed glomeruli which has proximal tubule segment I and II, an intermediate segment, distal tubule and collecting duct.

These group of tubules allows almost all the NaCl to be reabsorbed and finally achieving the formation of diluted or copious urine(20 mOsm)

Some salts are lost through faces and also in urine, urine also contain some nitrogenous waste as creatine, creatinine, amino acids, urea and a little ammonia.

Loss of salts through urine is minimized by almost complete reabsorption of NaCl in renal tubules.

Freshwater teleosts



Osmoregulation Strategies of Chondrichthyes (Elasmobranchs) and Coelacanths

Sharks, skates and rays maintain internal salt concentration ~ 1/3 seawater, remaining 2/3 is urea and trimethylamine oxide (TMAO). So total internal osmotic concentration equal to seawater.

Gill membrane has low permeability to urea so it is retained within the fish. Because internal inorganic and organic salt concentrations mimic that of their environment, passive water influx or efflux is minimized

Retension of Urea and TMAO: these fishes retain urea and TMAO in blood by reabsorption of thease solute from urine filtrate by special segment of urinary tubule

Secretion of excess salt by Ractal Glands: Gill of these fishes do not have special salt secreting chloride cells, although some salts are excreted in urine but kidneys are not the major source of excess NaCl secretion. To maintain the salt balance rectal glands secrest fluids containing higher concentration of NaCl.

Osmoregulation Strategies in Hagfishes

Osmoconformes **(no strategy) Hagfish internal salt concentration = seawater. However, since they live In the ocean. So no regulation required!**

Hagfishes do not drink sea water and their requirement of water for urine formation is met from the blood of the host

Osmoregulation Strategies in Lampreys

They live in both fresh water and sea water and often euryhaline. Regardless of the external environment, they have osmotic and ionic concentration from ¼ to 1/3 that of concentration of seawater

Their osmotic and ionic concentration very much similar to teleost

Control of Osmoregulation

A) Regulatory or Hormonal control

i) Adrenocortical hormone
ii) Thyroid hormone
iii) Prolactin

B) Obligatory factors

i) Gradient between extracellular compartment and environment
ii) Surface/Volume ratio
iii) Permeability of the gills.
iv) Feeding