MEDAVIE HealthEd ÉduSanté

Fluids, Electrolytes and Acid-Base Balancing

Advanced Care Paramedicine

Module: 04

Section: 04

Claude Bernard
1813 – 1878

Milieu intérieur (the internal environment)

"The constancy of the internal environment is the condition for a free and independent life"

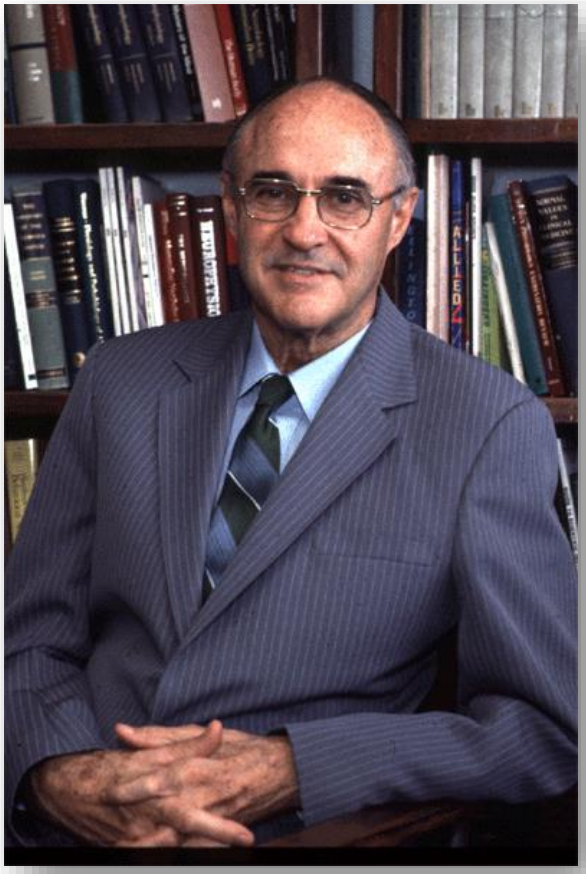
- Believed 3 relative constants of fluid environment were required
  - Temperature
  - Pressure
  - Chemical composition

Walter B Cannon 1932

- Coined the term “Homeostasis”
  - Greek meaning “homoios” (the same) “stasis” (always or staying)
  - Discussed in his book The Wisdom of the Body
- Presented four tentative propositions to describe the general features of homeostasis:
  - Constancy in an open system
  - Steady-state conditions require that any tendency toward change automatically meets with factors that resist change.
  - Regulating system that determines the homeostatic state consists of a number of cooperating mechanisms acting simultaneously or successively.
  - Homeostasis does not occur by chance, but is the result of organized self-government.

Arthur Guyton 1976

- *Textbook of Medical Physiology*
  - "Guyton Curves" describe the relationship between atrial pressures and cardiac output
  - form the basis of understanding the physiology of circulation
    - Capillary pressure (hydrostatic)
    - Interstitial fluid pressure
    - Plasma colloid osmotic pressure
    - Interstitial fluid colloid osmotic pressure

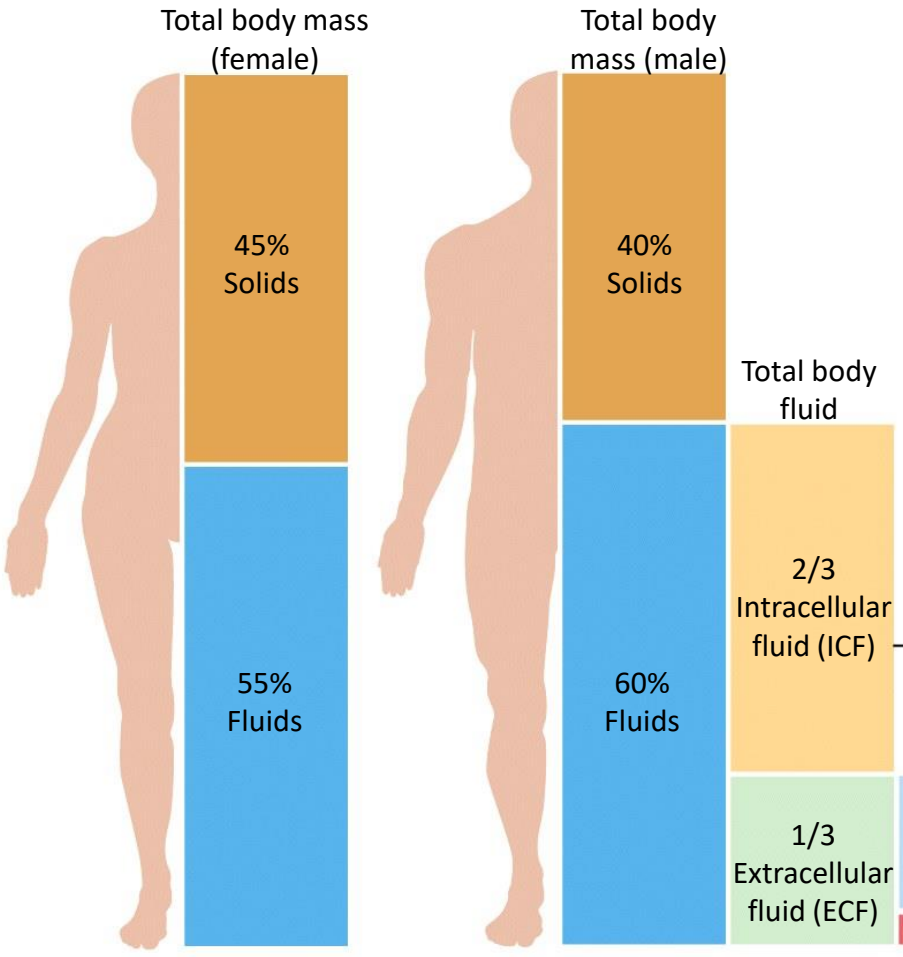


Total Body Water

- Normal values expressed as a percentage
- Differences occur due to age, sex and fat content

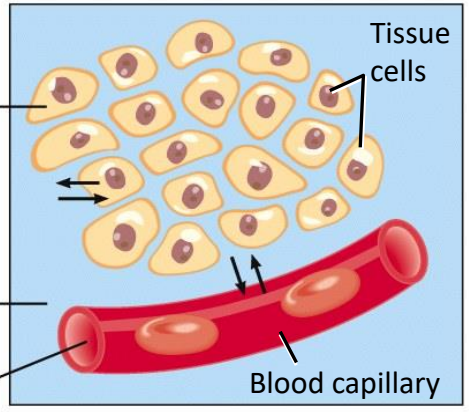
- Water
  - 80% Total body weight (Newborns)
  - 65% - 70% TBW (Children)
  - 50% - 60% TBW (Adults)
  - 45 % TBW (Elderly)

Body Fluid Compartments



(a) Distribution of body solids and fluids in average lean, adult female and male

- Extracellular
  - Plasma and interstitial fluid
  - Lymph, CSF, joint fluids and humors of the eye (transcellular fluid)
- Intracellular
  - Water inside the cells

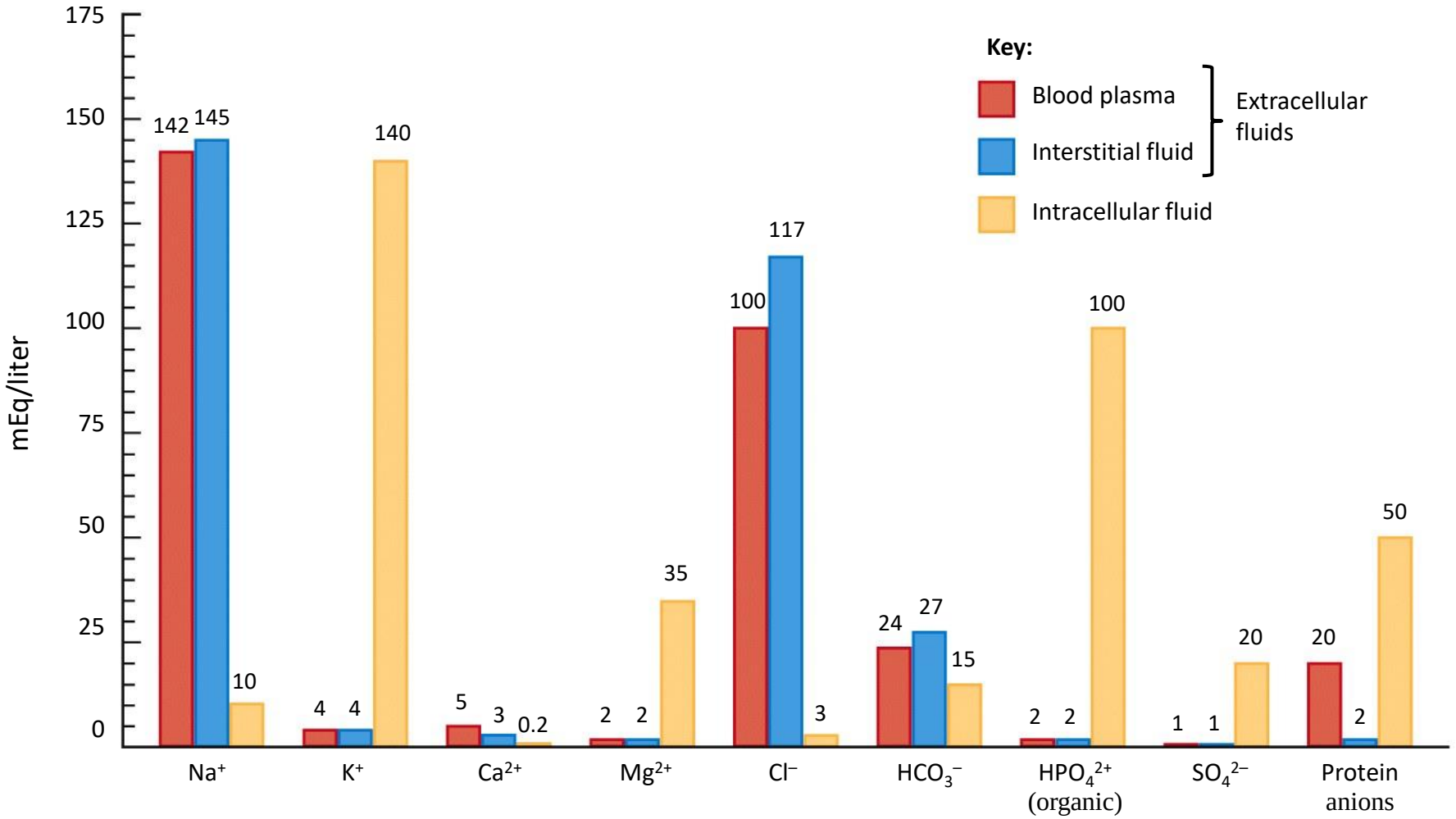


(b) Exchange of water among body fluid compartments

Fluid Composition

- A constant balance between the fluid and the electrolytes must exist for homeostasis
  - Water
  - Electrolytes
    - Salt substances that dissociate into charged components when dissolved in water (Na^+, K^+)
  - Non-electrolytes
    - Substances that do not carry an electrical charge in water (glucose, urea)

Distribution



Electrolytes

- Positively Charged Electrolytes (Cation)
  - Intracellular
    - Potassium K^+
    - Calcium Ca^{++}
    - Magnesium Mg^{++}
  - Extracellular
    - Sodium Na^+

Electrolytes

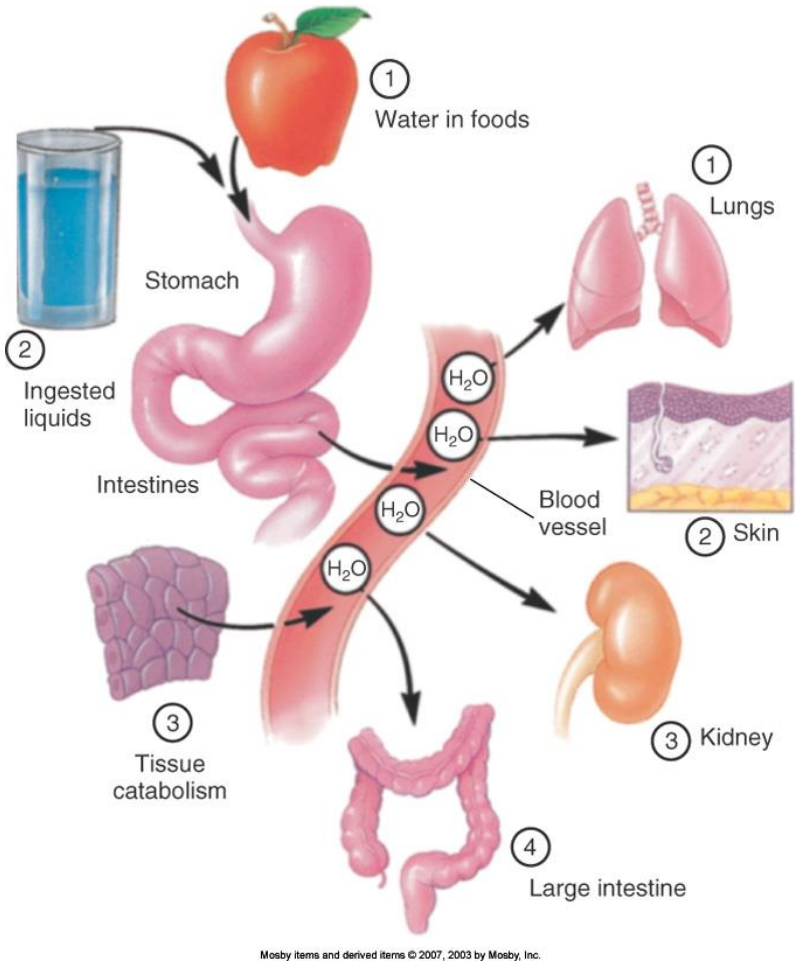
- Negatively Charged Electrolytes (Anion)
  - Intracellular
    - Phosphate PO_4^{3-}
  - Extracellular
    - Chloride Cl^-
    - Bicarbonate HCO_3^-

Electrolytes

- Aldosterone is the primary regulator of electrolyte concentrations
- Accomplishes this through reabsorption of Na^+ and K^+

Avenues

- Water enters the body
  - Digestive system
  - Cellular metabolism
- Water exits the body
  - Kidneys
  - Lungs
  - Sweat
  - Feces
- Input = Output



Factors Affecting Movement

- Net Filtration (Starling's law of the capillaries)
- Net filtration = forces favoring filtration vs. forces opposing filtration
  - Tonicity
  - Blood Hydrostatic pressure (BHP)
  - Blood Colloid Osmotic pressure (BCOP)
  - Interstitial fluid colloid osmotic pressure (IFCOP)
  - Interstitial fluid hydrostatic pressure (IFHP)
  - Membrane permeability

Tonicity

- Isotonic
  - Of **equal** solute concentration…
  - Same pressure
- Hypotonic
  - Of **lesser** solute concentration…
  - Less pressure
- Hypertonic
  - Of **higher** solute concentration…
  - More pressure

…than the fluid being compared

Blood Hydrostatic Pressure (BHP)

- The mechanical force of water against cellular membranes
- One of the primary forces in the movement of fluid
- Pressure created by contraction of Left Ventricle
- Filters fluid from blood
  - Allows fluid to pass from vascular space through the capillary wall
- Represents the blood pressure within the capillary network (approximately 25 – 30 mmHg)

Blood Colloid Osmotic Pressure (BCOP)

- The overall osmotic effect of colloids (plasma proteins) in the vasculature
- Opposes filtration of large solutes
- Maintains levels of intravascular fluids

Interstitial Fluid Colloid Osmotic Pressure (IFCOP)

- Generally a negative pressure
- Causes a suction of fluid into the interstitium
- Present due to solute concentration in the interstitium
- Works with capillary hydrostatic pressure in filtration

Interstitial Fluid Hydrostatic Pressure (IFHP)

- The mechanical force of water within the interstitium against cellular membranes
- Works with plasma osmotic pressure against filtration
- Keeps small quantities of plasma proteins which have leaked into the interstitium within the interstitium

Membrane Permeability

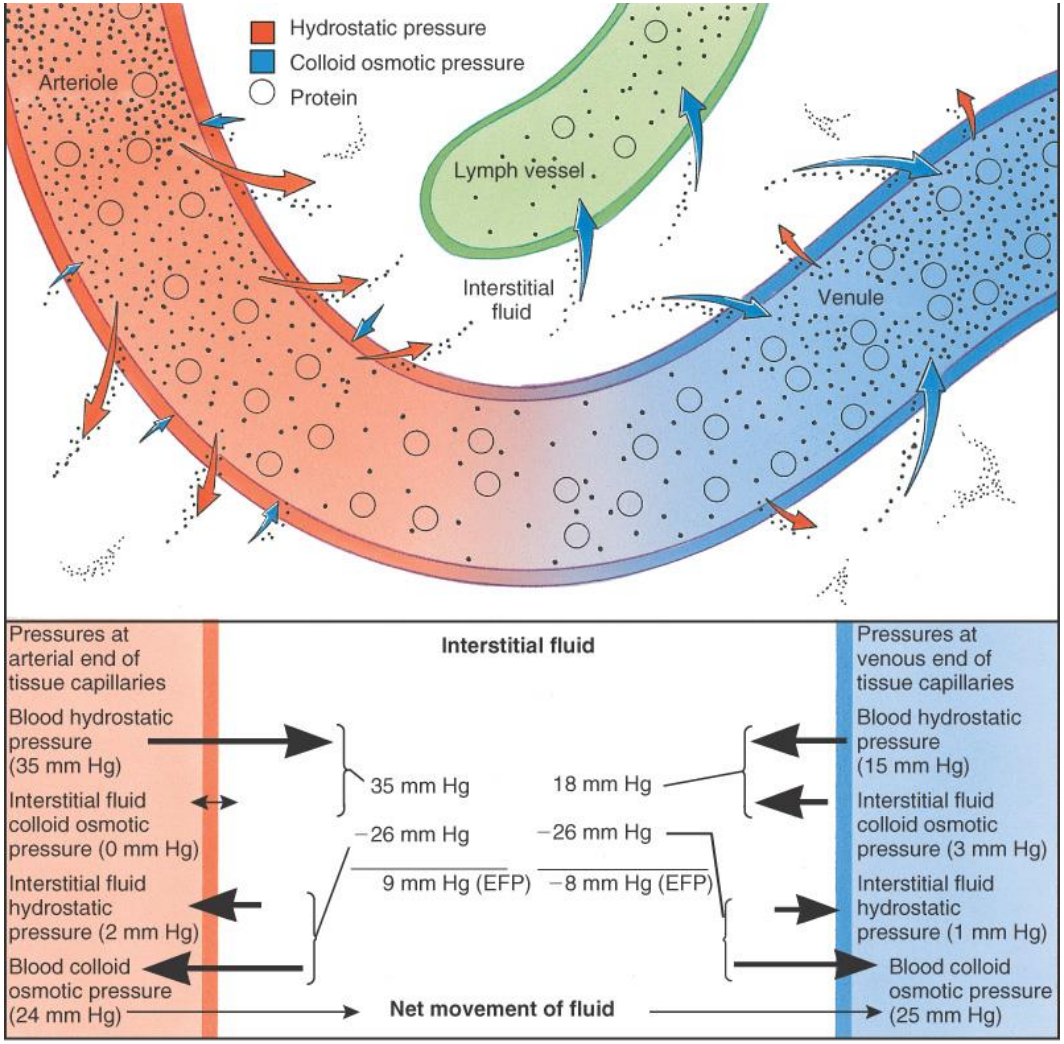
- Only a small portion of plasma proteins crosses capillary membranes
- Fluid passes easily, depending on the tonicity of each side of the membrane
- Electrolytes pass readily due their size and function

Factors Affecting Movement

- Therefore effective filtration pressure is:

$$EFP = \underbrace{(BHP + IFCOP)}_{\text{Moves fluid out of the capillaries}} - \underbrace{(IFHP + BCOP)}_{\text{Moves fluid into the capillaries}}$$

Movement of fluids

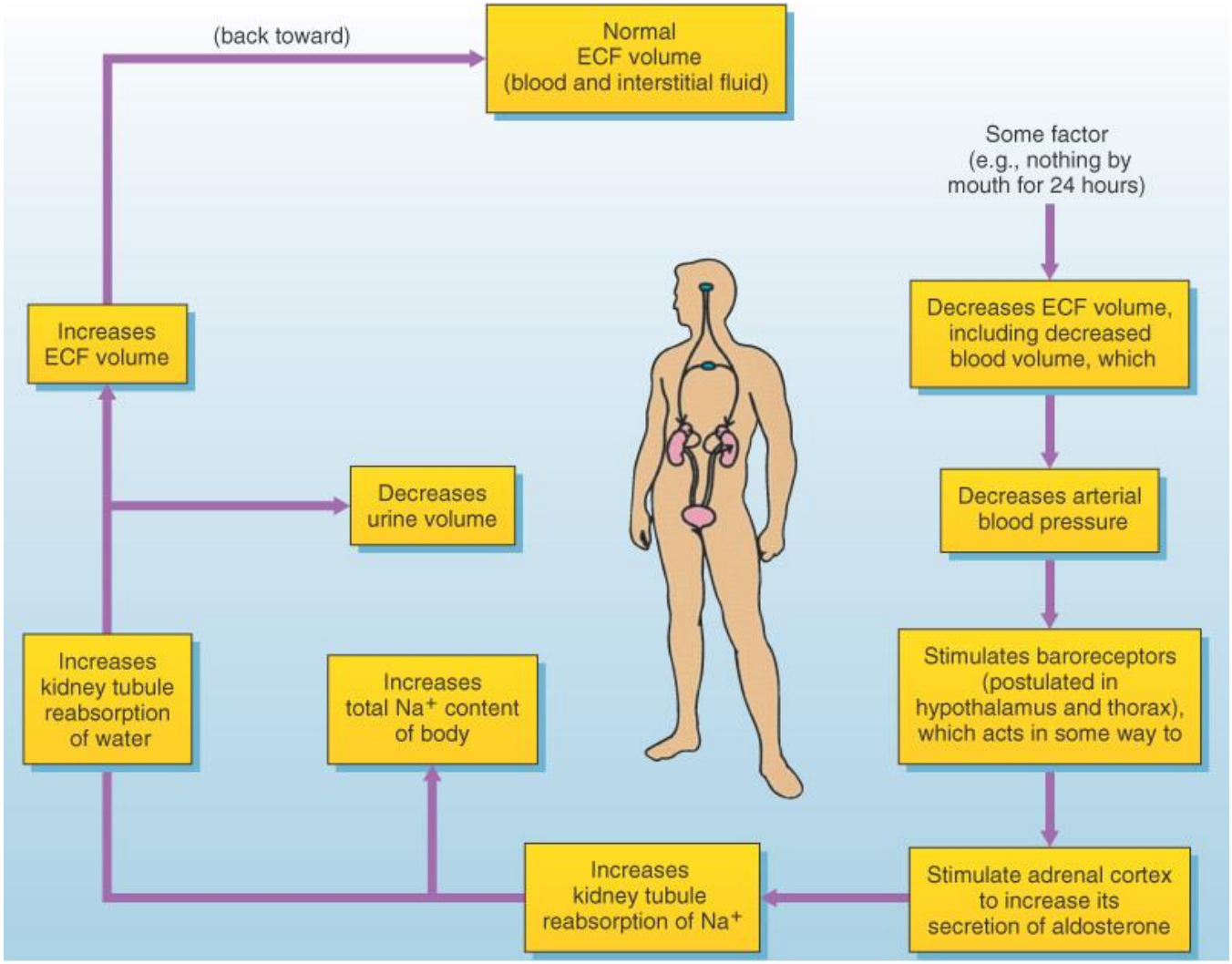


Solvent, solute and particulate transport

- Osmosis
  - The diffusion of water through a selectively permeable membrane
- Diffusion
  - Movement of atoms, ions or molecules from a region of high concentration to a region of low concentration
- Active Transport
  - Moves substances against (“uphill”) a concentration gradient
- Facilitated Diffusion
  - Moves substances down the gradient by use of a carrier protein

Water Balance

- Water balance regulated by ADH and perception of thirst.
- ADH released due to:
  - Increased plasma osmolality
  - Decreased circulating blood volume
  - Lowered venous and arterial pressure
- Following the release of ADH water is reabsorbed from renal tubules and collecting ducts of the kidneys



Aldosterone

- Aldosterone regulates Na^+, K^+ and water retention:
  - Stimulates the secretion of K^+ into the tubular lumen
  - Stimulates Na^+ and water reabsorption from the gut, salivary and sweat glands in exchange for K^+
  - Stimulates H^+ secretion in the collecting duct, regulating plasma bicarbonate (HCO_3^-) levels and its acid/base balance
  - Stimulates the posterior pituitary gland to release ADH

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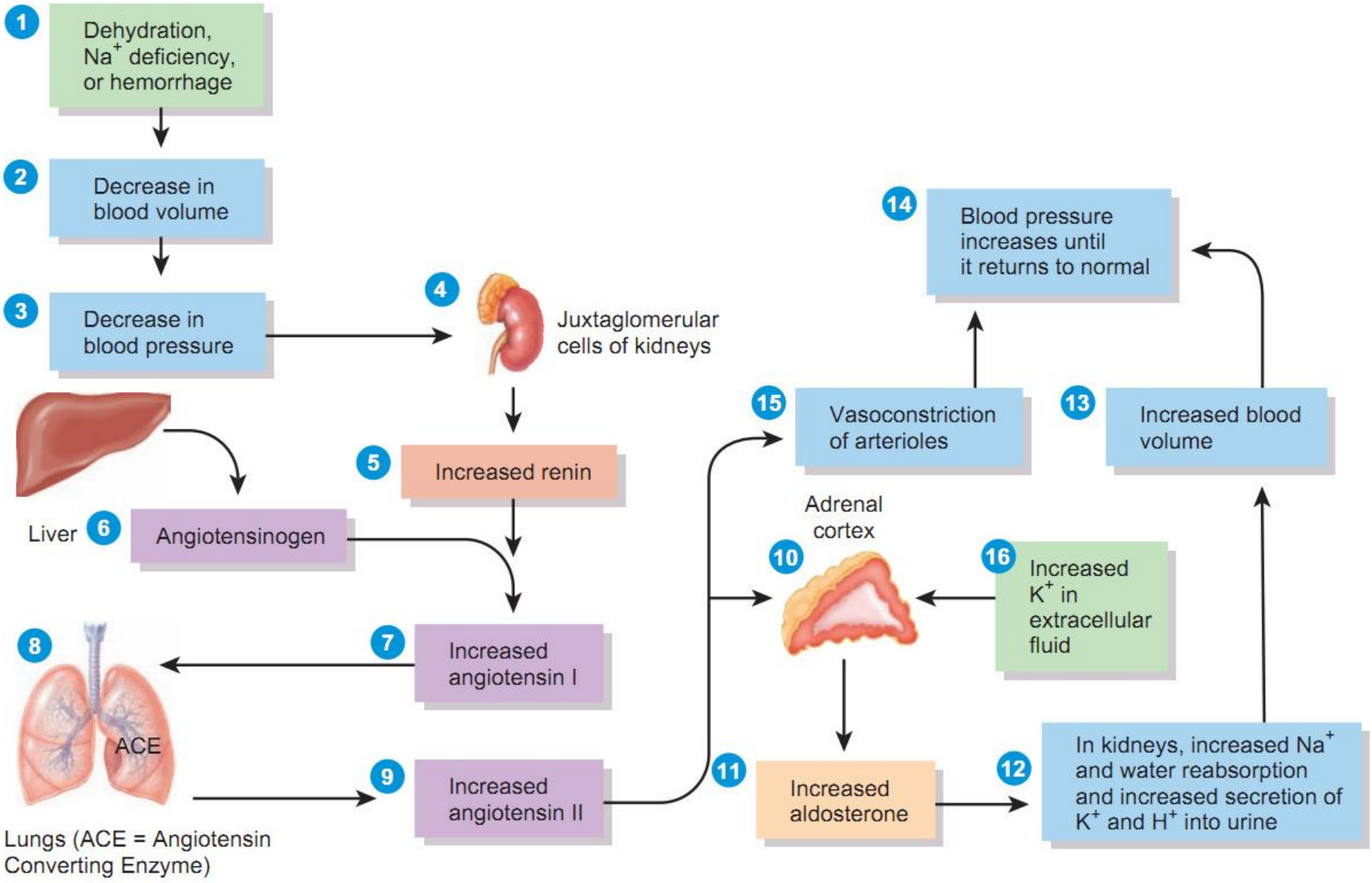
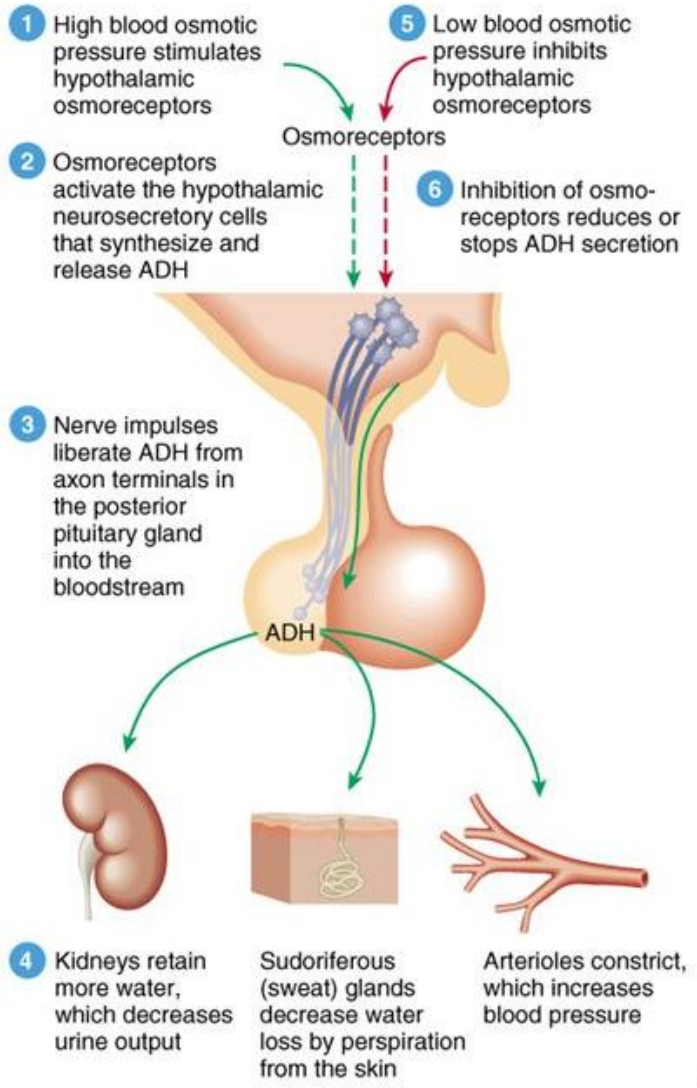
Renin-Angiotensin-Aldosterone System (RAAS)



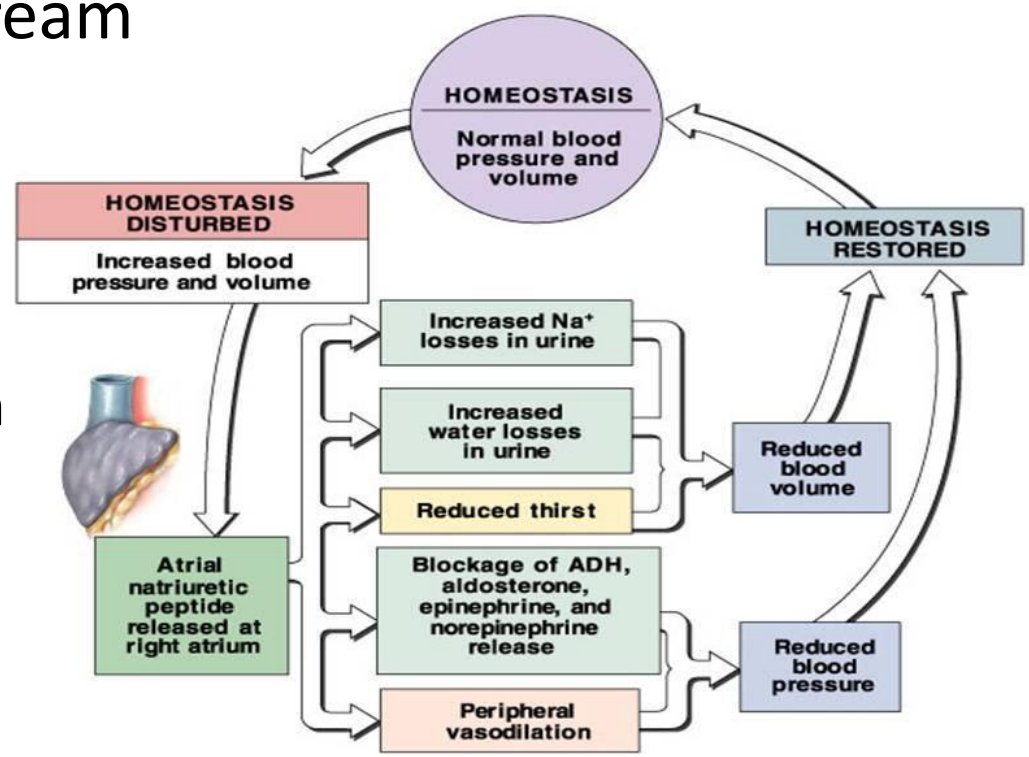
Antidiuretic Hormone (ADH)

- ADH also referred to as Vasopressin
  - Created in the hypothalamus and stored in the posterior pituitary gland
- Stimulated to be released as a result of Angiotensin II (that was released due to a drop in blood volume)

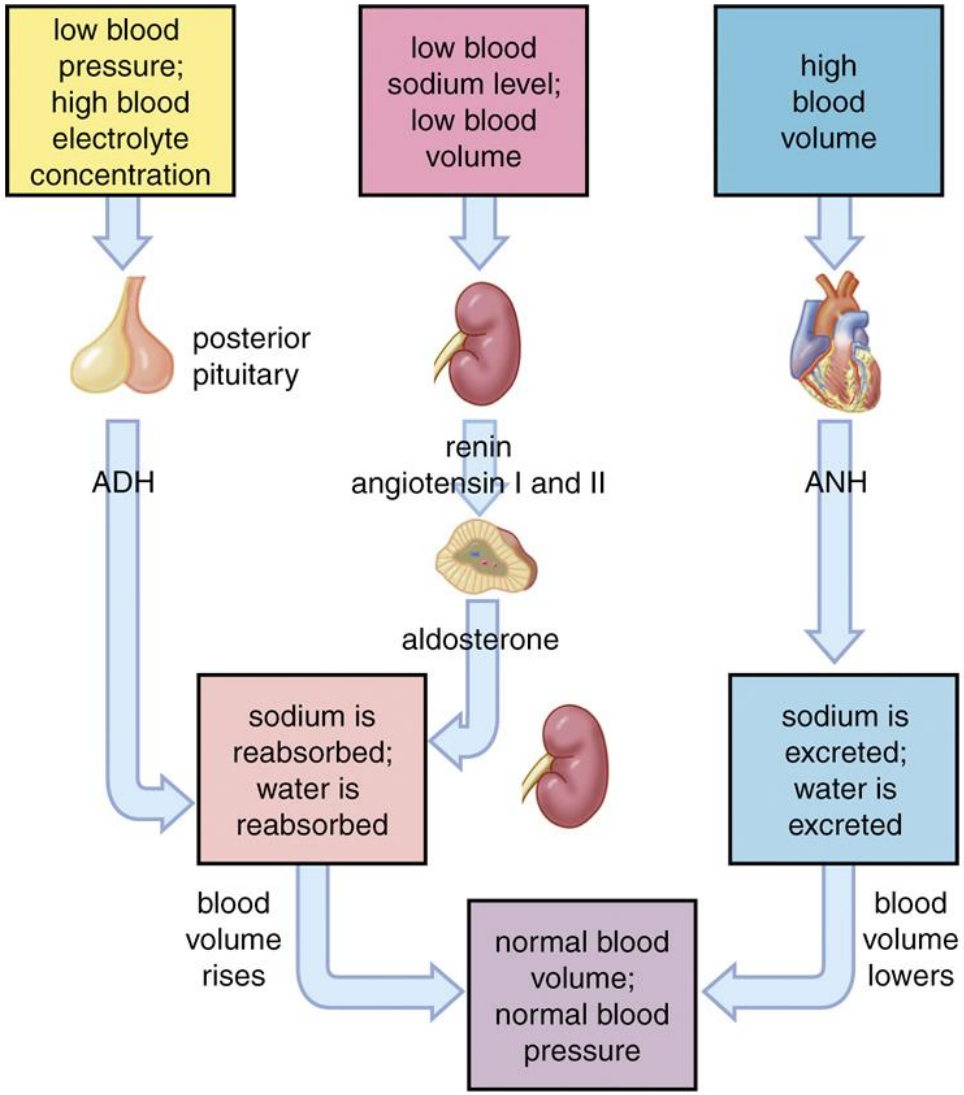


Atrial Natrieurtic Hormone (ANH)

- Increasing blood volume (RAAS and ADH) and pressure causes right atrium to over stretch
- This stimulates the release of ANH from the cardiac cells into the blood stream
- ANH causes:
  - ↓ Na+ reabsorption
  - ↑ GFR
  - Peripheral vasodilation
  - Inhibits ADH
  - Inhibits Aldosterone



Balance


low blood pressure; high blood electrolyte concentration
low blood sodium level; low blood volume
high blood volume
posterior pituitary
ADH
renin
angiotensin I and II
aldosterone
ANH
sodium is reabsorbed; water is reabsorbed
sodium is excreted; water is excreted
blood volume rises
blood volume lowers
normal blood volume; normal blood pressure

Fluid/Electrolyte Imbalances

- Hypovolemia (Dehydration)
  - Isotonic
  - Hyponatremic
  - Hypernatremic
- Hypervolemia (Overhydration)

Isotonic

- Excessive loss of equal amounts of Na and Water
  - Severe or long term vomiting/diarrhea
  - Systemic infection
  - Intestinal obstruction

Hyponatremic

- A serum decrease in Na
  - Excess loss of Na
  - Decrease in [Na] relative to water
- Causes
  - Use of salt-wasting diuretics
  - Excessive perspiration
  - Salt losing renal disorders
  - Increased water intake
  - Excessive use of water enemas

Hyponatremic

- S/S
  - Muscle cramps
  - N/V
  - Postural BP changes
  - Poor skin tugor
  - Fatigue
  - Dyspnea
  - Confusing, Hemiparesis, Seizures and Coma (due to cerebral swelling in severe cases)

Hypernatremic

- Elevation of serum levels
  - Loss of water in excess of Na
  - Elevated Na levels
- Causes
  - Lack of fluid intake
  - Diabetes Insipidus
  - CHF
  - Renal failure
  - Excessive misuse of diuretics
  - Na intake in absence of water
  - Profuse watery diarrhea

Hypernatremic

- S/S
  - Similar to hyponatremia
  - Thirst
  - Disorientation
  - Lethargy
  - Seizures

Overhydration

- Increased body water with a decrease in solute concentration
  - Excessive IV fluid administration
  - Impaired cardiac function
  - Impaired renal function
  - Endocrine dysfunction

Roles of Electrolytes

- Na^+
  - Nerve, muscle and cardiac function
- Cl^-
  - Neural activity and muscle function, gastric juice
- K^+
  - Nerve, muscle and cardiac function
- Ca^{++}
  - neurotransmission, cell membrane permeability, hormone secretion, growth, ossification of bones and muscle contraction
- PO_4^{2-}
  - Used in buffering
- Mg^+
  - activates many enzymes, nervous system and MSK effects similar to calcium

TABLE 27.2

Blood Electrolyte Imbalances

	DEFICIENCY		EXCESS	
ELECTROLYTE*	**NAME AND CAUSES**	**SIGNS AND SYMPTOMS**	**NAME AND CAUSES**	**SIGNS AND SYMPTOMS**
Sodium (Na^+) **136–148 mEq/liter**	**Hyponatremia** (hī-pō-na-TRĒ-mē-a) may be due to decreased sodium intake; increased sodium loss through vomiting, diarrhea, aldosterone deficiency, or taking certain diuretics; and excessive water intake.	Muscular weakness; dizziness, headache, and hypotension; tachycardia and shock; mental confusion, stupor, and coma.	**Hypernatremia** may occur with dehydration, water deprivation, or excessive sodium in diet or intravenous fluids; causes hypertonicity of ECF, which pulls water out of body cells into ECF, causing cellular dehydration.	Intense thirst, hypertension, edema, agitation, and convulsions.
Chloride (Cl^-) **95–105 mEq/liter**	**Hypochloremia** (hī-pō-klō-RĒ-mē-a) may be due to excessive vomiting, overhydration, aldosterone deficiency, congestive heart failure, and therapy with certain diuretics such as furosemide (Lasix®).	Muscle spasms, metabolic alkalosis, shallow respirations, hypotension, and tetany.	**Hyperchloremia** may result from dehydration due to water loss or water deprivation; excessive chloride intake; or severe renal failure, hyperaldosteronism, certain types of acidosis, and some drugs.	Lethargy, weakness, metabolic acidosis, and rapid, deep breathing.
Potassium (K^+) **3.5–5.0 mEq/liter**	**Hypokalemia** (hī-pō-ka-LĒ-mē-a) may result from excessive loss due to vomiting or diarrhea, decreased potassium intake, hyperaldosteronism, kidney disease, and therapy with some diuretics.	Muscle fatigue, flaccid paralysis, mental confusion, increased urine output, shallow respirations, and changes in electrocardiogram, including flattening of T wave.	**Hyperkalemia** may be due to excessive potassium intake, renal failure, aldosterone deficiency, crushing injuries to body tissues, or transfusion of hemolyzed blood.	Irritability, nausea, vomiting, diarrhea, muscular weakness; can cause death by inducing ventricular fibrillation.

*Values are normal ranges of blood plasma levels in adults.

TABLE 27.2

Blood Electrolyte Imbalances

	DEFICIENCY		EXCESS	
ELECTROLYTE*	**NAME AND CAUSES**	**SIGNS AND SYMPTOMS**	**NAME AND CAUSES**	**SIGNS AND SYMPTOMS**
Calcium (Ca^{2+}) Total = 9.0–10.5 mg/dL; ionized = 4.5–5.5 mEq/liter	**Hypocalcemia** (hī-pō-kal-SĒ-mē-a) may be due to increased calcium loss, reduced calcium intake, elevated phosphate levels, or hypoparathyroidism.	Numbness and tingling of fingers; hyperactive reflexes, muscle cramps, tetany, and convulsions; bone fractures; spasms of laryngeal muscles that can cause death by asphyxiation.	**Hypercalcemia** may result from hyperparathyroidism, some cancers, excessive intake of vitamin D, and Paget's disease of bone.	Lethargy, weakness, anorexia, nausea, vomiting, polyuria, itching, bone pain, depression, confusion, paresthesia, stupor, and coma.
Phosphate (HPO_4^{2-}) 1.7–2.6 mEq/liter	**Hypophosphatemia** (hī-pō-fos′-fa-TĒ-mē-a) may occur through increased urinary losses, decreased intestinal absorption, or increased utilization.	Confusion, seizures, coma, chest and muscle pain, numbness and tingling of fingers, decreased coordination, memory loss, and lethargy.	**Hyperphosphatemia** occurs when kidneys fail to excrete excess phosphate, as in renal failure; can also result from increased intake of phosphates or destruction of body cells, which releases phosphates into blood.	Anorexia, nausea, vomiting, muscular weakness, hyperactive reflexes, tetany, and tachycardia.
Magnesium (Mg^{2+}) 1.3–2.1 mEq/liter	**Hypomagnesemia** (hī′-pō-mag′-ne-SĒ-mē-a) may be due to inadequate intake or excessive loss in urine or feces; also occurs in alcoholism, malnutrition, diabetes mellitus, and diuretic therapy.	Weakness, irritability, tetany, delirium, convulsions, confusion, anorexia, nausea, vomiting, paresthesia, and cardiac arrhythmias.	**Hypermagnesemia** occurs in renal failure or due to increased intake of Mg^{2+}, such as Mg^{2+}-containing antacids; also occurs in aldosterone deficiency and hypothyroidism.	Hypotension, muscular weakness or paralysis, nausea, vomiting, and altered mental functioning.

*Values are normal ranges of blood plasma levels in adults.

Fluids, Electrolytes and Acid Base Balancing

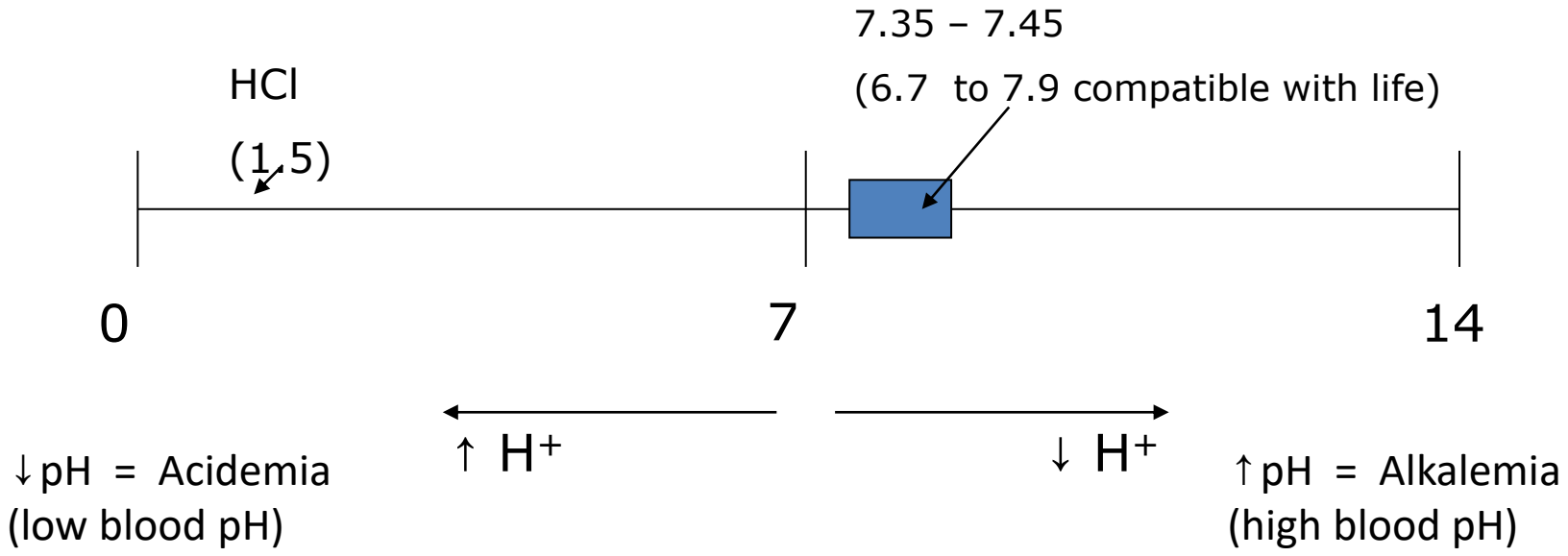
ACID-BASE BALANCING

Acid-Base Balancing

- One of the most important balances in the body homeostatic mechanisms
  - Acids (proton donators)
    - Hydrogen ions (H^+)
  - Bases (proton acceptors)
    - Hydroxide ions (OH^-)

Acid / Base

- Hydrogen ion concentration
- Measured in moles/L (represented as pH)
- Acidity/alkalinity increases tenfold with every unit change



Le Chatelier's Principle

- Recall, that changes made to a reaction already at equilibrium will result in a shift to either the left or right to return the reaction to equilibrium

$$A + B \leftrightarrow AB + Heat$$

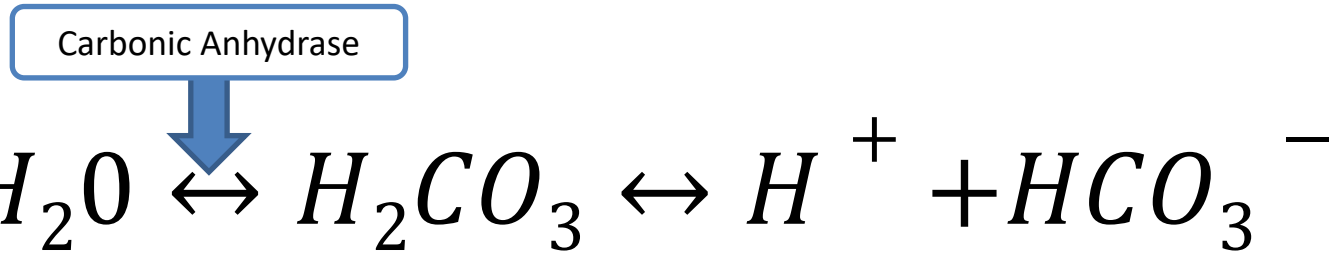
- Increase in concentration of reactants or products will cause shift away from the increase
- Decrease in concentration of reactants or products will cause a shift toward the decrease

Buffer systems

- Chemical (rapid)
  - Carbonic acid (Bicarbonate buffering)
  - Phosphate buffering
  - Protein buffering
- Physiological (secondary)
  - Respiratory buffering
  - Renal buffering

Carbonic Acid Buffer

- Normal carbonic acid to bicarbonate ratio is 1 – 20 = normal pH range
  - HCO_3^-, CO_2 and carbonic acid present in blood stream
  - HCO_3^- results from the transport of CO_2 in the blood
  - Carbonic anhydrase causes CO_2 to dissolve in water of blood to form carbonic acid (H_2CO_3)
  - H_2CO_3 breaks down into H^+ and HCO_3^-
- Increased H_2CO_3 = acidosis
- Increased HCO_3^- = alkalosis



Protein Buffering

- Negative charges allow proteins to serve as buffers for alterations in $[H^+]$
- Primarily occurs intracellularly
  - Example:
    - Hb combines with H^+ to form a weak acid and CO_2
    - At lungs Hb binds with O_2 and releases H^+ and CO_2
    - H^+ then combines with HCO_3^- ions to form H_2CO_3

Renal Buffering

- Recovery of bicarbonate and filtered into tubules
- Excretion of H^+ against a gradient to increase urine acidity
- Excretion of ammonium which carries H^+

Acid-Base Balancing

- Metabolic Causes
  - HCO_3^- ion
- Respiratory Causes
  - CO_2

Acid-Base Balancing

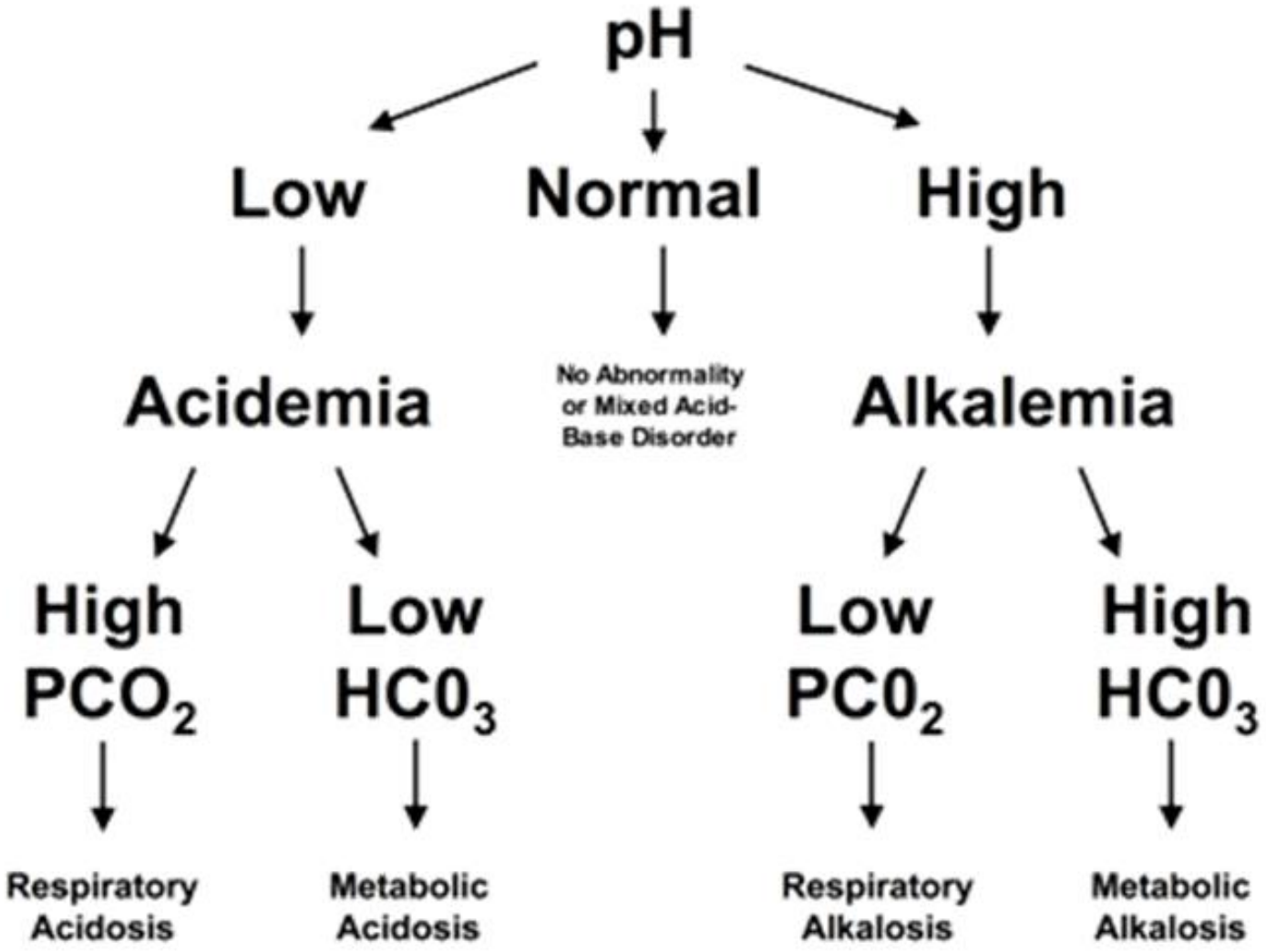
Acidosis

- Metabolic Acidosis
  - ↓ HCO_3^-
- Respiratory Acidosis
  - ↑ CO_2

Alkalosis

- Metabolic Alkalosis
  - ↑ HCO_3^-
- Respiratory Alkalosis
  - ↓ CO_2

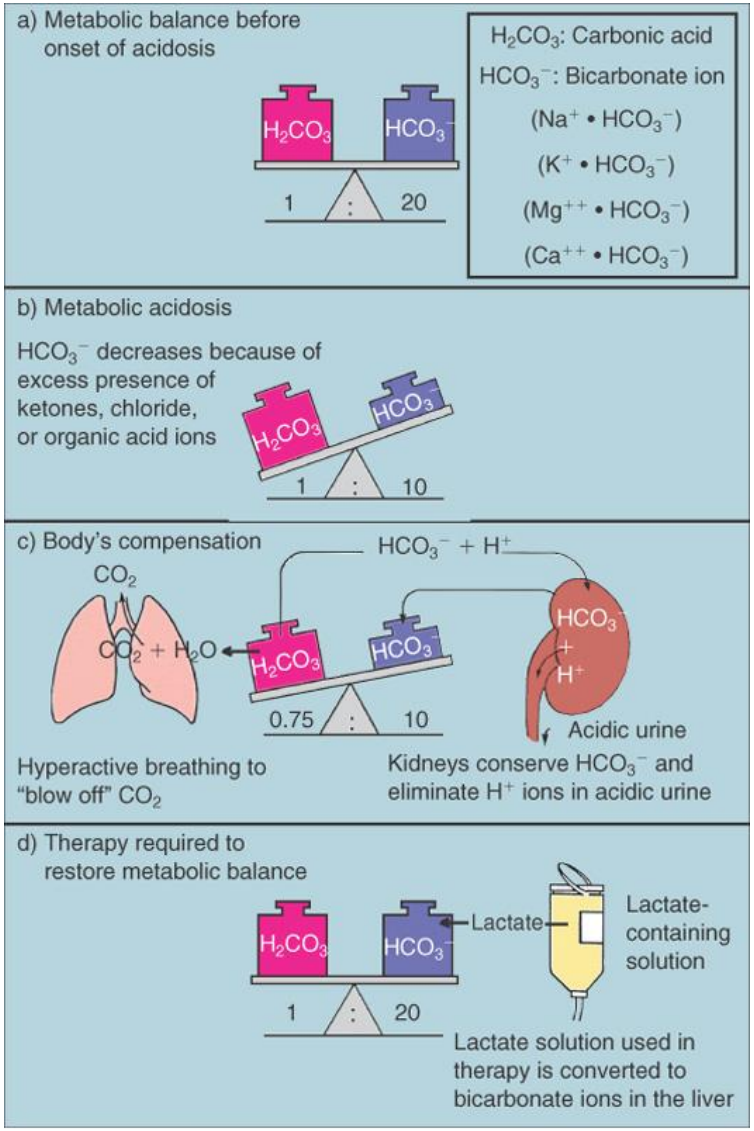
Acid-Base Balancing



Acid-Base Balancing

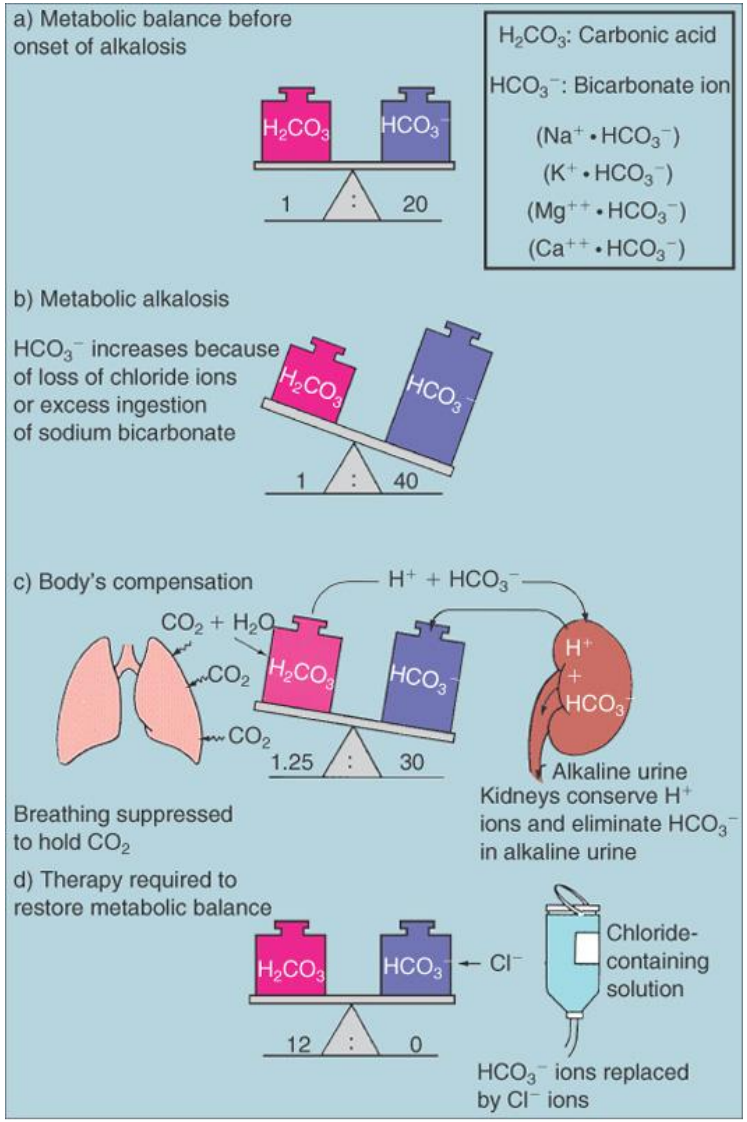
- Metabolic Acidosis:
  - Caused by excessive accumulation of acid or deficiency in base
  - Affects the bicarbonate side of equation
  - Excessive acid production = bicarbonate buffer consumption
  - Common Types:
    - Lactic acidosis
    - Diabetic ketoacidosis
    - Renal failure
    - Ingestion of toxins

$$CO_2 + H_20 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$



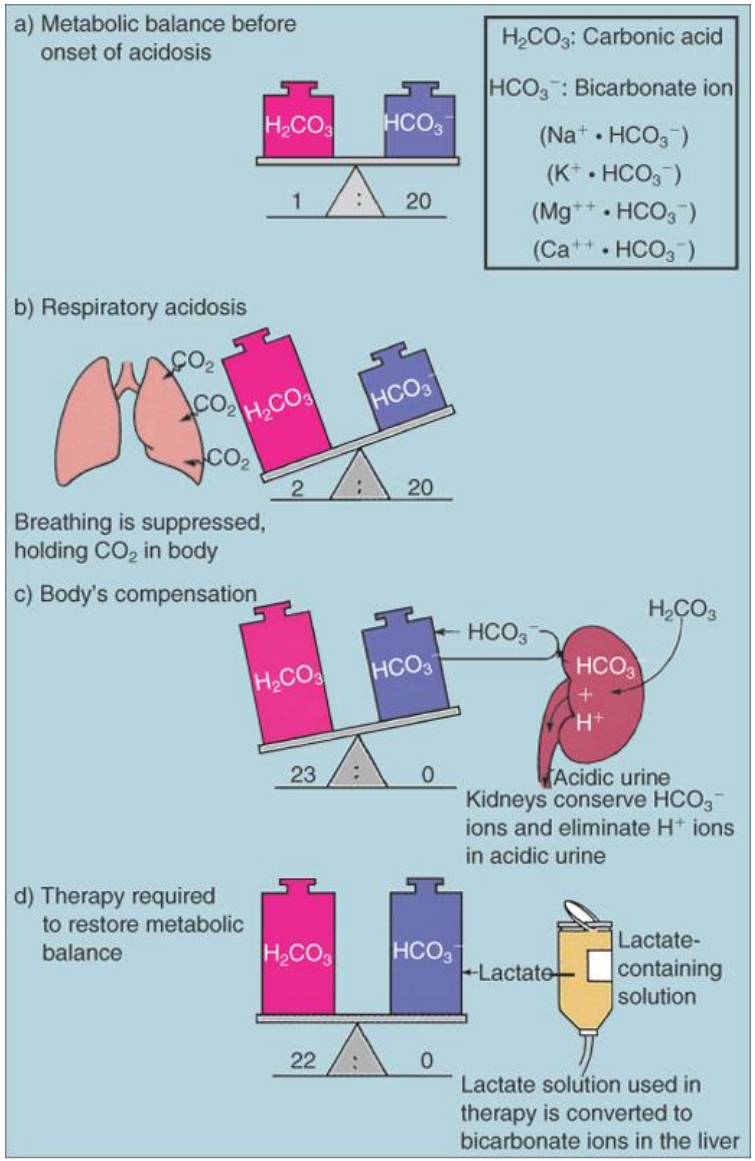
Acid-Base Balancing

- Metabolic Alkalosis:
  - Rare
  - Results from a loss of H^+
    - Primarily through the GI related to excessive antacid ingestion
    - Over administration of IV $NaHCO_3$
    - Over administration of diuretics



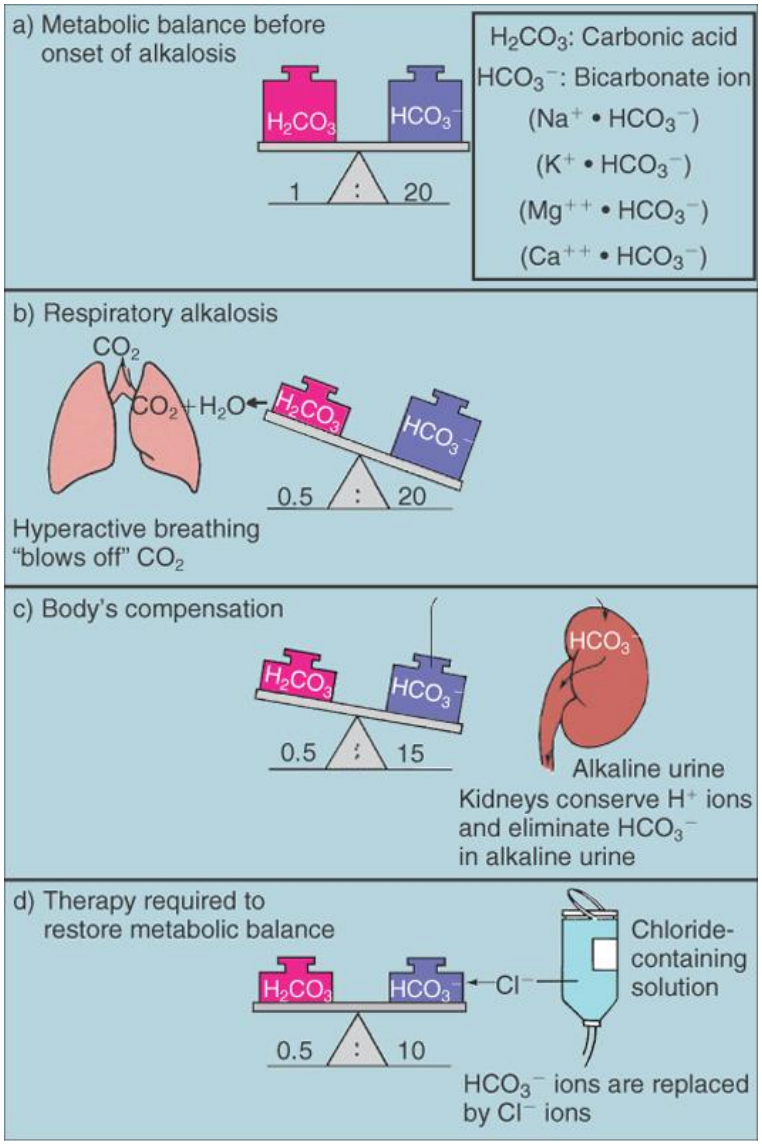
Acid-Base Balancing

- Respiratory Acidosis:
  - Results from retained CO_2 and increased PCO_2
    - Depressed respiratory centre
      - drug abuse, injury or disease
      - Anesthetics, sedatives, narcotics
    - Obstructive airways disease
      - Emphysema
      - Chronic Bronchitis
      - Asthma
      - Sever pneumonia
    - Blockages
      - Inhaled foreign object
      - Vomit
    - Bronchoconstriction (Acute asthma)



Acid-Base Balancing

- Respiratory Alkalosis:
  - Results from decreased PCO_2 through hyperventilation
    - Sepsis
    - Peritonitis
    - Shock
    - CO poisoning
    - Head injury
    - Dka



Blood gas analysis

- Determines
  - Blood oxygenation
  - Acid-base balance
- Arterial blood used to identify respiratory function
- pH indicates acidosis/alkalosis
  - PCO_2 indicates presence/absence of respiratory component
  - HCO_3 indicates presence/absence of metabolic component

Acid-Base Balancing

Disorder	pH	Primary Disturbance	Compensatory Response
Metabolic Acidosis	↓	↓ $[HCO_3^-]$	↓ pCO_2
Metabolic Alkalosis	↑	↑ $[HCO_3^-]$	↑ pCO_2
Respiratory Acidosis	↓	↑ pCO_2	↑ $[HCO_3^-]$
Respiratory Alkalosis	↑	↓ pCO_2	↓ $[HCO_3^-]$

- Complete Compensation (pH within normal limits)
- Partial Compensation (pH near normal limits)
- Uncompensated (pH above or below normal limits)