*] Respiratory failure :- When pt's respiratory apparatus is unable to meet the demand of ventilation

→ Type I :- Hypoxic (Heart failure, pneumonia, ARDS ← alveolar diseases, Interstitial disease → pneumocystis carnii (interst. pneumonia), interstitial edema, ILD ; Vasculature disease :- pulm. embolism, pulm. HTN, vasculitis) Respiratory failure (O_2 can't come in) [pCO_2 ↓]

→ Type II :- Hypercapnic respiratory failure (↑pCO_2) [∵ CO_2 mounts in alveoli → a) Hypoventilation (↓RR & ↓Tidal volume) ∴ ↑RR (hyperventilation ↓pCO_2), b) Obstructive airway diseases (coz they interfere ∈ expiration) eg. COPD] [pO_2 may vary ↑↓]

state of barrier does not affect the diffusion of CO_2, only the conc. gradient affects ; CO_2 is M/I to be looked in ABGs

*] Why do ABGs → a) look for O_2 status of pt → look for pO_2 → Ⓝ 100 mm Hg but if <60 mm Hg ⇒ Hypoxia [Can be done by looking SaO_2 ⇒ pulse oxymeter ⇒ Ⓝ 100%, Hypoxia (<90%)]

→ b) Acid-Base status → look for pH [-ve log [H]] Ⓝ 7.35-7.45 [↑7.45-Alk ; ↓7.35-Acid] [M/I coz Enzymes depend on pH]

→ c) Bicarbonate → level modulated by Kidneys → Acts as Buffer (to maintain pH) Ⓝ 22-26 mmol/L of ECF

→ d) pCO_2 → Ⓝ 36-44 mm/L → level modulated by the lungs (use 40 mmol/L for calculations)

*] Henderson-Hasselbach equation :- Summarised as $pH \propto \frac{HCO_3}{pCO_2}$

*] Primary metabolic disorders :- Resp. & Metabolic acidosis & alkalosis ; CO_2 prob → Resp. while HCO_3 prob → Metabolic

*] Compensation → Effort of the body to try & maintain the pH near normal [Normal phenomenon]
- → Always present
- → Always incomplete → ∴ near normal
- → Both should be in opposite direction [i.e. for Resp. Acidosis do Metab Alk. & vice versa]

*] Mixed disorder → Two pathologies in one ABG

*] Clinical scenario :- a) Septic shock ∈ lactic acidosis :- Metabolic acidosis

b) Sepsis ∈ community acquired pneumonia :- Metabolic acidosis + Resp. alkalosis

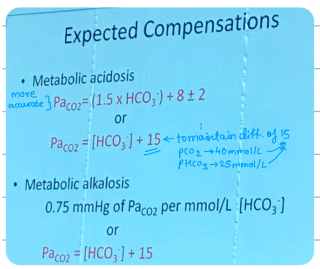
c) Sepsis ∈ Acute exacerbation of COPD :- Metabolic acidosis + Resp. acidosis

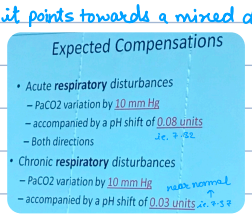
d) Acute exacerbation of COPD (∈ Pulm. HTN) on diuretics :- Resp. Acidosis + Metabolic Alkalosis

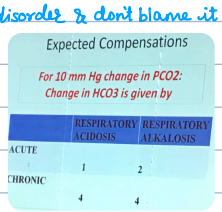
e) liver cirrhosis on diuretics :- Resp. alkalosis [coz Ascites → diaphragm moves up → lung vol. ↓ so to compensate RR↑ → ↓CO_2] + Metabolic Alkalosis

*] How to Interpret ABGs :- i] Henderson-Hasselbach equation :- Summarised as $pH \propto \frac{HCO_3}{CO_2}$ [use 7.4 as Ⓝ pH for calculation purpose] [∵ 1st look for pH]

ii] look for HCO_3 [use Ⓝ 25 mmol/L for calculation purpose] [If pH & HCO_3 move in same direction ie. HCO_3 is primarily responsible for change in pH but if they don't move in same direction ie. HCO_3 is not the primary cause of change in pH ∴ its CO_2 ⇒ if pH↑, HCO_3↓ ⇒ Resp. alkalosis] [Don't look for pCO_2]







*] purpose of calculating compensation is to search for mixed disorders, If the expected value of compensation does not match the expected value it points towards a mixed disorders & don't blame it on compensation eg.

pH	HCO_3	pCO_2	
7.4	25	40	
7.2	20	30 ← Instead of 25 ⇒ M.Ac + Rs. Alk.	Mixed disorders
		if 50 ← Resp. Acidosis + M.Acidosis	

*] In case of Resp. disorders the compensation by Kidney comes in a phased manner ∴ In acute resp. scenario the pH fluctuations are drastic while in chronic the pH is maintained near normal

*] Always look for pCO_2 after calculating expected pCO_2

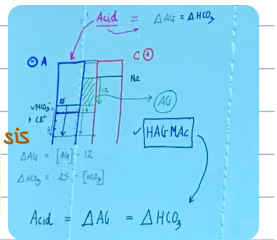
*] Anion Gap = $Na^+ - [(Cl^-) + (HCO_3^-)]$ → Ⓝ 10-12 [Anions :- Bicarb, chlorides, weak acids - sulfate/phosphate, proteins ; Cations :- Li^{2+}, potassium, sodium, Mg^{2+} ⇒ Body :- Anion = Cation [electrically neutral]

[we take Na^+ as representative of all cations while $Cl^- + HCO_3^-$ constitutes major anions ∴ taken as representative of all]

*] Metabolic Acidosis → a] High Anion Gap :- Extra Acid in the sys. which consumes HCO_3^- → >12 & Highly fatal [cause → lactic acidosis (Sepsis, Shock, Hypoxia, Metformin, antiretroviral drugs), Ketoacidosis (DKA, Starvation, Alcoholics, Toxins [methanol poisoning, Aspirin poisoning, ethylene glycol or antifreeze]), AKI/CKD)

[HARD-UP] (Pancreatic drainage (fistula), ureterosigmoidostomy (ureteral diversion))

↔ b] Non-Anion Gap :- Independent loss of Bicarbonate [Diarrhea, Renal tubular acidosis - RTA, Drugs - Acetazolamide, Amphotericin B, Vincristin, Cisplatin, Hyper-Kalemia] & either loss of Na^+ or ↑reabsorption of Cl^- ∴ aka Hyperchlorenic metabolic acidosis



*] Δ (delta) - Bicarbonate :- High Anion Gap metabolic acidosis ⇒ Amt of Acid added = Change in Anion Gap = Change in HCO_3^- if pt has only High Anion Gap Met. Acidosis.

If Δ Anion gap ≠ ΔHCO_3^- → Δ Anion gap > ΔHCO_3 ∴ Additional metabolic alkalosis

→ Δ Anion gap < ΔHCO_3 ∴ Additional non-anion gap met. acidosis

∴ Δ Anion Gap = new Anion gap - 12

ΔHCO_3^- = 25 - new HCO_3^-

eg. CKD + Vomiting ; ABG ⇒ pH = 7.08 , Na^+ = 143 , Cl^- = 100 , HCO_3^- = 8 ⇒ ∴ Metabolic acidosis , Anion gap = 35 ∴ High Anion gap metabolic acidosis ∴ ΔAnion gap = 23 ie. ΔHCO_3^- should be 23 ∴ HCO_3 should have been 25-23 = 2 but it's 8 ∴ additional metabolic alkalosis (can be done via formula ΔHCO_3 = 25-8 = 17 ie. ΔAnion gap > ΔHCO_3^- = Met. Alk)

eg. Diarrhea & DKA ; ABG ⇒ pH = 7.08 , Na^+ = 136 , Cl^- = 110 , HCO_3^- = 5 ∴ Metabolic Acidosis , Anion gap = 21 ⇒ High anion gap Met. acidosis ⇒ ΔAnion gap = 9 , ΔHCO_3 = 20 so by formula additional Non-Anion gap met. acidosis [∵ ΔAniongap < ΔHCO_3^-] so in this pt ΔAnion gap = 9 ∴ HCO_3^- should have been 16 but its 5 ∴ this additional fall of 11 denotes Non AG Met. Acid.

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*] Stepwise approach to ABG ⟶

1] pH & Bicarbonate then pCO_2 → Same direction or Not

2] Primary Diagnosis [Metabolic / Respiratory]

3] Compensation
- Metabolic
  - Acidosis :- 1 mEq/L fall in HCO_3^- ≈ 1-2 mm of Hg fall in pCO_2
  - Alkalosis :- 1 mEq/L rise in HCO_3^- ≈ 0.7 mm of Hg rise in pCO_2
- Respiratory

	Acute	Chronic
Acidosis :- For every 10mm rise in pCO_2 ≈ Rise in HCO_3^- by	1	4
Alkalosis :- For every 10mm fall in pCO_2 ≈ Fall in HCO_3^- by	2	4

4] If Metabolic ⟶ Acidosis ⟶ Calculate Anion Gap / Corrected Anion Gap [If Albumin given]
- HAGMA → Calculate Δ ratio [ΔAG/ΔHCO_3^-]
  - 1-2 → Normal
  - <1 → Additional NAGMA
  - >2 → Additional Metabolic Alkalosis
- Exogenous cause → Calculate Osmolar Gap
  - Present → Methanol / Ethylene glycol
  - Absent → Salicylate / Paraldehyde
- Endogenous cause → Diabetic Ketoacidosis, Lactic Acidosis, Uremic Acidosis
- NAGMA → Calculate Urine Anion Gap
  - Positive → RTA I & III [Negative in RTA II ie. Proximal]
  - Negative → GI loss of HCO_3^- [Diarrhoea, small Bowel tumour, Ureterosigmoidostomy & Anion Exchange Resin]

*] Base excess :- -4 , -3 , [-2 to +2] , +3 , +4
Acidosis ← Normal → Alkalosis

*] SID [Strong Ion Difference] = HCO_3^- + Albumin + Phosphate
<40 ← Acidosis 40 mEq/L Alkalosis → >40

*] Measured Osmolarity − Calculated Osmolarity = >10
ie. Osmolar gap present

*] Formulas in ABG analysis :-

1] Henderson equation :- $pH = pKa + \log \frac{[\text{Dissociated form}]\ ie.\ [A^-]}{[\text{Associated form}]\ ie.\ [AH]}$

2] Corrected Anion Gap = Anion Gap + 2.5 [4.5 − Serum Albumin] [Serum Anion Gap (UA − UC) = $Na^+ - [Cl^- + HCO_3^-]$]

3] Measured Bicarbonate $[HCO_3^-] = 24 \times \frac{pCO_2}{H^+}$

4] Winters Formula for Compensation in Metabolic Acidosis :- $pCO_2 = 1.5 \times HCO_3^- + 8 \pm 2$

5] Strong Ion Difference [SID] = $(Na^+ + K^+ + Mg^{2+} + Ca^{2+}) - (Cl^- + \text{Lactate})$ ⇒ Difference bet^n Measured strong Cations & Anions
= HCO_3^- + Phosphate + Albumin

6] Calculated Osmolarity = $2Na^+ + \frac{\text{Blood Glucose}}{18} + \frac{B.U.N}{2.8}$ = 285-295 Ⓝ [Measured Osmolarity = By Osmometer]

*) Anion Gap / Δ :- Concentration of Unmeasured Anions in the Plasma like Phosphates, Sulphates, Organic Acids, Protein Anion ⇒ Ⓝ 10-12 mmol/L

Acid-Base Balance - Normal Values

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Component	Normal Range	Optimal Value
pH	7.35 - 7.45	7.4
HCO_3^-	22 - 28 mEq/L	24 mEq/L
pCO_2	35 - 45 mmHg	40 mmHg
Anion gap	8 - 12 mEq/L	<10 mEq/L
O_2 saturation	> 95%	
pO_2	75 - 100 mmHg	

Type 1- Acute hypoxemic respiratory failure	Type 2-Respiratory failure
Due to failure of oxygenation, this type of respiratory failure occurs with alveolar flooding and subsequent intrapulmonary shunt physiology	Due to defect in ventilation, this type of respiratory failure is a consequence of alveolar hypoventilation and results from the inability to eliminate carbon dioxide effectively
PaO2: Low (<60 mm Hg)	PaO2: Low (<60 mm Hg)
PaCO2: Normal or low (<or equal to 49mm Hg)	PaCO2: Increased (>49 mm Hg)
Seen in:	Seen in:
Pulmonary edema	Diminished CNS drive: drug overdose, brainstem injury, sleep-disordered breathing and severe hypothyroidism.
Pneumonia	Impaired neuromuscular transmission: myasthenia gravis, Guillain-Barré syndrome, amyotrophic lateral sclerosis
Alveolar haemorrhage	Respiratory muscle weakness: myopathy, electrolyte derangements, fatigue
ARDS	Obstructive lung disease: COPD, foreign body
Emphysema	

*] Causes of Metabolic Acidosis :-

1] HAGMA ⟶ Methanol	2] NAGMA ⟶ Fistula pancreatic
[MUDPILES] Uremia [Renal failure → Acute/Chronic]	[FUSED CAR] Ureterosigmoidostomy
Diabetic Ketoacidosis	Small Bowel Fistula
Paraldehyde	Extra Chloride [Hyperalimention]
Iron tablets, Isoniazid [INH]	Diarrhea
Lactic Acidosis	Carbonic Anhydrase Inhibitors
Ethylene Glycol	Addison's disease
Salicylates	Renal Tubular Acidosis

*] Acidosis favours Ionisation of Ca^{2+}

*] Hypercalcemia can cause Metabolic alkalosis but Alkalosis itself can cause deionisation of Ca^{2+} (As major form of Ca^{2+} (50%) is in ionised form) causing hypocalcemic signs like Tetany, Chvostek's sign, laryngospasm

*] Causes of Metabolic Alkalosis :-

i] Loss of Hydrogen :- i] Gastrointestinal loss → a) Vomiting / Nasogastric Suction
b) Chloride losing diarrhea
c) Gastrocolic Fistula
d) Villous Adenoma
e) Antacid therapy, particularly if combined with Cation Exchange Resin

ii] Renal loss → a) Loop / Thiazide diuretics
b) Excess Mineralocorticoid (1° Hyperaldosteronism, Cushing's, Steroids, Licorice, ↑Renin secretion)
c) Post Chronic Hypercapnia
d) Hypercalcemia, Milk of Alkali syndrome

iii] H^+ movement into the cell → Hypokalemia

2] Exogenous Alkali :- Administration of $NaHCO_3$, Na citrate / gluconate / acetate / antacids, Massive Blood transfusion (Na citrate anticoag. → Bicarb in body)

3] Contraction Alkalosis :- Loop / Thiazide diuretics, Sweat losses in Cystic fibrosis & Gastric losses in Achlorhydria

4] Miscellaneous :- Bartter's syndrome & Gitelman's syndrome

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*] Causes of Respiratory Alkalosis :-

i] Central :- a) Drugs
b) Stroke
c) Infection

ii] Airway :- a) Obstruction
b) Asthma

iii] Parenchyma :- a) Emphysema
b) Pneumoconiosis
c) Bronchitis
d) ARDS
e) Barotrauma

iv] Neuromuscular :- a) Myasthenia Gravis
b) Poliomyelitis
c) Kyphoscoliosis
d) Muscular Dystrophies

v] Miscellaneous :- a) Obesity
b) Hypoventilation
c) Permissive Hypercapnia

*] Decreased Anion Gap :- <6 mEq/L

1] Hypoalbuminemia (eg. Nephrotic syn) [Albumin is an Unmeasured Anion]
2] Plasma Cell Dyscrasia
3] Monoclonal protein
4] Bromide Intoxication
5] Addition to the blood of Abnormal Cations eg. Lithium
6] Hyperviscosity
7] Severe Hyperlipidemia

Nephrotic syndrome leads to a **decrease in serum albumin** which is an **unmeasured anion**. Albumin at physiological pH is the major contributor to the unmeasured anions of the body.

A **reduced anion gap** is seen in **nephrotic syndrome**. The major cause of this is hypoalbuminemia. A fall in serum albumin by 1 g/dL from the normal value (4.5 g/dL) decreases the anion gap by 2.5 mEq/L.

This is because the consumption of bicarbonate by the unmeasured anions increases the anion gap by lowering the serum bicarbonate level. Therefore, when the unmeasured anions decrease, anion gap also decreases.