Acid base balance and the respiratory system

By

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Remember

- Generally, the pH of:
  A: Neutral solution is equal to 7
  B: Acidic solution is less than 7 because it contains more H^+ ions (**proton donors**).
  C: Basic solution is more than 7 because it contains less H^+ ions (**proton acceptors**).
- ***pH range:*** It starts from 1-14.

- **Normal blood pH is kept within a very limited range (7.35-7.45)**

Acidosis	Normal	Alkalosis
Below 7.35	7.35–7.45	Above 7.45

- **Arterial oxygen partial pressure (PaO_2)= 75 –100 mmHg**

- **Arterial carbon dioxide partial pressure ($PaCO_2$)= 35–45 mmHg**

- **Bicarbonate (HCO_3^-) = 22-26 mmol/L**

- During metabolic reactions inside the body, acids and bases are formed, or they may be taken by any mean.

- It is very important to keep the pH of the blood and tissues **around 7.4**, which is suitable to the functions of most body enzymes. **(enzymes, which control metabolic reactions, are very sensitive to changes in pH. So any acid or base formed inside the body should be rapidly and effectively buffered to allow such reactions to proceed).**

pH fighters

There are 3 lines of defenses ***(pH fighters)*** which regulate the pH:

- 1- The first line of defense is the **blood buffer.**
- 2- The second line of defense is the **respiratory regulation.**
- 3- The third line of defense is the **renal regulation.**

Buffers

- **Def.** They are solutions that **resist changes** in their pH when moderate amounts of acids or bases are added.

- Composition of a Buffer

Buffers are of two types:

a. Mixtures of weak acids and their salt with a strong base.
Carbonic acid / Na-bicarbonate mixture **(H_2CO_3 / $NaHCO_3$)**

Acetic acid / Na acetate mixture **(CH_3COOH /CH_3COONa)**

b. Mixtures of weak bases and their salt with a strong acid.
Ammonium hydroxide / ammonium chloride **(NH_4OH /NH_4CL)** mixture.

Mechanism of action:

- 1- Addition of a strong acid as HCL to carbonic / bicarbonate system, it reacts with the bicarbonate as follows:

$$NaHCO_3 + HCL \longrightarrow NaCL + H_2CO_3$$

So HCL which is a strong acid is neutralized forming NaCL and H2CO3. The latter is a weak acid which produces minimal change in the pH of the solution.

- 2- Addition of strong base as NaOH to carbonic-bicarbonate system, it reacts with carbonic acid as follows:

$$H_2CO_3 + NaOH \longrightarrow NaHCO_3 + H_2O$$

$NaHCO_3$ is a weak basic salt, which produces minimal change in the pH of the solution and the OH^- of NaOH is neutralized to form water.

- Addition of excess amounts of acids or bases to a buffer, **may cause depletion** of the buffer system which is followed by marked change in the pH of the solution.

TYPES OF BUFFER:

- There are two types of buffers: Physiological buffer systems & blood buffer.

- **PHYSIOLOGICAL BUFFER SYSTEMS:**

The most important physiological buffer systems are:

-Bicarbonate

-Phosphate and

-Protein systems

- **Blood buffers:**

Include all the physiological buffer system mentioned above. The protein system includes the plasma proteins, albumin, globulins, and fibrinogen, in the plasma, and the **hemoglobin** and **oxyhemoglobin** buffering system in the red blood cells.

Bicarbonate system(BHCO3/H2CO3)

- The normal plasma **bicarbonate level is 24mmol/l** while the normal plasma **carbonic acid is 1.2 mmol/L**.
- It is found that **the ratio between bicarbonate to carbonic acid is equal to 20:1.**
- B denotes to Na^{+} ions if the system acts extracellular or K^{+} ions if the system acts intracellular.

(BHCO3/H2CO3)

- Bicarbonate buffer system accounts for 65 % of buffering capacity in plasma and 40 % of buffering action in the whole body.

- Bicarbonate is regulated by the kidney **(Metabolic component)** while the carbonic acid is under respiratory regulation **(Respiratory component).**

- The bicarbonate system is the most efficient for the buffering of all acids added to the blood, **other than carbonic acid**, because:

A- It is present at a higher concentration than the other buffers.

B- The ratio **$BHCO_3/H_2CO_3$**, which determines the pH of the system **(20:1 at pH 7.4),** can be readily corrected by respiration. This is because H_2CO_3 can be rapidly converted to CO_2, by the help of the enzyme **carbonic anhydrase,** and disposed of by the lungs.

Thus, if an acid is added to the blood, it converts the $BHCO_3$ to H_2CO_3, decreasing their ratio below 20:1. the blood pH decreases, and acidosis occurs.

This rapidly stimulates respiration, leading to loss of CO_2 through the lungs and decreasing H_2CO_3. the ratio $BHCO_3/H_2CO_3$ increases to 20:1 and the blood pH becomes 7.4.

Alkali Reserve:

- Bicarbonate represents the alkali reserve and it has to be sufficiently high to meet the acid load. If it was too low to give a ratio of 1, all the HCO3–would have been exhausted within a very short time; and buffering will not be effective.
- So, under physiological circumstances, the ratio of 20 (a high alkali reserve) ensures high buffering efficiency against acids.

Buffers Act Quickly, But Not Permanently

- Buffers can respond immediately to addition of acid or base, but they do not serve to eliminate the acid from the body.
- They are also **unable to replenish the alkali reserve of the body.**
- For the final elimination of acids, the **respiratory** and **renal** regulations are very essential.

pH of Buffers

- The dissociation of weak acids is a reversible reaction that obeys the law of mass action:

$$HA \longleftrightarrow H^+ + A^-$$

where [H+] is the concentration of hydrogen ions, [A–] = the concentration of anions or conjugate base, and [HA] is the concentration of undissociated molecules.

Thus, at equilibrium:

$$Ka = \frac{[H^+][A^-]}{[HA]}, \qquad [H^+] = \frac{K_a\ [HA]}{[A^-]}$$

- Where Ka is the dissociation constant of the acid. Stronger acids have a higher Ka.

$$[H^+] = \frac{K_a\ [HA]}{[A^-]}$$

$$H^+ = Ka \times \frac{Acid}{Salt}$$

Taking – log this equation we get:

$$-\log [H^+] = -\log Ka + -\log \frac{Acid}{salt}$$

$$-\log [H^+] = -\log Ka + -\log \frac{\text{Acid}}{\text{salt}}$$

$$pH = pKa + \log \frac{\text{Salt}}{\text{Acid}}$$

The relationship between pH, pKa, concentration of acid and conjugate base (or salt) is expressed by the **Henderson-Hasselbalch equation.**

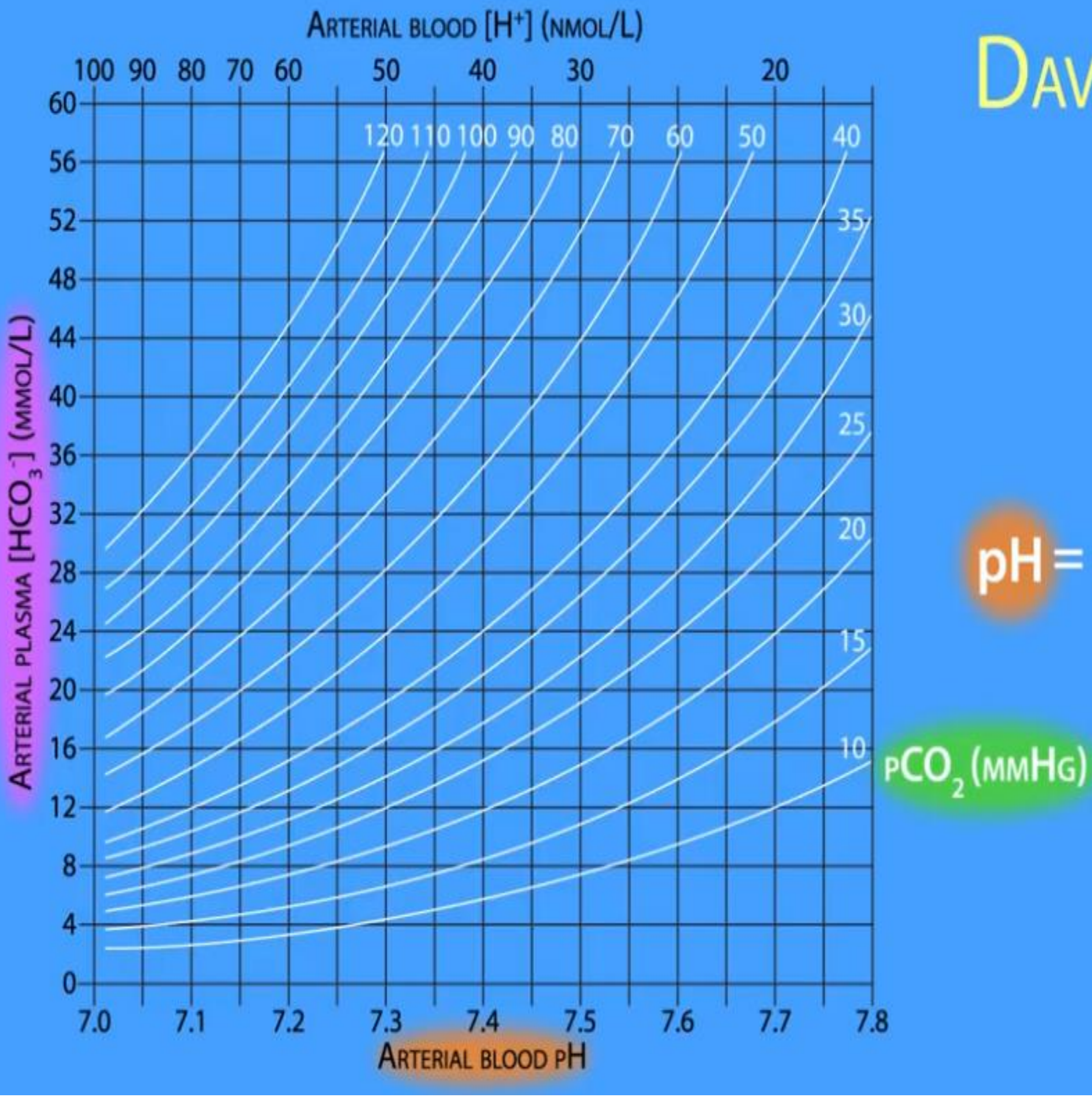
Application of the Equation

i. The pH of a buffer on addition of a known quantity of acid and alkali can, therefore, be predicted by the equation.

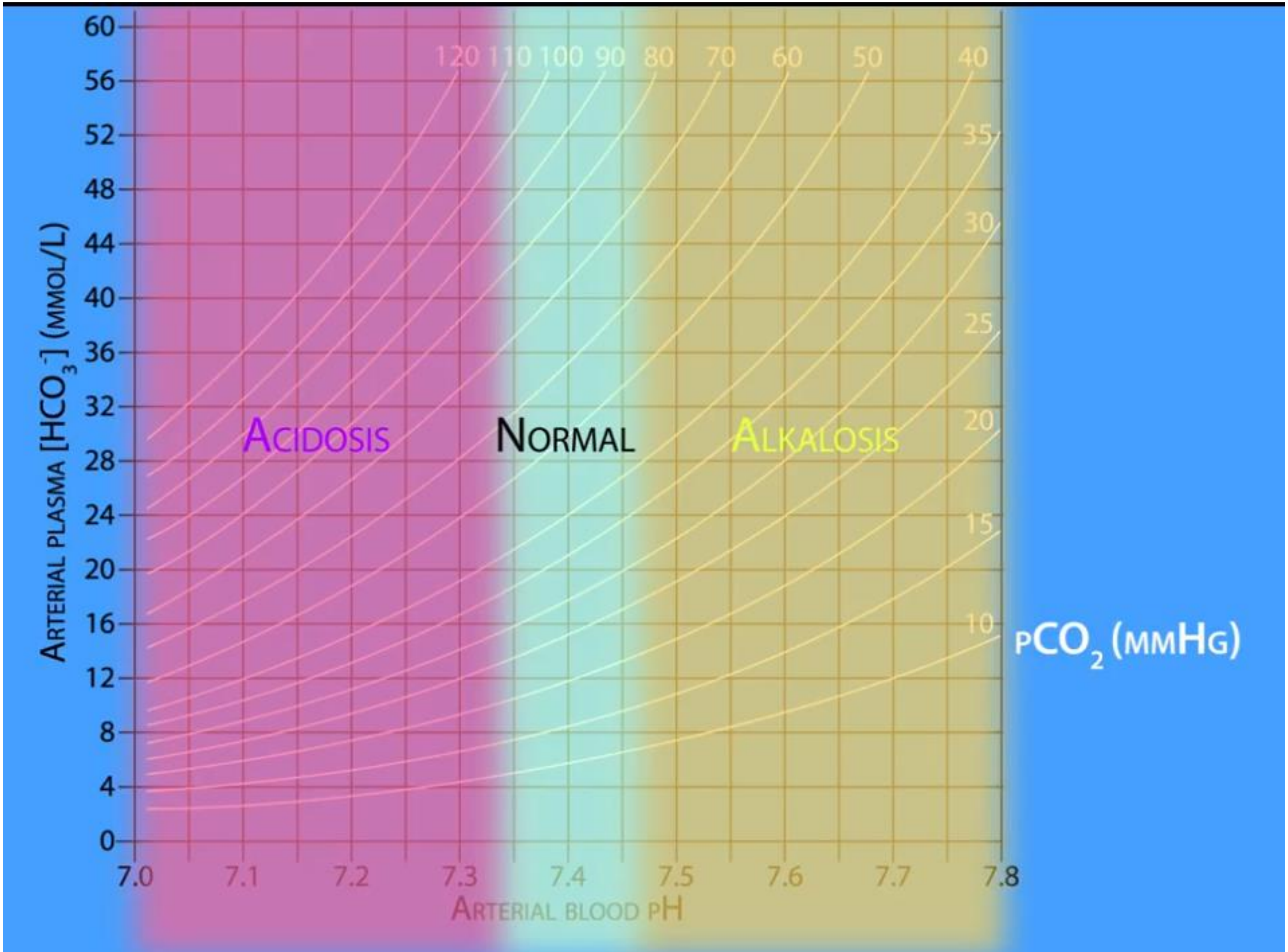
ii. Moreover, the concentration of salt or acid can be found out by measuring the pH.

iii. The Henderson-Hasselbalch's equation, therefore, has great practical application in clinical practice in assessing the acid-base status.

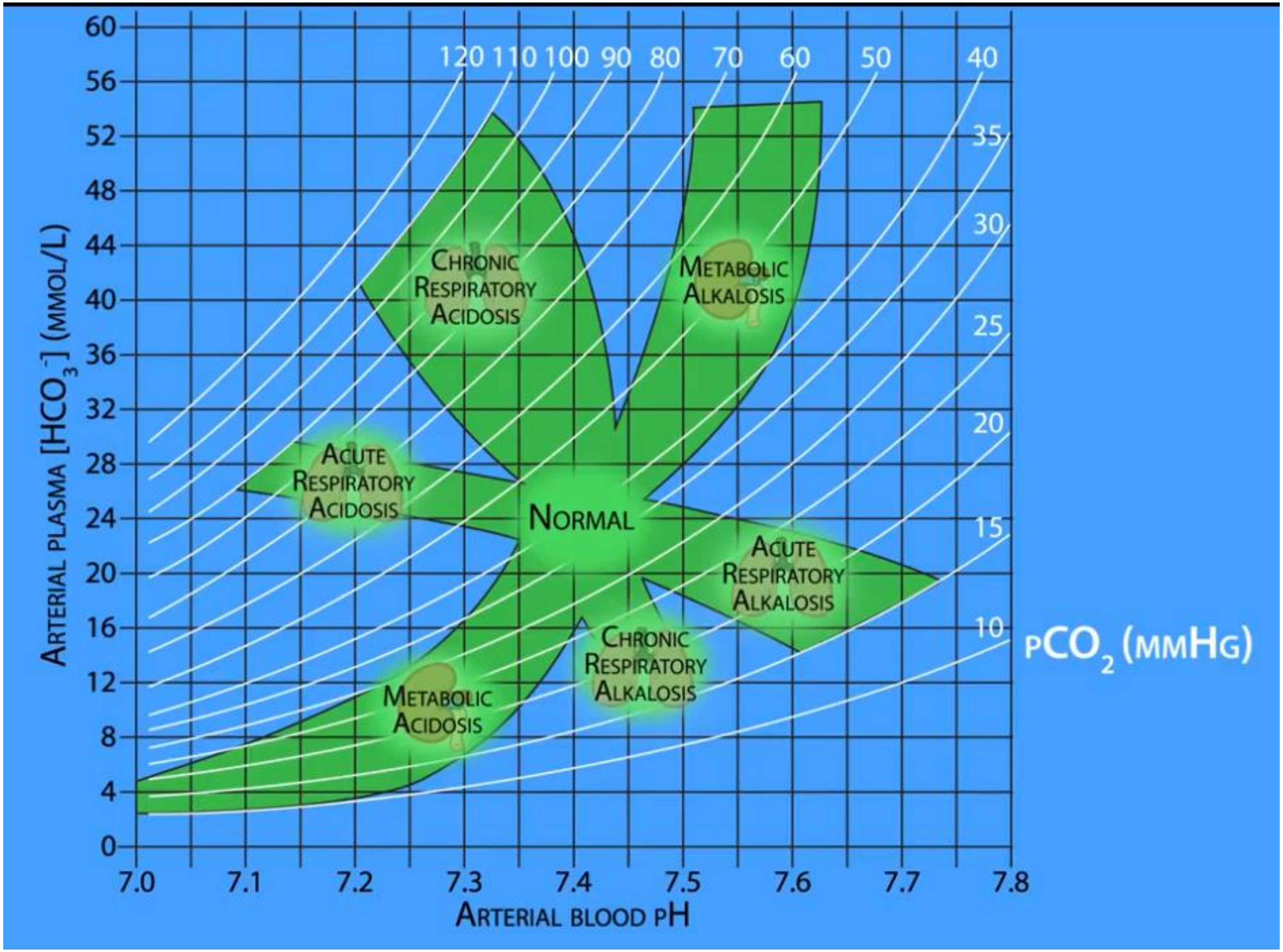
DAVENPORT DIAGRAM

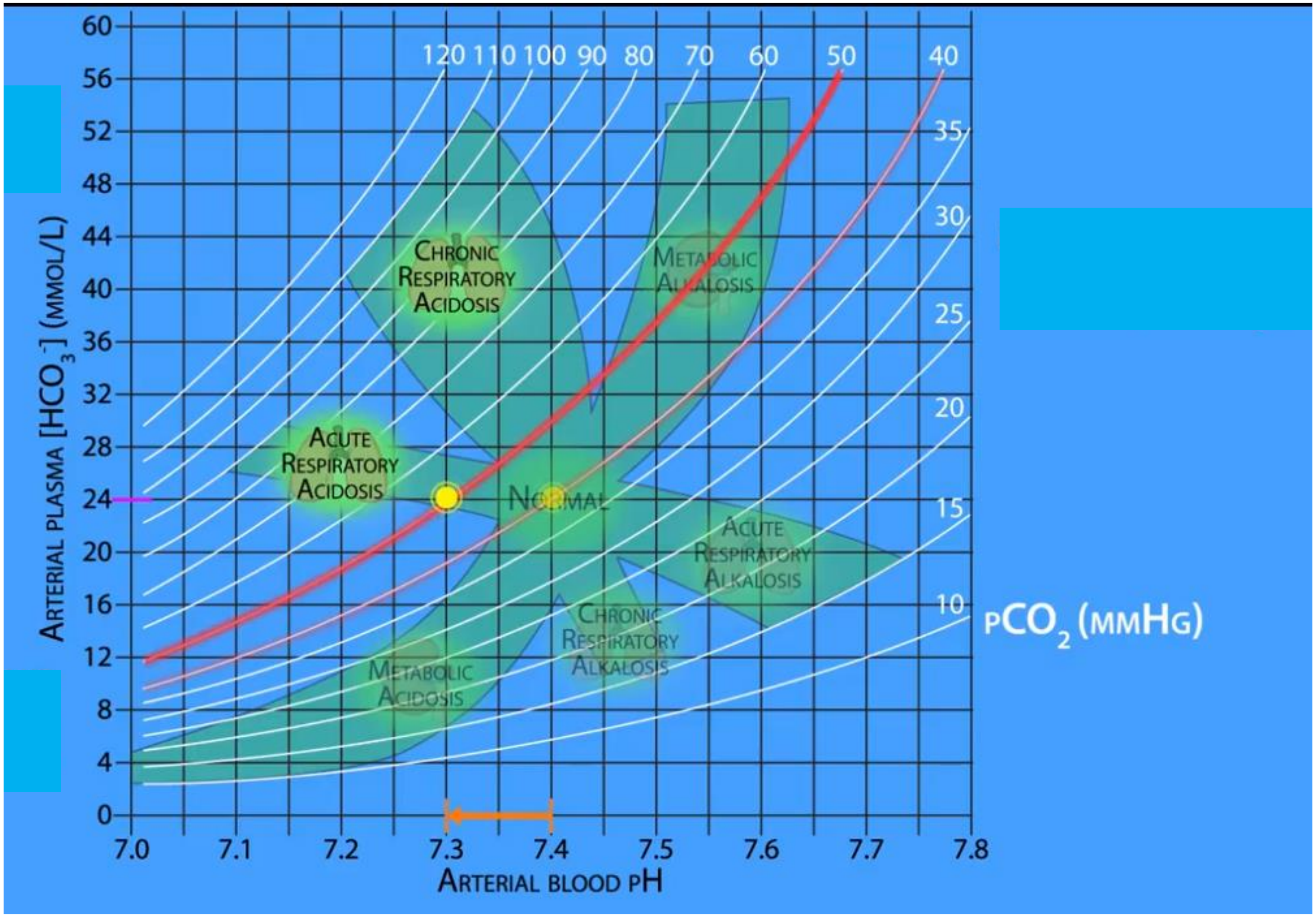


$$pH = 6.1 + \log\left[\frac{[HCO_3^-]}{0.03 \times pCO_2}\right]$$



Acidosis
Normal
Alkalosis
120 110 100 90 80 70 60 50 40
35
30
25
20
15
10
pCO2 (mmHg)
Arterial plasma [HCO3-] (mmol/L)
60 56 52 48 44 40 36 32 28 24 20 16 12 8 4 0
7.0 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8
Arterial blood pH


Arterial plasma [HCO_3^-] (mmol/L)
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
7.0
7.1
7.2
7.3
7.4
7.5
7.6
7.7
7.8
Arterial blood pH
120
110
100
90
80
70
60
50
40
35
30
25
20
15
10
pCO_2 (mmHg)
Chronic Respiratory Acidosis
Metabolic Alkalosis
Acute Respiratory Acidosis
Normal
Acute Respiratory Alkalosis
Chronic Respiratory Alkalosis
Metabolic Acidosis



120 110 100 90 80 70 60 50 40
35
30
25
20
15
10
pCO2 (mmHg)
Chronic Respiratory Acidosis
Acute Respiratory Acidosis
Metabolic Alkalosis
Normal
Acute Respiratory Alkalosis
Chronic Respiratory Alkalosis
Metabolic Acidosis
Arterial plasma [HCO3-] (mmol/L)
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
7.0 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8
Arterial blood pH

<u>RESPIRATORY REGULATION OF pH</u>

- **The Second Line of Defense**

i. This is achieved by changing the pCO2 (or carbonic acid, the denominator in the equation). The CO2 diffuses from the cells into the extracellular fluid and reaches the lungs through the blood.

ii. The rate of respiration (rate of elimination of CO2) is controlled by the <u>chemoreceptors in the respiratory center which are sensitive to changes in the pH of blood.</u>

iii. When there is a fall in pH of plasma (acidosis), the respiratory rate is stimulated resulting in **<u>hyperventilation</u>**. This would eliminate more CO2, thus lowering the H2CO3 level.

iv. However, this cannot continue for long. The respiratory system responds to any change in pH immediately, but it cannot proceed to completion.

Acidosis

- Acidosis is a condition in which the blood pH becomes **< 7.35.**
- It usually results from the formation or absorption of acids at a rate exceeding that of their neutralization and elimination.
- It may also result from the loss of excessive amounts of bases from the body.
- Acidosis may be **respiratory** or **metabolic**.

Respiratory acidosis

- It is caused by increased plasma H_2CO_3 due to failure of the lungs to excrete CO_2 at the proper rate.

- This occurs in pneumonia, emphysema, asphyxia, bronchial asthma, and inhibition of the respiratory center as in morphine poisoning.

- In respiratory acidosis we first get decreased plasma ratio of HCO3/H2CO3.
- The blood pH decreases and the condition is called <u>**uncompensated respiratory acidosis**.</u>

(HCO3 normal---H2CO3 increased---pH **<**7.35)

This stimulates the kidneys to reabsorb more HCO3^{-}, increasing the plasma HCO3^{-} till the ratio HCO3^{-}/H2CO3 approaches 20:1.

The blood pH is now near normal but the alkali reserve HCO3^{-} is increased and the condition is called <u>**compensated respiratory acidosis**.</u>

(HCO3 increased--H2CO3 increased---pH **near** 7.35)

Alkalosis

- It is a condition in which the blood pH becomes **>** 7.45.
- It usually results from the loss of excessive quantities of acids from the body.
- It may also result from the absorption or formation of bases inside the body at a rate exceeding that of their neutralization and elimination.
- Alkalosis may be **respiratory** or **metabolic**.

Respiratory alkalosis

- It is caused by decreased plasma H_2CO_3 due to increased loss of CO_2 through the lungs.

- This occurs in any condition leading to **hyperventilation** such as fevers, encephalitis, going to high altitudes, hysterical hyperventilation, and early stages of salicylates poisoning.

- In respiratory alkalosis we first get increased plasma ratio of HCO_3^-/H_2CO_3. the blood pH increases and the condition is called **<u>uncompensated respiratory alkalosis</u>**.

(HCO_3^- normal---H_2CO_3 decreased---pH>7.45)

This inhibits the renal tubular reabsorption of HCO_3^- decreasing the plasma HCO_3^- till the ratio HCO_3^-/H_2CO_3 approaches 20:1

The blood pH is now near normal, but the alkali reserve is decreased, and the condition is called **compensated respiratory alkalosis.**

(HCO_3^- decreased---H_2CO_3 decreased---pH near 7.45)