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Electrolytes, pH, and Acid-Base Balance

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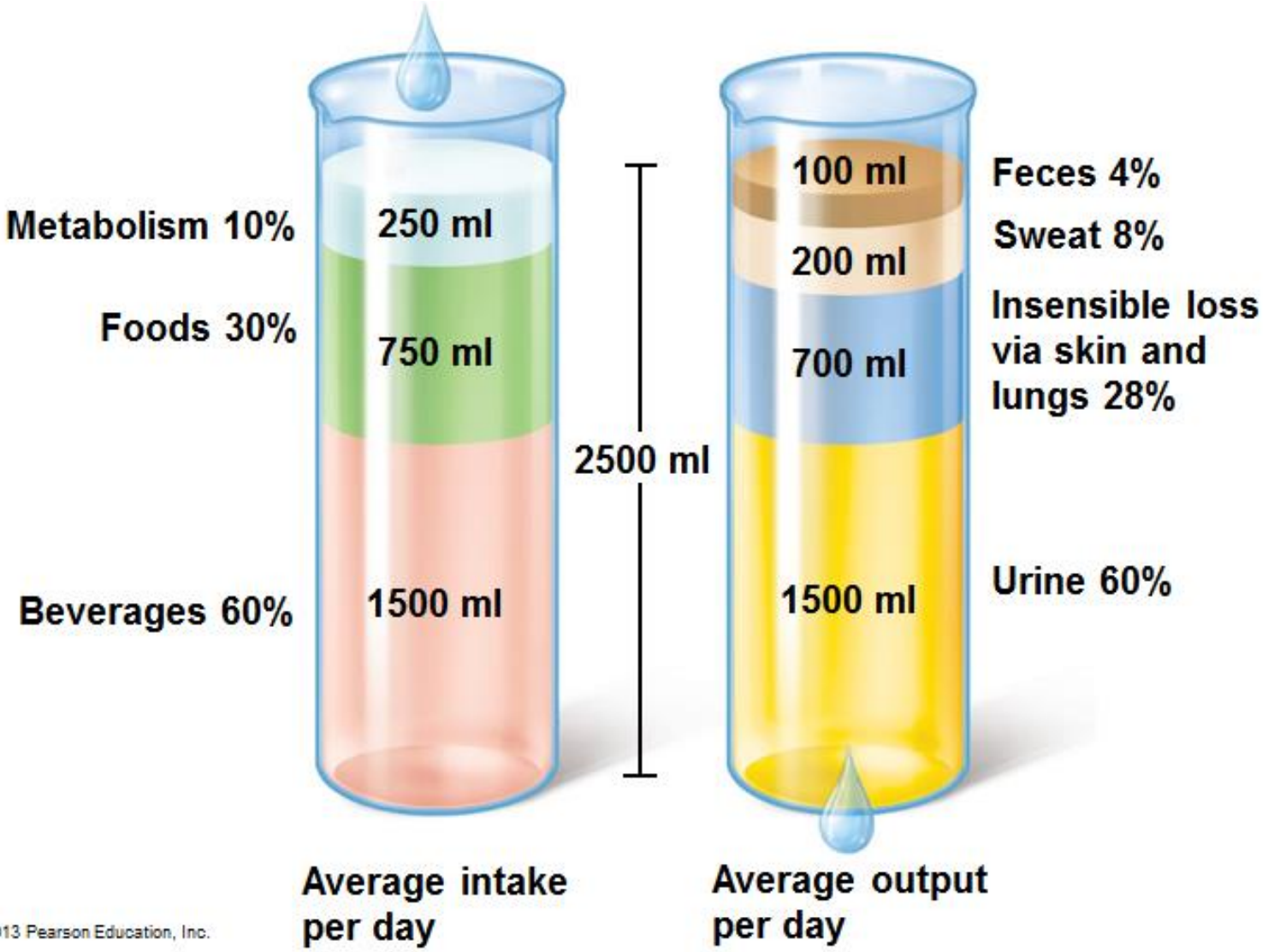

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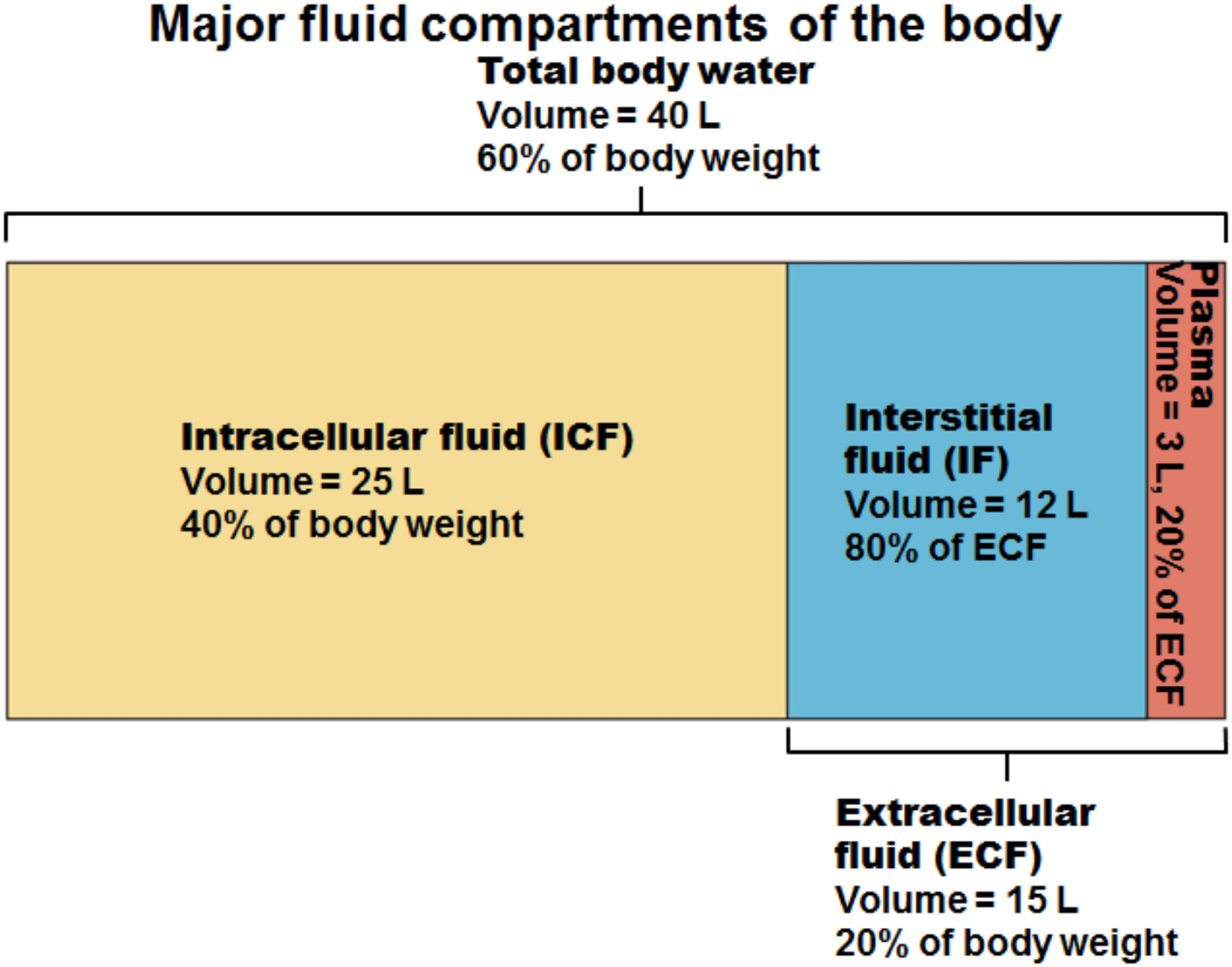
Major fluid compartments of the body



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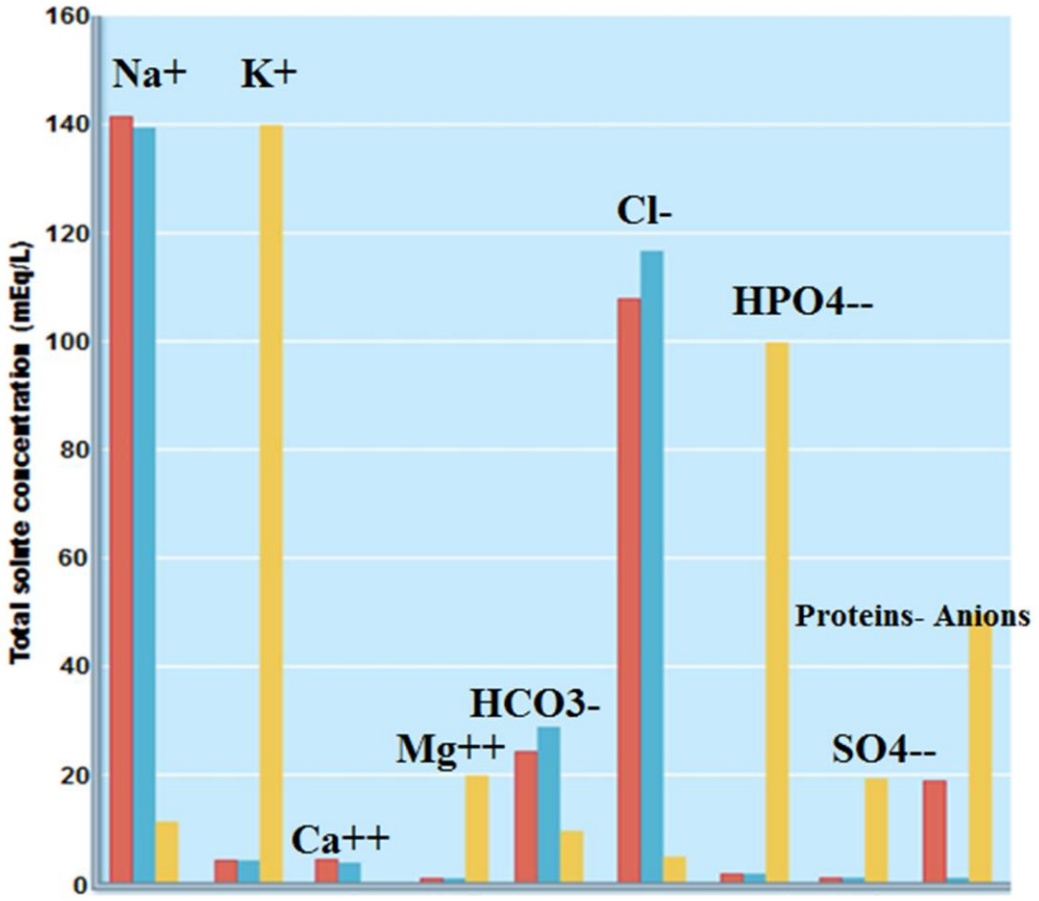
Electrolyte Composition of Plasma, Interstitial Fluid, and Intracellular Fluid

Blood plasma
Interstitial fluid
Intracellular fluid

Na^+	Sodium
K^+	Potassium
Ca^{2+}	Calcium
Mg^{2+}	Magnesium
HCO_3^-	Bicarbonate
Cl^-	Chloride
HPO_4^{2-}	Hydrogen phosphate
SO_4^{2-}	Sulfate



Normal saline = 0.9% NaCl = 9 g NaCl in 1 L

MW(NaCl)=58.5

(9 g/L)/(58.5 g/mole) = 0.15 mole/L = 150 mM/L

D5W = 5% dextrose in water = 278 mM/L

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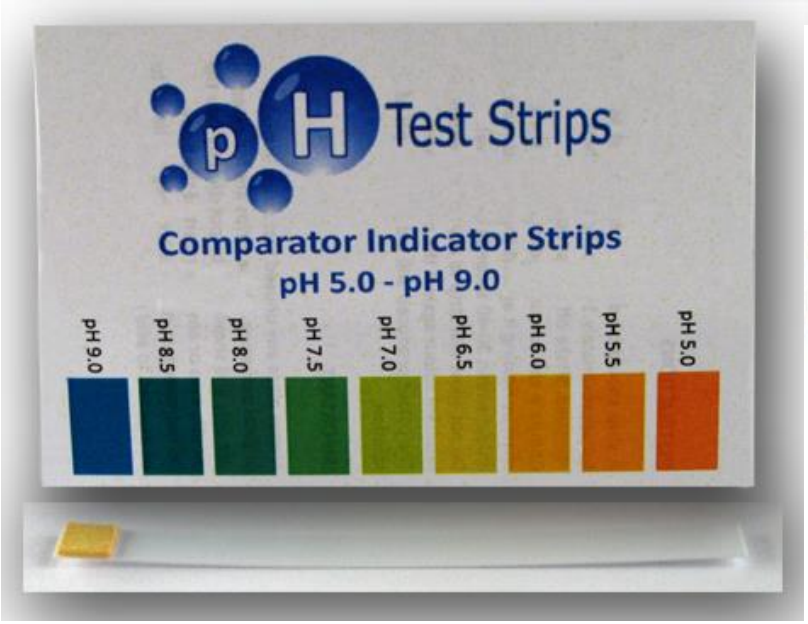
Acids and Bases

$$[H^+]$$

$$[OH^-]$$

pH

$$pH = -\log[H^+]$$


pH Test Strips
Comparator Indicator Strips
pH 5.0 - pH 9.0
pH 9.0
pH 8.5
pH 8.0
pH 7.5
pH 7.0
pH 6.5
pH 6.0
pH 5.5
pH 5.0


pH
1-11

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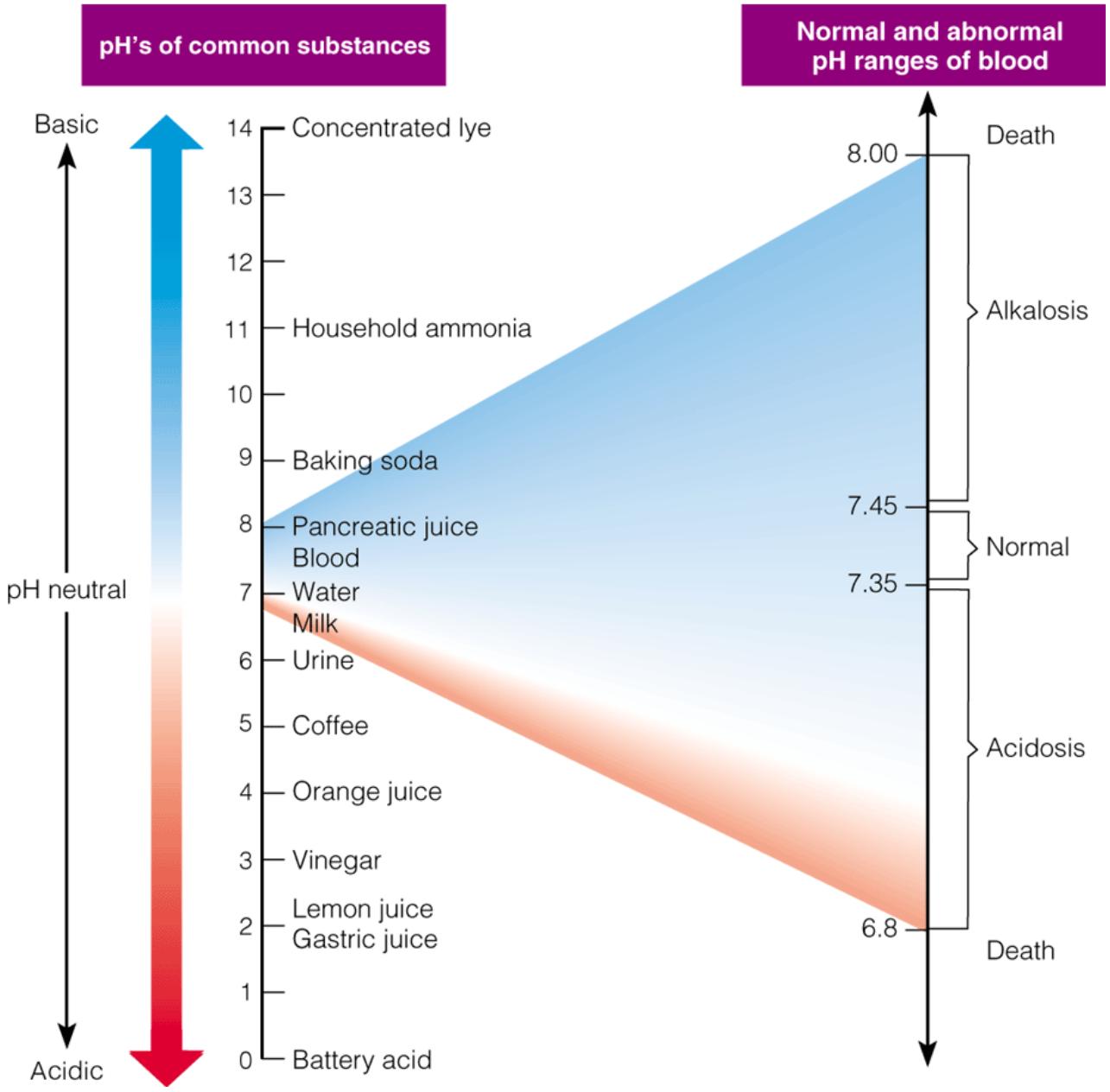
pH	Examples of solutions
0	Battery acid, strong hydrofluoric acid
1	Hydrochloric acid secreted by stomach lining
2	Lemon juice, gastric acid, vinegar
3	Grapefruit juice, orange juice, soda
4	Tomato juice, acid rain
5	Soft drinking water, black coffee
6	Urine, saliva
7	“Pure” water
8	Sea water
9	Baking soda
10	Great Salt Lake, milk of magnesia
11	Ammonia solution
12	Soapy water
13	Bleach, oven cleaner
14	Liquid drain cleaner



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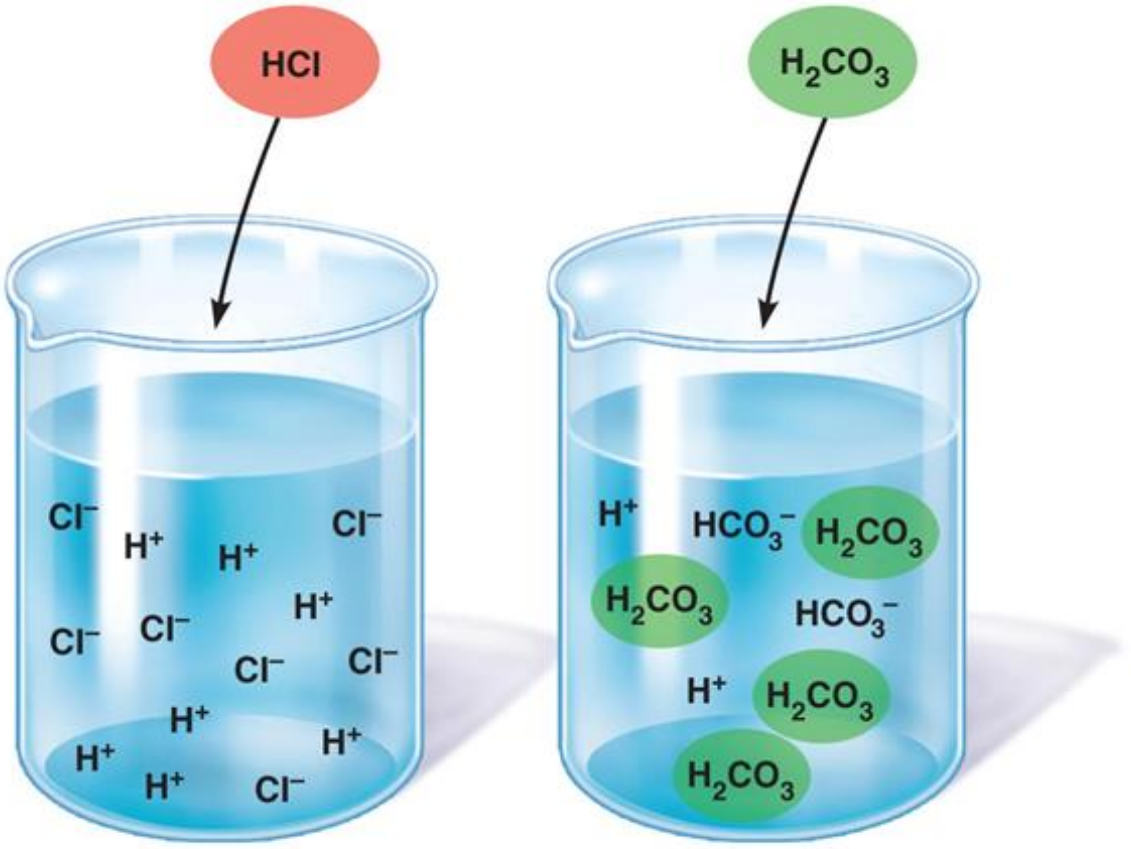
Strong Acids -Weak Acids



(a) A strong acid such as HCl dissociates completely into its ions.

(b) A weak acid such as H_2CO_3 does not dissociate completely.

pK

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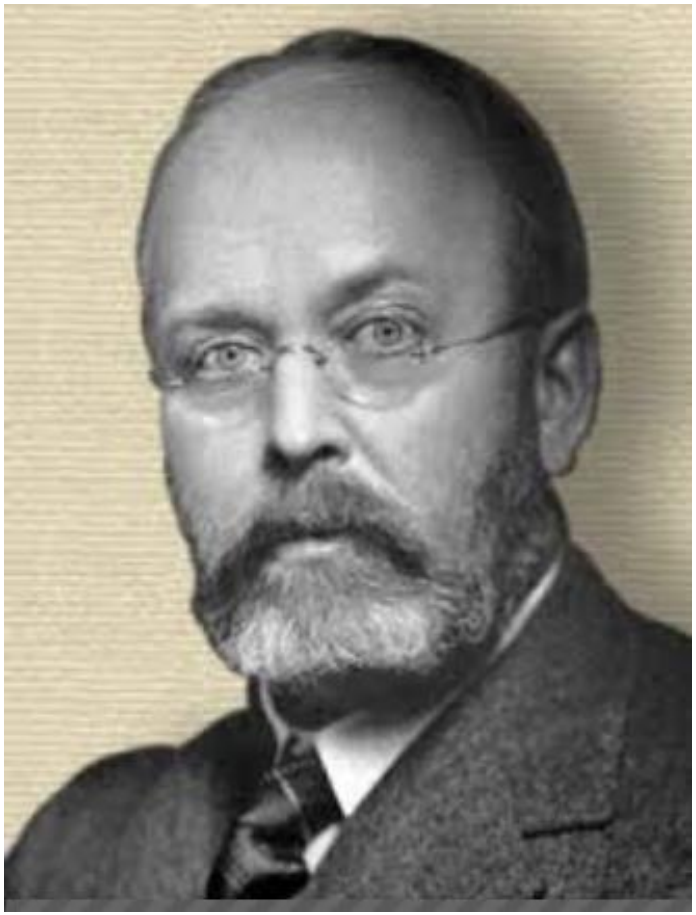
Lawrence Joseph Henderson

(June 3, 1878, Lynn, Massachusetts – February 10, 1942, Cambridge, Massachusetts) was a physiologist, chemist, biologist, philosopher, and sociologist. He became one of the leading biochemists of the early 20th century.



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Karl Albert Hasselbalch

(1 November 1874 in Aastrup, Denmark – 19 September 1962) was a physician and chemist.

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Henderson–Hasselbalch equation

$$\mathrm{pH} = \mathrm{p}K_\mathrm{a} + \log_{10}\left(\frac{[\mathrm{A}^-]}{[\mathrm{HA}]}\right)$$

سوال

در خون یک بیمار، غلظت اسید کربنیک 1.2 میلی اکی والان گرم و غلظت یون بیکربنات 24 میلی اکی والان گرم است.

1. pH خون چقدر است؟
2. آیا نیازی به درمان هست؟

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Pk اسید کربنیک معادل 6.1 است.

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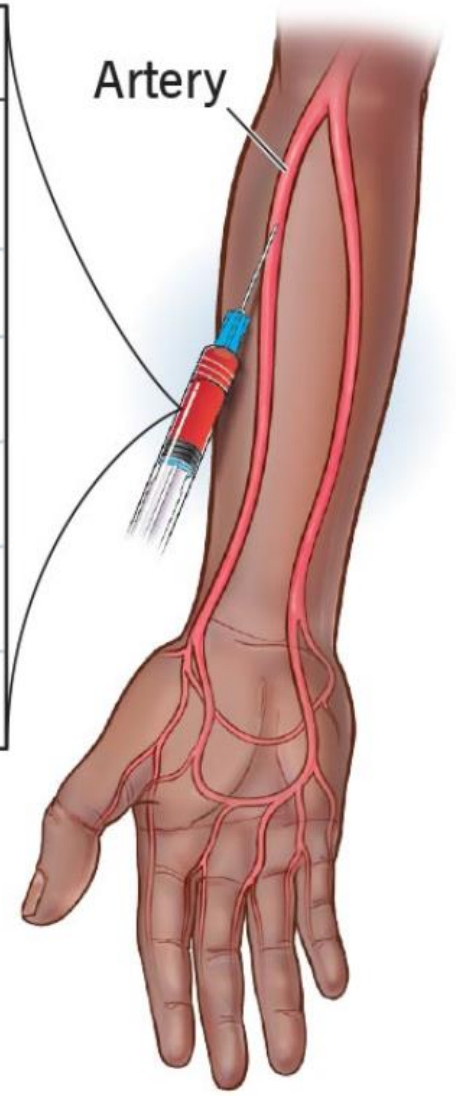
پاسخ: طبیعی

$$pH=6.1+1.3=7.4$$

Arterial Blood Gas (ABG)

ABG	Normal range
O_2CT	15-23% per 100 mL of blood
pH	7.35-7.45
$PaCO_2$	35-45 mmHg
PaO_2	80-100 mmHg
HCO_3	22-26 mEq/L
O_2Sat	95-100%



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Buffer

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Henderson–Hasselbalch equation

$$\mathrm{pH} = \mathrm{p}K_\mathrm{a} + \log_{10}\left(\frac{[\mathrm{A}^-]}{[\mathrm{HA}]}\right)$$

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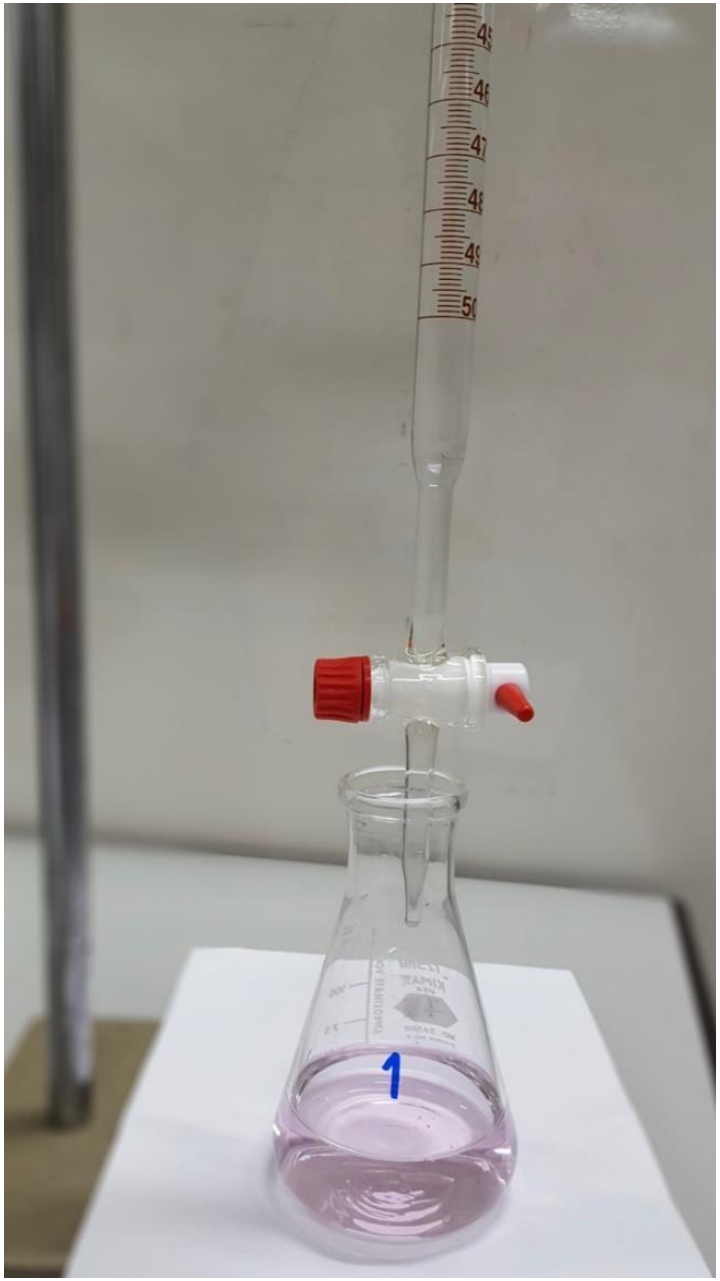
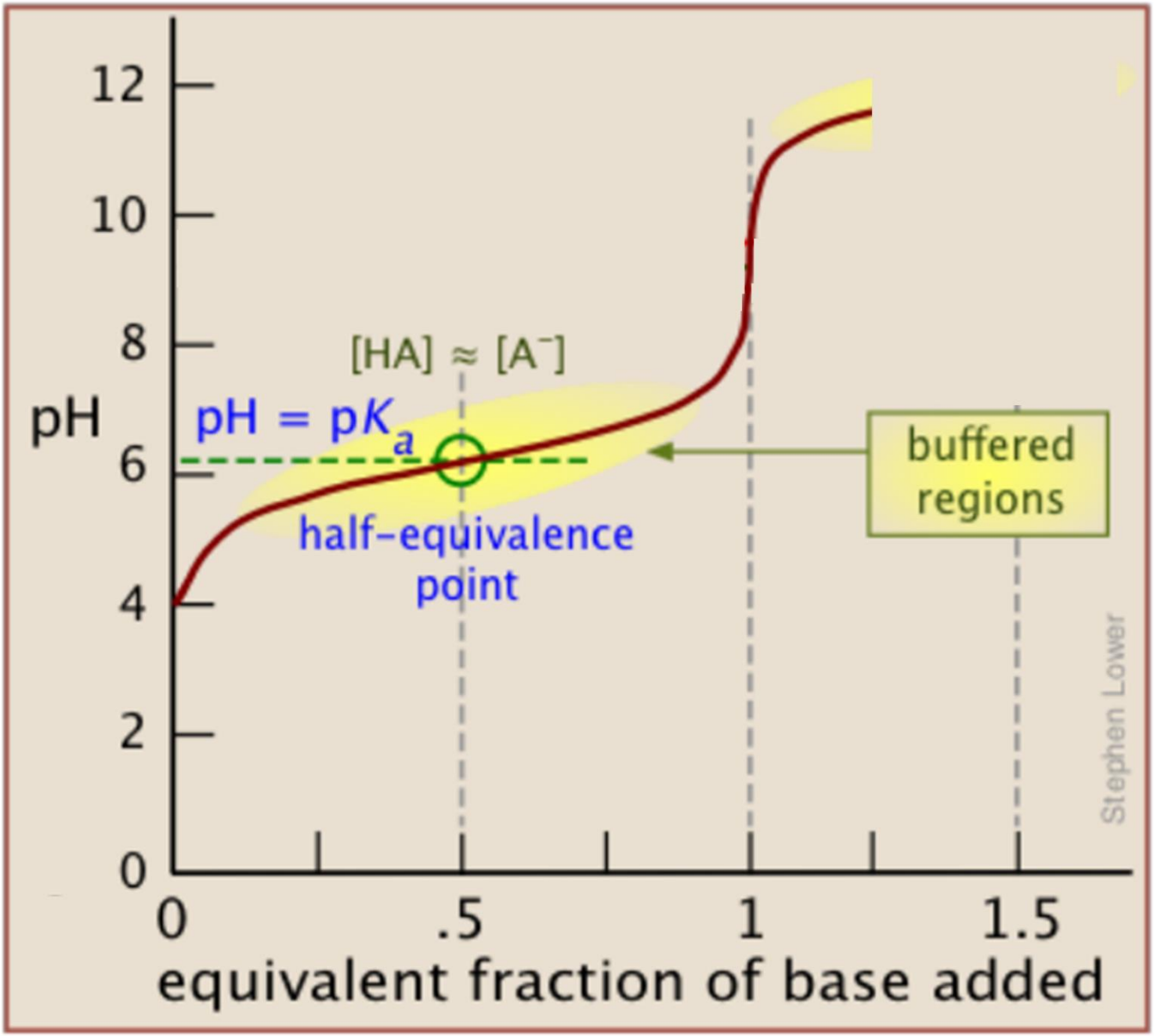
Titration




12
10
8
6
4
2
0
pH
[HA] ≈ [A⁻]
pH = pKa
half-equivalence point
buffered regions
0
.5
1
1.5
equivalent fraction of base added
Stephen Lower

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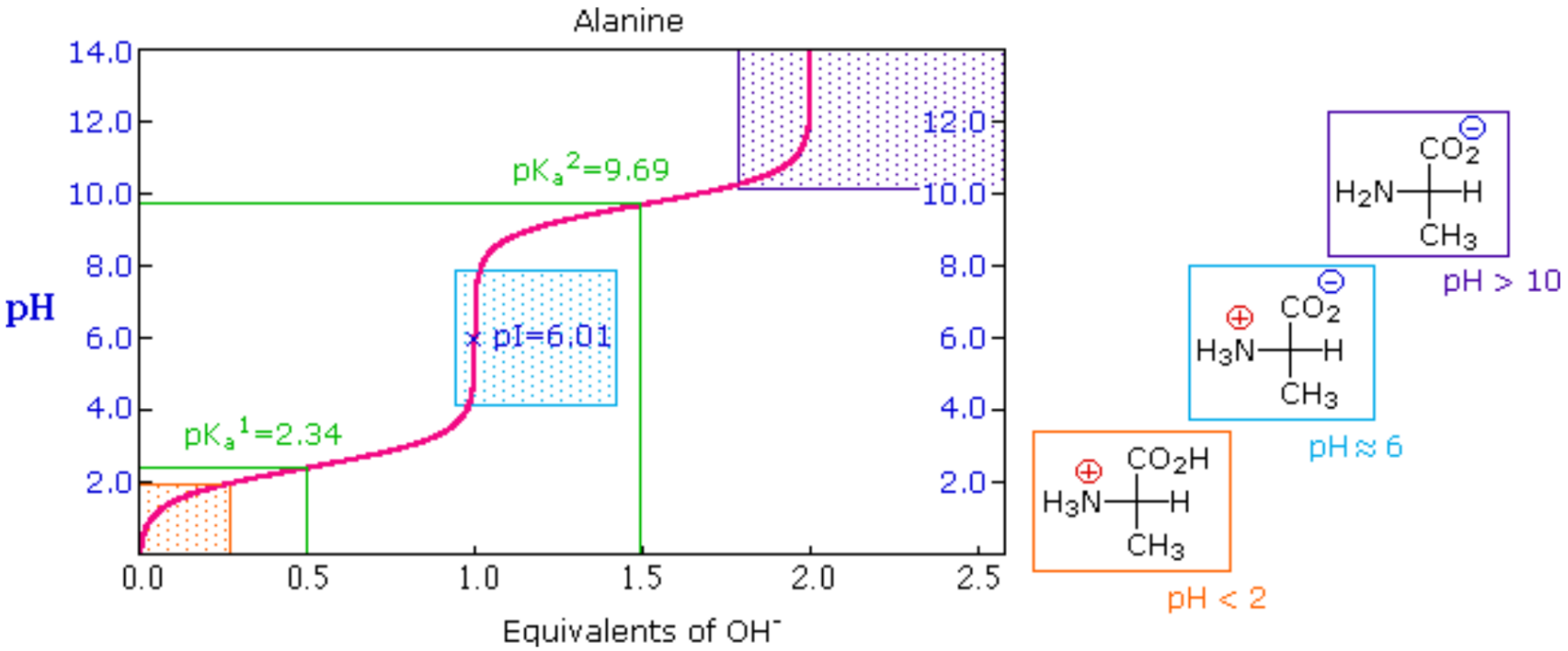
Amino acids


Alanine
pH
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.5
1.0
1.5
2.0
2.5
Equivalents of OH⁻
pK$_a^2$=9.69
pI=6.01
pK$_a^1$=2.34
pH > 10
pH ≈ 6
pH < 2

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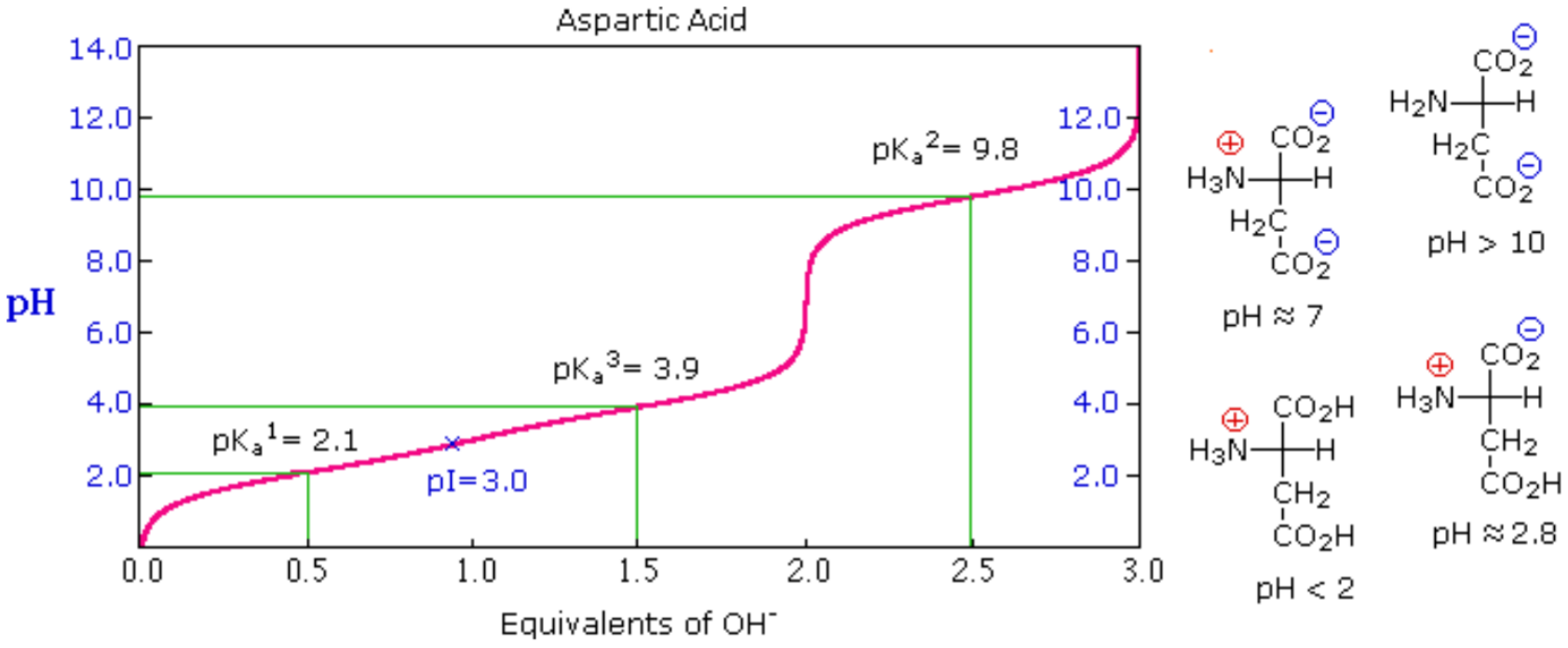
Titration of an Acidic Amino Acid



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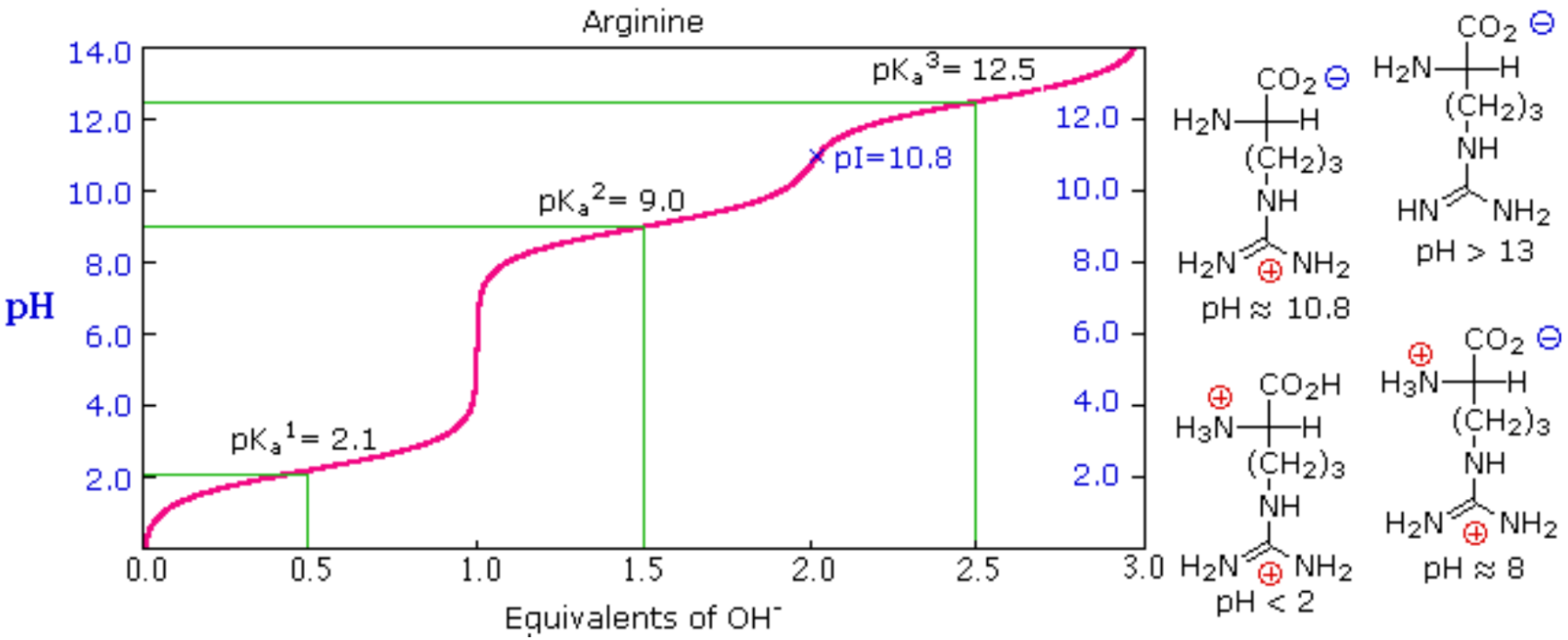
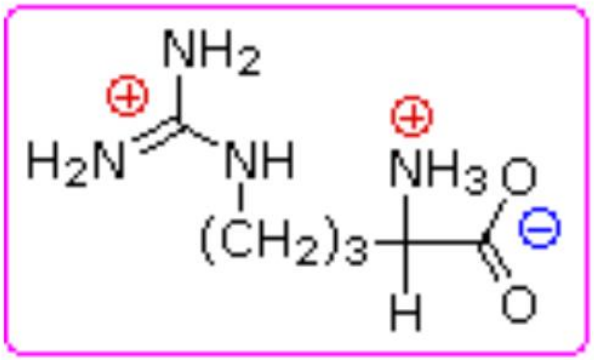
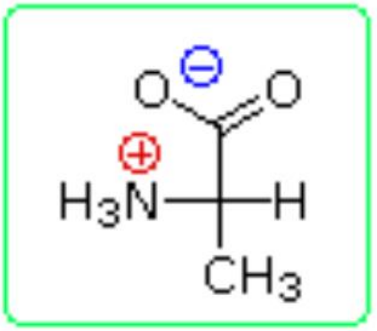
Titration of a Basic Amino Acid



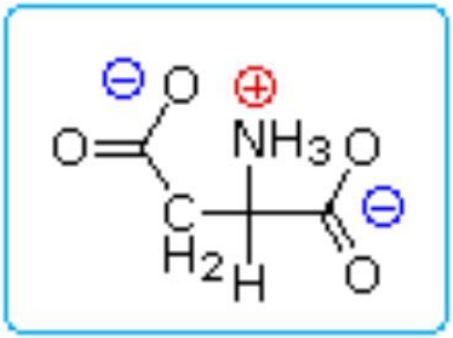
The pI of different amino acids



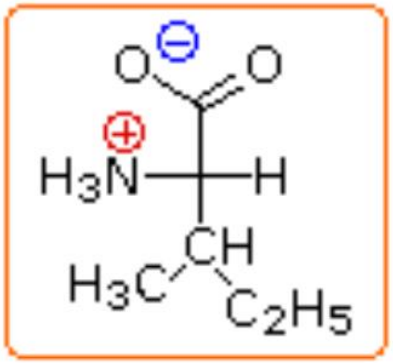
arginine pI=10.77



alanine pI=6.01



aspartic acid pI=2.80

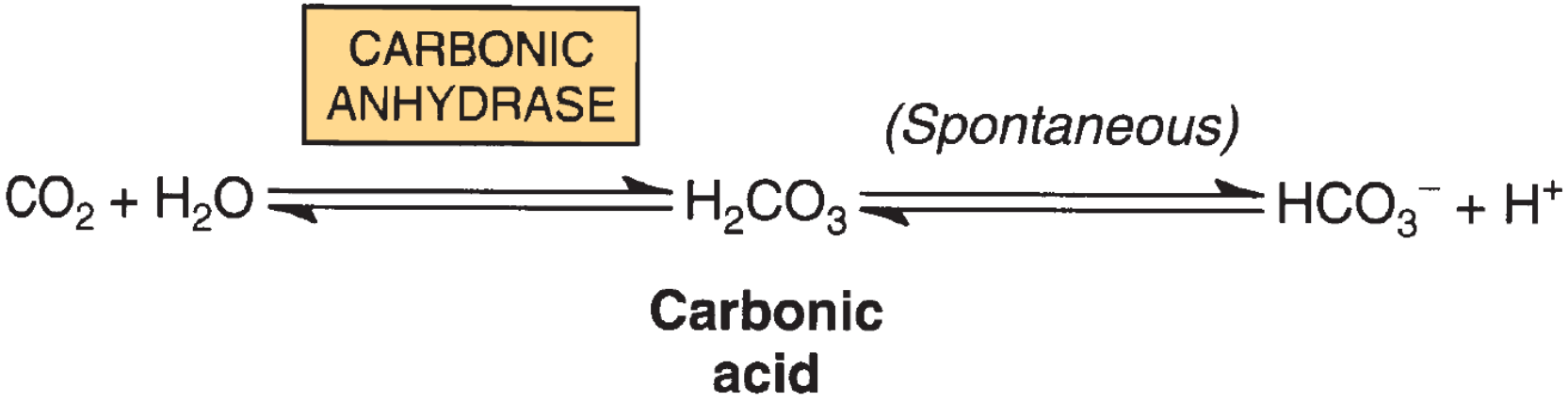


isoleucine pI=6.02

Main Biologic Buffers

1. Proteins: Albumin, Hb, Mb
2. Phosphate
3. Bicarbonate

Bicarbonate Buffer



$$\mathrm{pH} = \mathrm{pK}_a + \mathrm{Log}\frac{[\mathrm{HCO}_3^-]}{[\mathrm{H2CO}_3]}$$

$$pH = pK_a + \text{Log}\frac{[HCO_3^-]}{[PCO_2]}$$

سوال

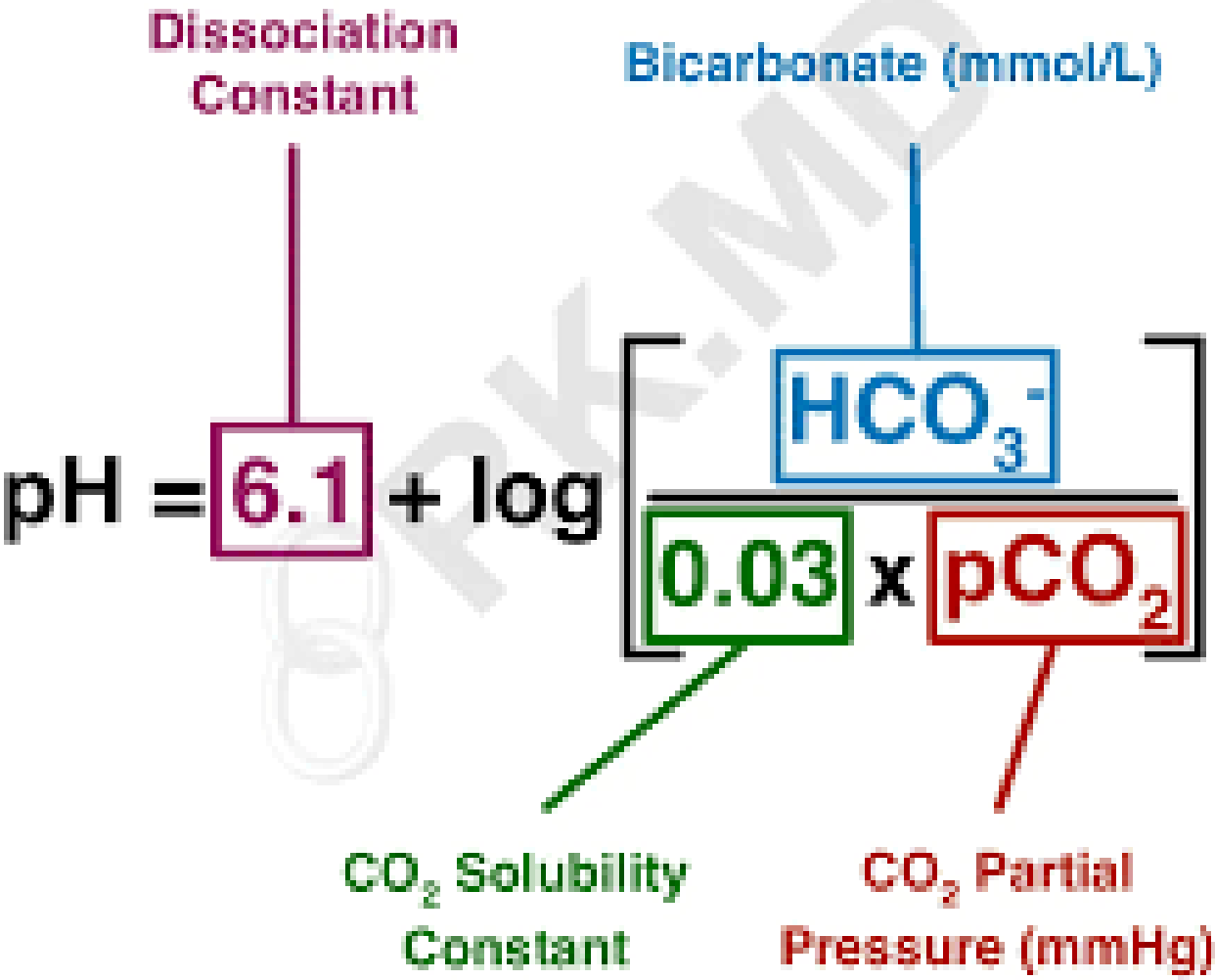
فشار گاز CO2 در خون یک بیمار 60 میلی متر جیوه و غلظت یون بیکربنات 24 میلی اکی والان گرم است.

1. pH خون چقدر است؟
2. آیا نیازی به درمان هست؟

راهنمایی

1. هر میلی متر جیوه از CO2 معادل 0.03 اکی والان گرم اسید کربنیک تولید می کند.
2. فشار CO2 در خون 40 میلی متر جیوه است.
3. Pk اسید کربنیک معادل 6.1 است.

HENDERSON-HASSELBALCH



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پاسخ: اسیدوز تنفسی

$$pH=6.1+1.1=7.2$$

$$pH = pK_a + Log \frac{[HCO_3^-]}{[PCO_2]}$$

Respiratory Acidosis

اسیدوز تنفسی	بیماری ریوی فلج عضلات تنفسی مصرف داروی خواب آور	کلیه: بازجذب بیکربنات تولید آمونیاک

$$pH = pK_a + \text{Log}\frac{[HCO_3^-]}{[PCO_2]}$$

Respiratory Alkalosis

آلکالوز تنفسی	هیپرونتیلاسیون افزایش تهویه ریوی	کلیه: دفع بیکربنات

$$pH = pK_a + Log \frac{[HCO_3^-]}{[PCO_2]}$$

Metabolic Acidosis

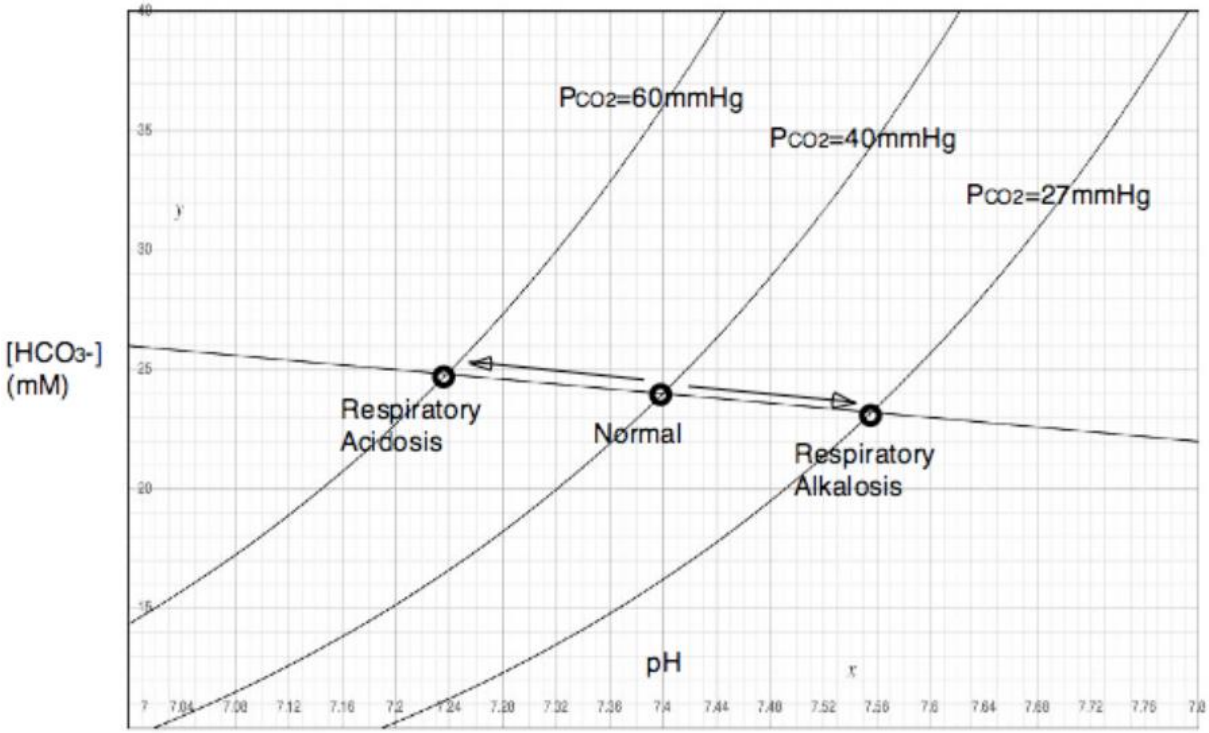
اسیدوز متابولیک	اسهال شدید کتواسیدوز اختلال کلیوی	ریه: دفع CO2 کلیه: دفع هیدروژن

$$pH = pK_a + \text{Log}\frac{[HCO_3^-]}{[PCO_2]}$$

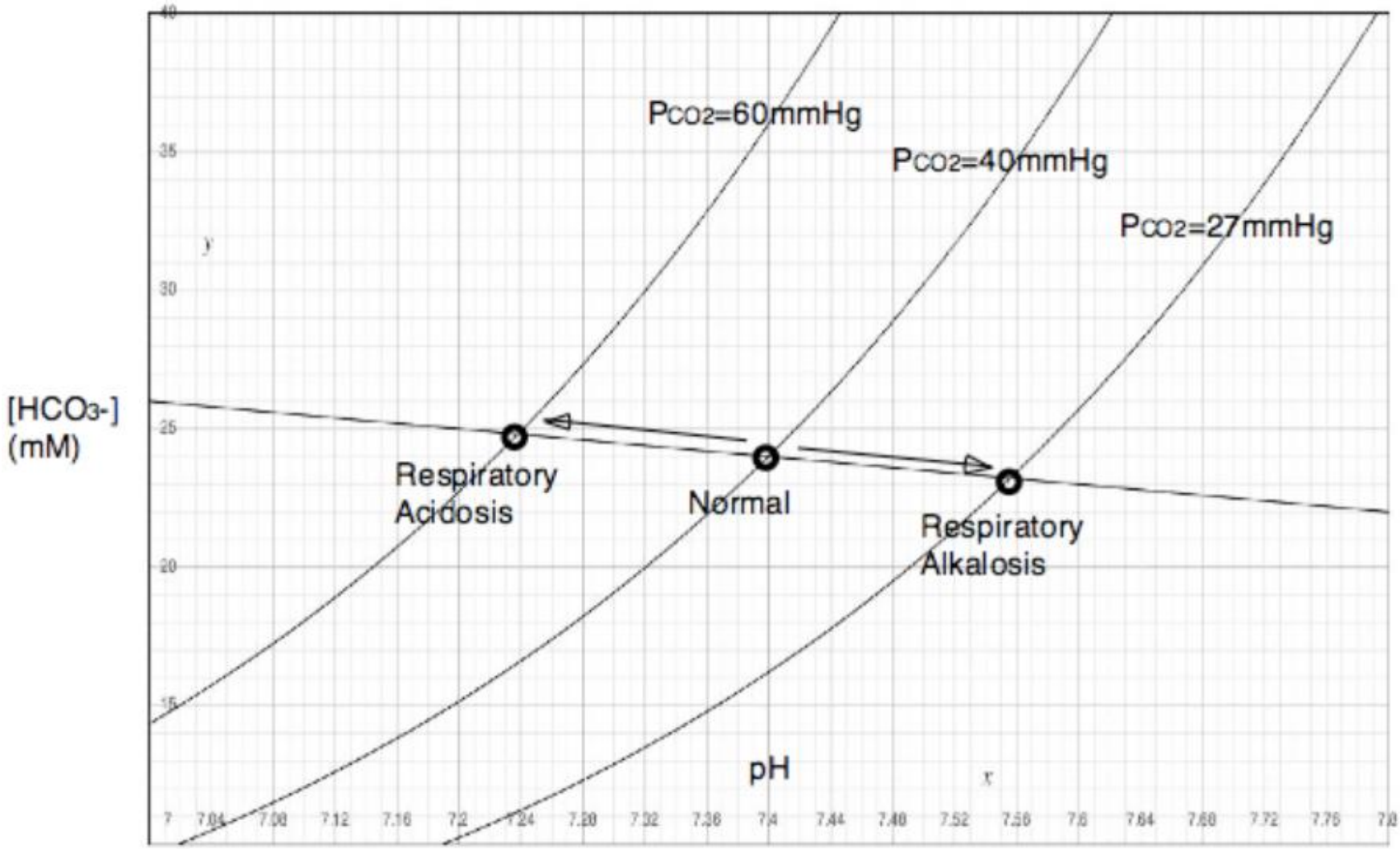
Metabolic Alkalosis

آلکالوز متابولیک	مصرف بیکربنات سدیم استفراغ دفع اسید ها از ادرار	ریه: کاهش تنفس کلیه: دفع بیکربنات

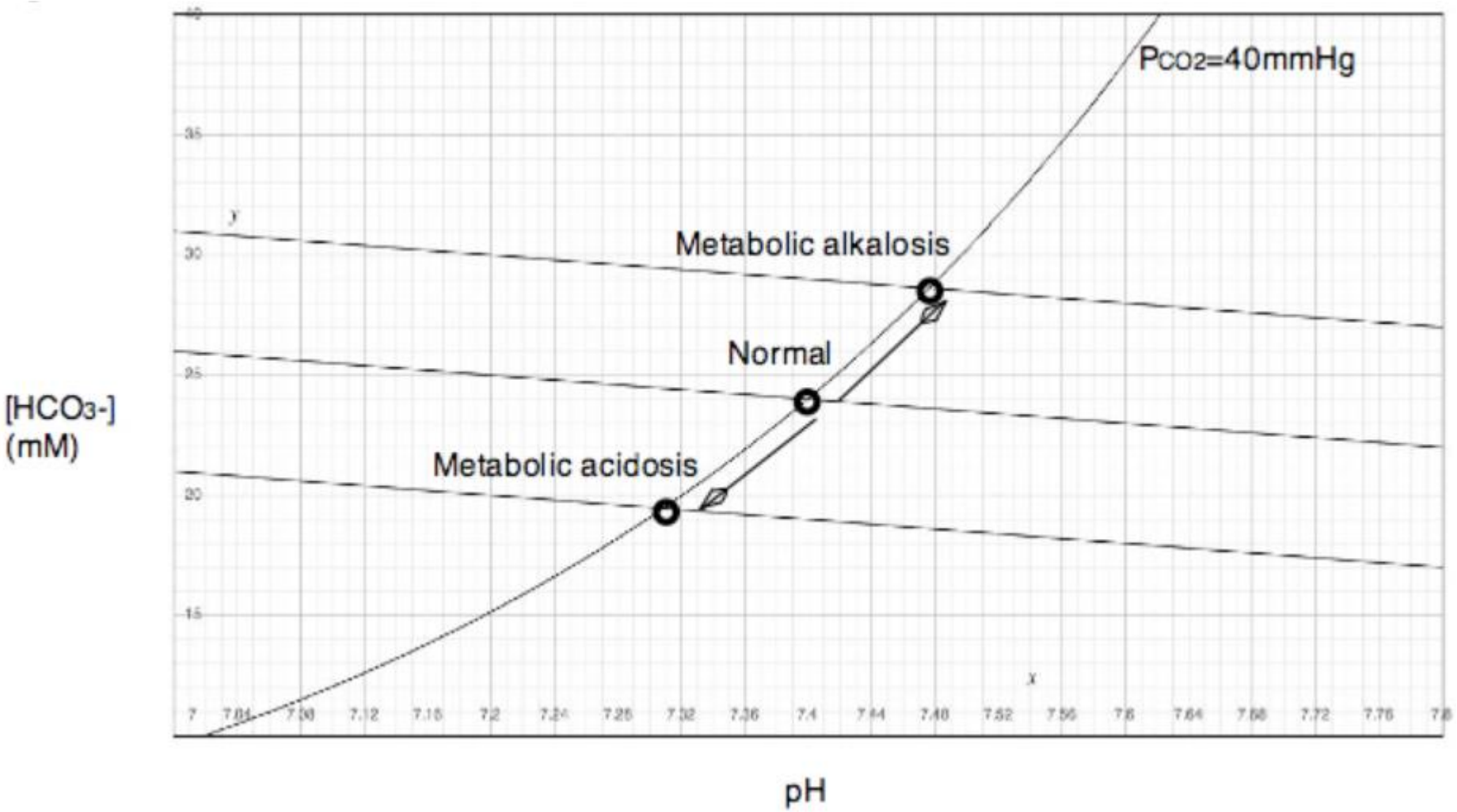
Respiratory Acidosis and Compensation (Davenport Diagram)



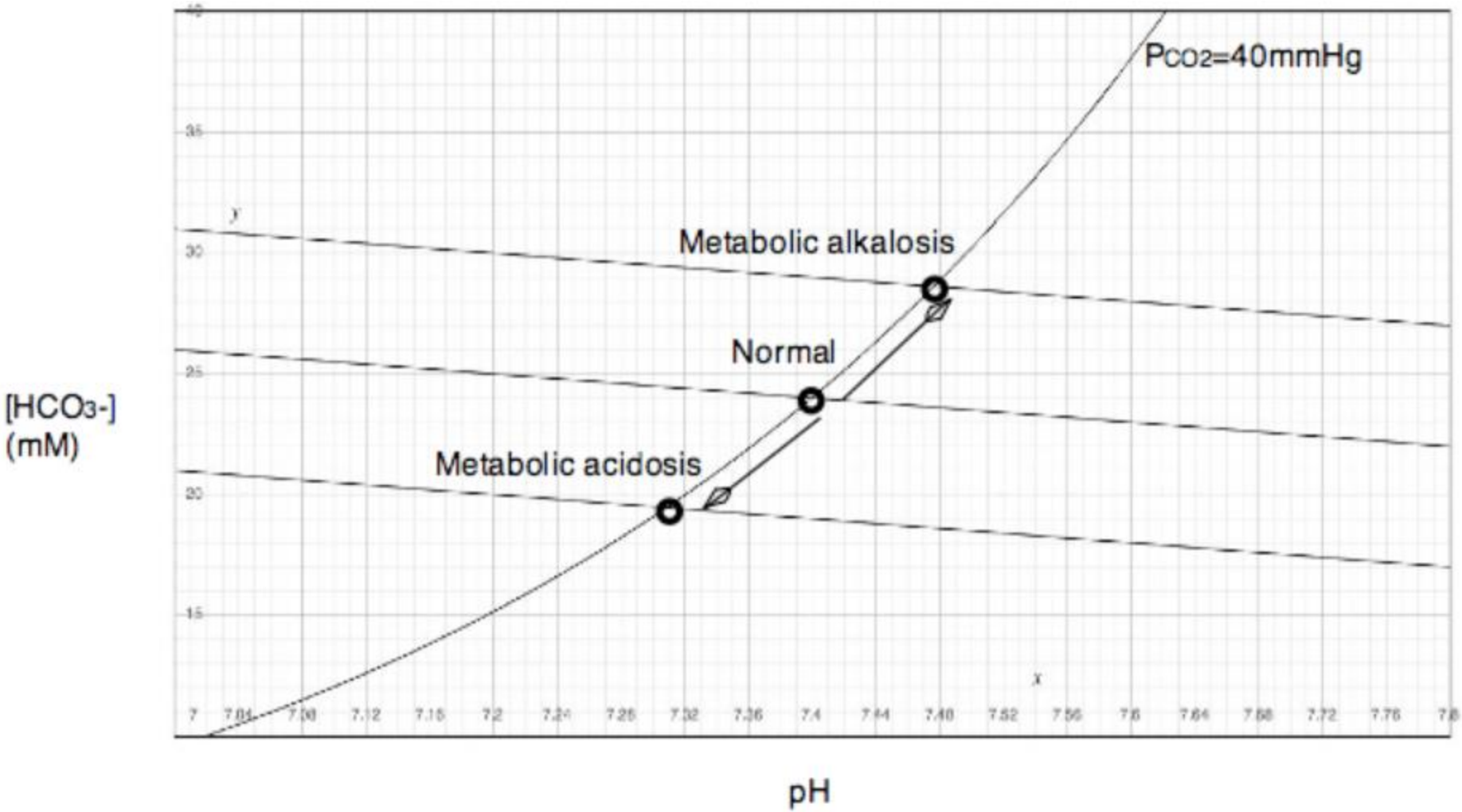
Respiratory Alkalosis



Metabolic Acidosis



Metabolic Alkalosis



AG or **AGAP**

Serum anion gap

$$(Na^+ + K^+) - (Cl^- + HCO_3^-)$$

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AG

$$(Na^{+}) - (Cl^{-} + HCO_3^{-}) = 20\ mEq/L$$

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References:

1. Murray R.K., Granner D.K., Rodwell V.W. Harper's Illustrated Biochemistry, 30th edition. McGraw Hill, 2015.
2. Author' articles: ncbi.nlm.nih.gov
3. https://en.wikipedia.org