Acid Base in ITU

"Life is a struggle, not against Sin, nor against Money nor Power .. but against Hydrogen ions."

H.L. MENCKEN

ACID BASE IN ITU - OUTLINE

- Why worry?
- Acid base - traditional methods
- Acid base - modern Stewart's physicochemical method
- Clinical examples

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Acid-base - why does it matter ?

Metabolic acidosis - base deficit > 5	
Cause	Risk of death
Increase of unmeasured anions *(lactate)*	Doubled
Hyperchloraemic acidosis	No change

"Base deficit does not predict mortality when secondary to hyperchloremic acidosis"

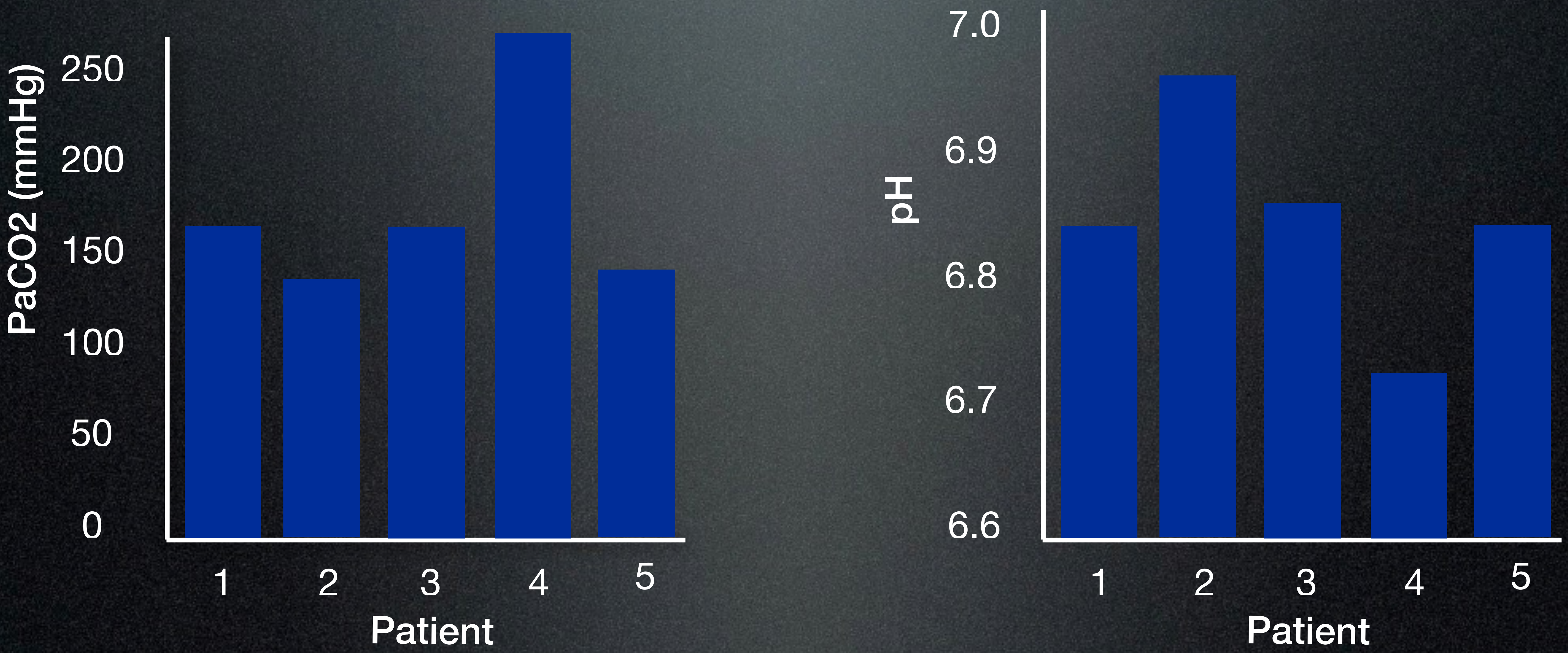
Shock Vol 17, No 6. pg 459-462, 2002

Consider [H+] disturbance as a symptom of an underlying disease

Acid-base - why does it matter ?

"Apneic oxygenation was carried for 15-55 minutes.

Severe respiratory acidosis (without anoxia) lasting > 30 minutes, can be well tolerated in normal subjects."



Frumin et al Anesthesiology 1959; 20:789-98

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Definitions

pH:

Quantification of [H+] expressed as a negative logarithm

Acidic:

A solution is acidic if $[H^+] > [OH^-]$

Basic:

A solution is basic if $[H^+] < [OH^-]$

Strong electrolyte:

Completely dissociates in water

No molecules of the parent compound are present.

Weak electrolyte:

Partially dissociates in water

Molecules of the parent compound and products of dissociation all exist together.

Traditional approaches to Acid-base

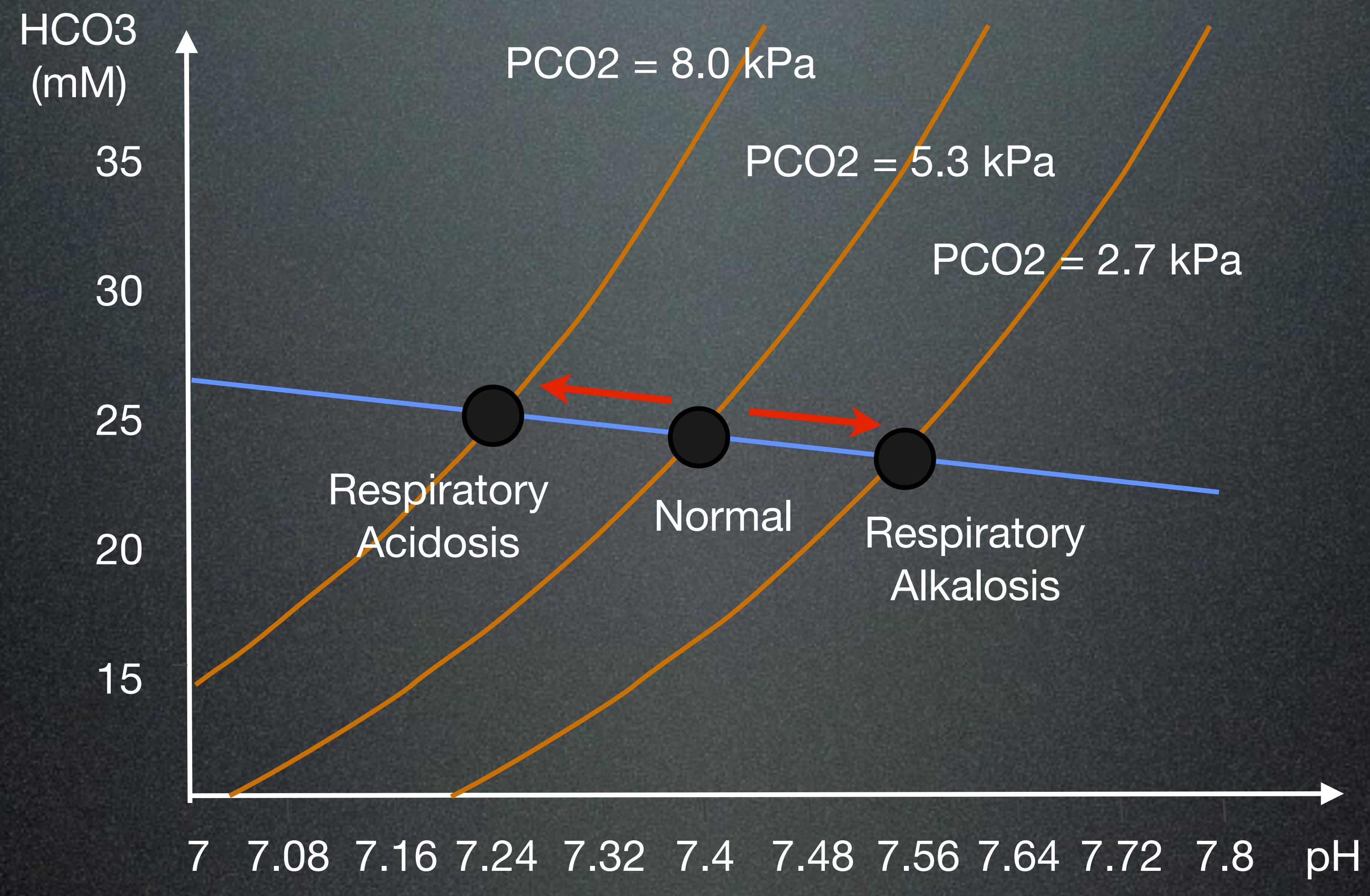
- “Bicarbonate centered”
- “Base deficit/excess” approach

Traditional approaches to Acid-base

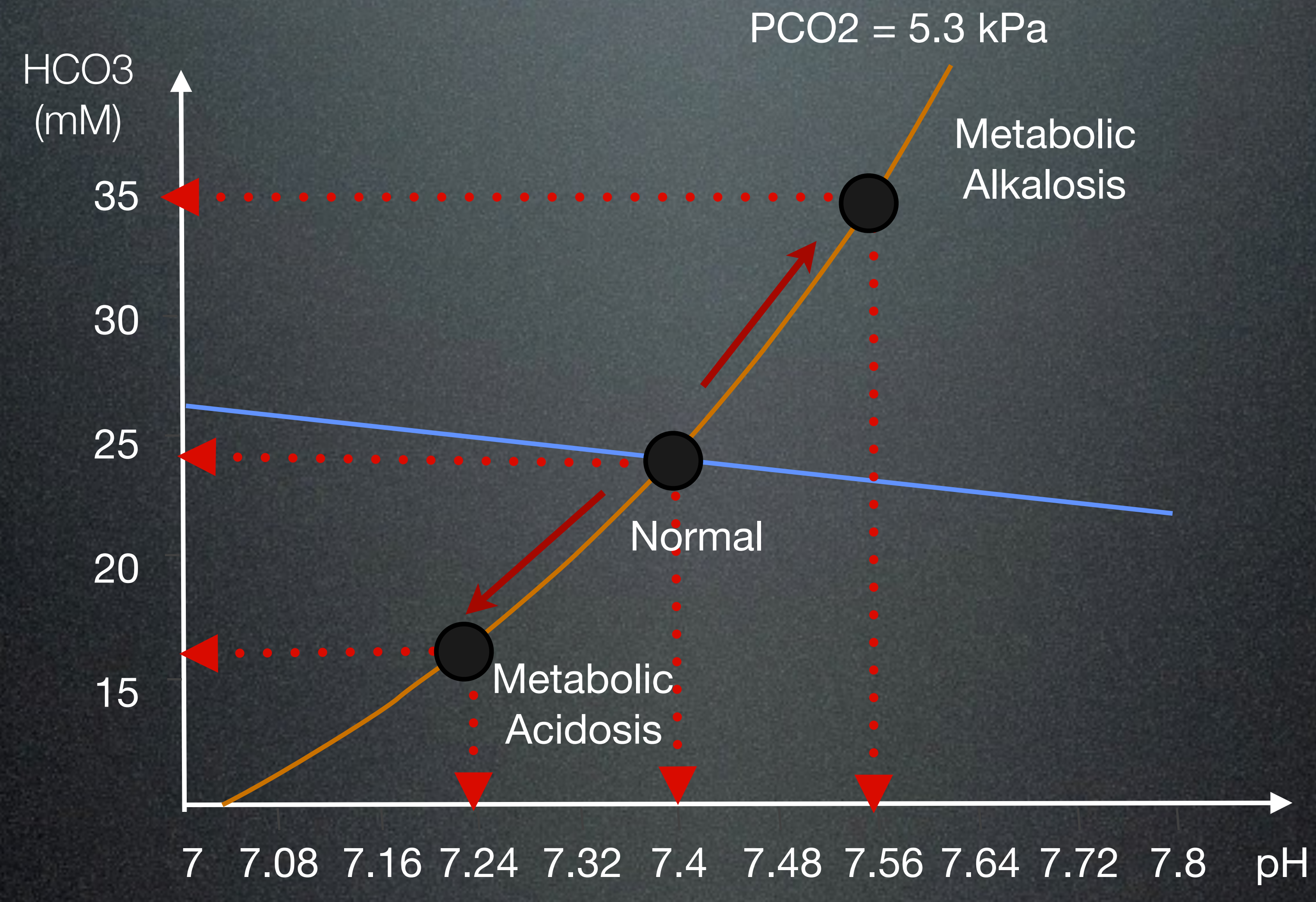
“Bicarbonate centered”

views the pH as a function of the concentration of bicarbonate and pCO2 (Henderson-Hasselbach)

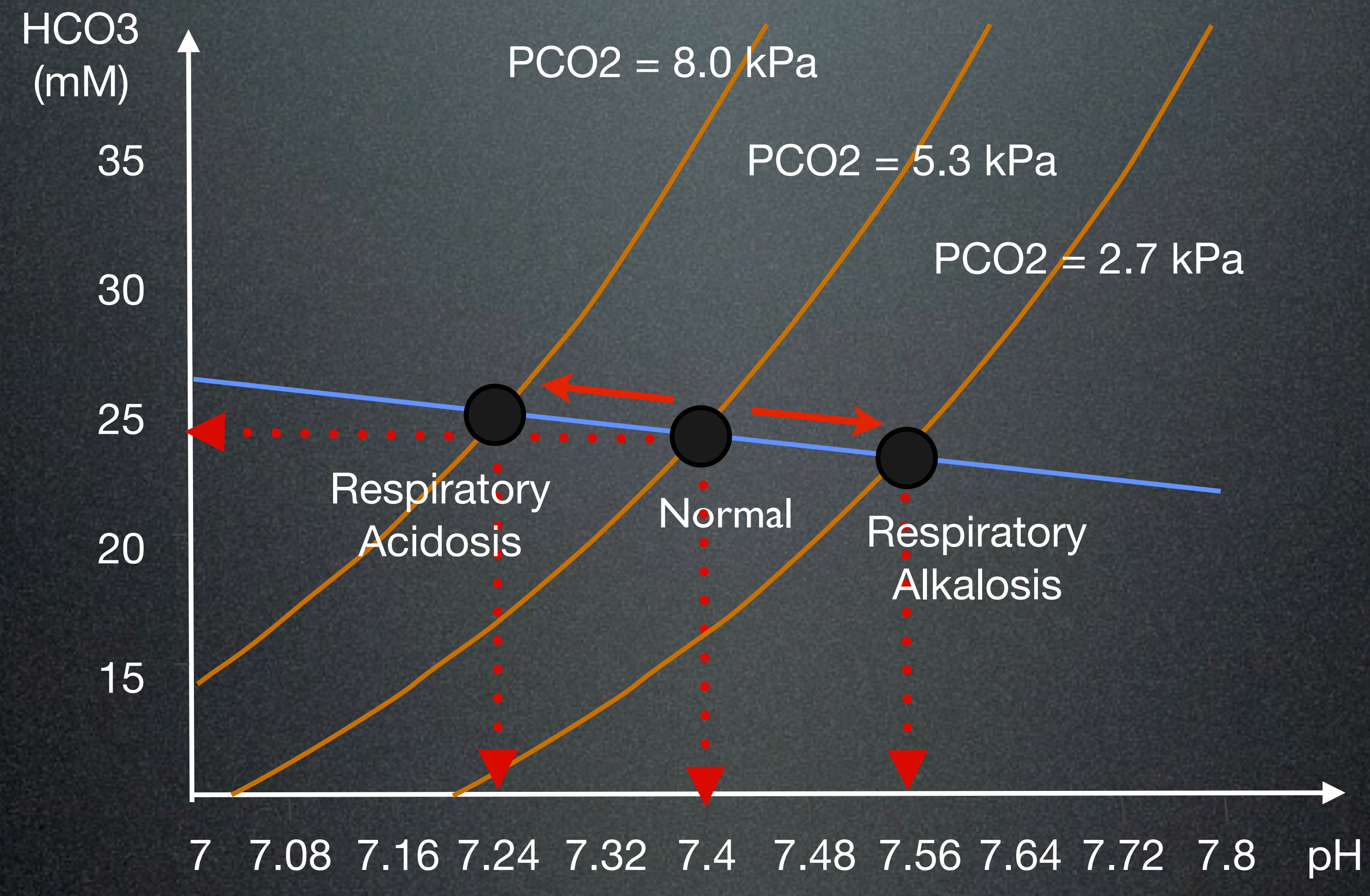
Davenport Diagram



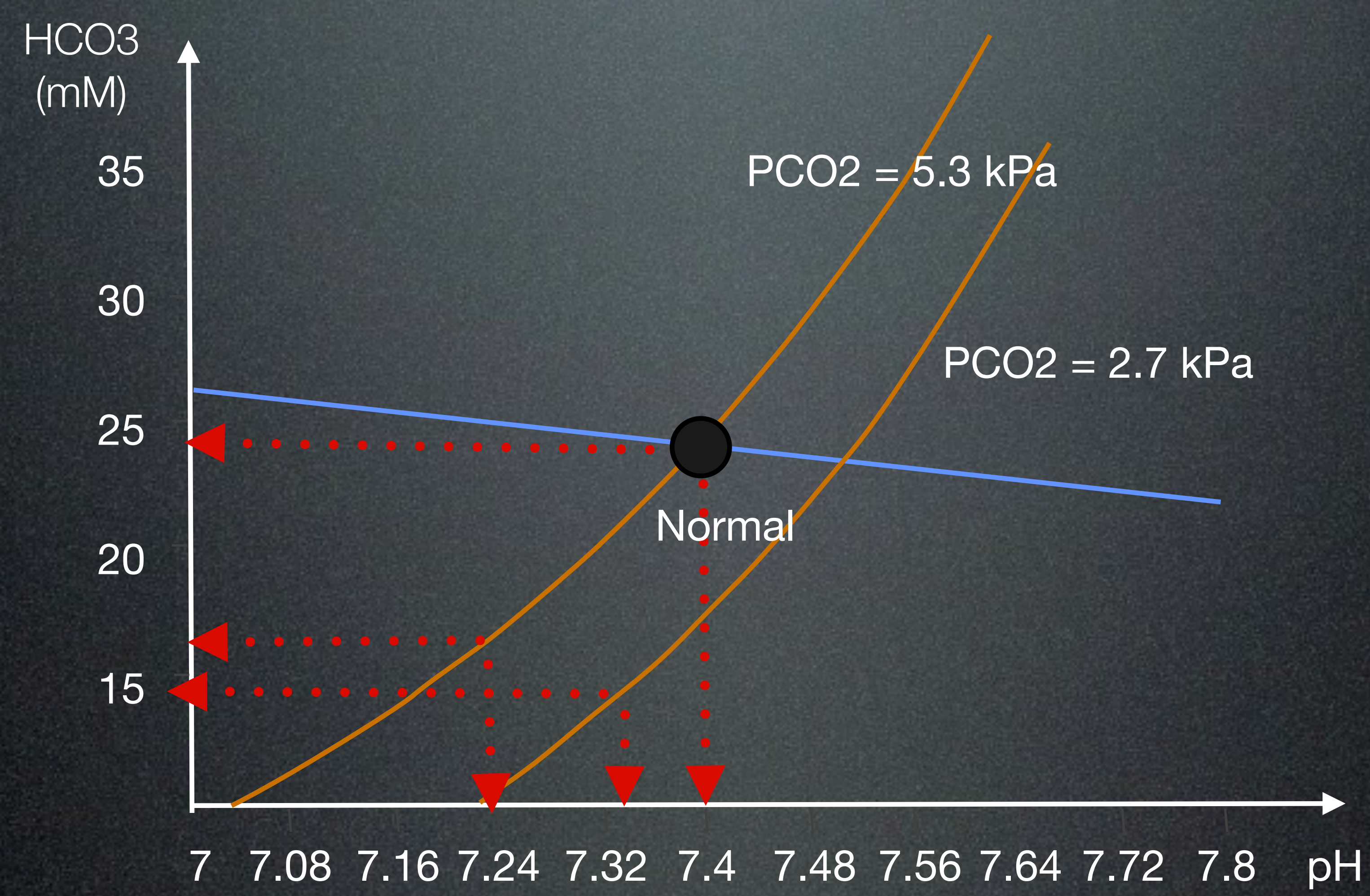
Metabolic acidosis / alkalosis



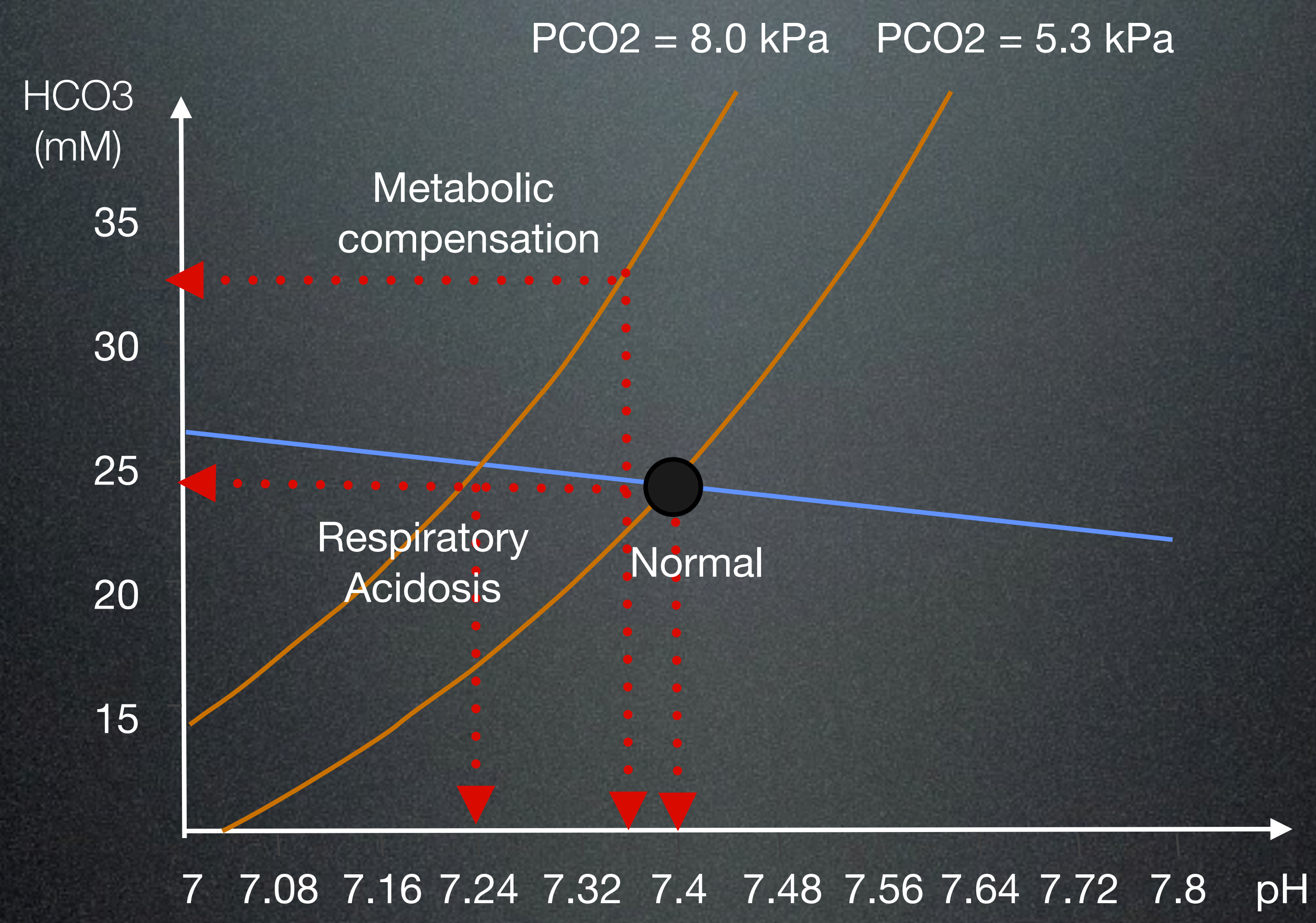
Respiratory acidosis / alkalosis



Respiratory compensation of metabolic acidosis



Metabolic compensation of respiratory acidosis



Traditional approaches to Acid-base

“Base deficit/excess” approach

(Sigaard-Andersen)

"Base deficit / excess" approach

Base deficit - amount of strong alkali required to return pH to 7.4

when pCO2 is normalised

Base deficit is an "average" of often <u>opposing influences</u>

it does not explain cause(s):

ex. ketones, hyperchloraemia, nor water excess/deficit.

Clinical Case

Multiple trauma, ARDS, Sepsis

pO2	14.5
pH	7.32
pCO2	5.5
HCO_3^-	21
Base deficit	4

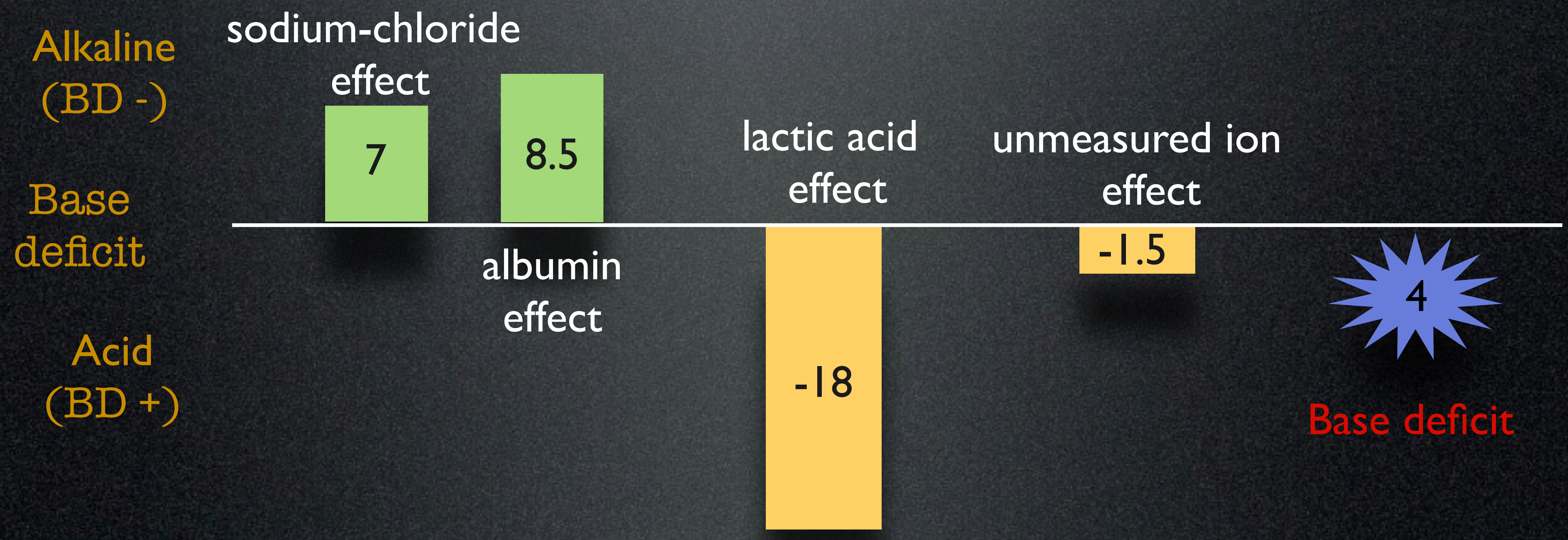
Diagnosis ?

Clinical Case

Multiple trauma, ARDS, sepsis

pH	**7.32**	Na^+	**131**
pCO2	**5.5**	Cl^-	**86**
HCO_3^-	**21**	Albumin (g/L)	**8**
Base deficit	**4**	Lactic acid	**18**

the severity of the acidosis is greatly underestimated



Both traditional approaches were derived from large populations of patients and abstracted “back” to produce nomograms

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Inductive reasoning

“Data trawling”

Problems with traditional approaches

Clinicians struggle with acid-base because traditional methods do not teach **understanding** of the underlying biophysical chemistry.

- Little quantitative data on patient's acid base status
- Protein and electrolytes ⇒ not considered
- No diagnostic information

Major disturbances may be "hidden" within normal ABGs.

Problems with traditional approaches

BJA

Strong ion and weak acid analysis in severe preeclampsia: potential clinical significance†

"…in critically ill patients simultaneous acid/base derangements may offset each other and ultimately lead to a minimally deranged pH, HCO3, BE and AG "

"A quantitative physicochemical approach analyses the difference in strong plasma cations and anions, the concentration of weak acids (mainly albumin and phosphate), and the PC02."

"multiple severe acid-base disorders have been demonstrated in various disease processes, despite normal pH and BE. "

British Journal of Anaesthesia 115 (2): 275–84 (2015)

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Stewart's physicochemical approach

Considers the physical chemistry of :

- pure water
  - add strong ions
    - add weak acid
      - add CO_2

Uses sound **deductive** mathematical reasoning

Acid-base - Let's get some perspective

Compared to $[Na^+]$, $[Cl^-]$

$[H^+]$ is orders of magnitude smaller

1 L Plasma contains :

$[H^+]$ - 40 nano Moles/L (=pH 7.40)

$[Na^+]$ - 140,000,000 nano Moles/L - 140 mMol/L

$[H_20]$ - 55.000,000,000 nano Moles/L - 55 Mol/L

"biological impact of [H+] is out of all proportion to it's magnitude"

Stewart

Fundamental Principles

Conservation of mass:

The amount of substance in an aqueous solution remains constant (unless added or removed from outside)

The product of $[H^+]$ and $[OH^-]$ is **constant**

an increase in one leads to a decrease in the other

Electroneutrality:

An aqueous solution contains the **same** number of negative and positive charges

.......otherwise we would become a battery!

All acid-base states result from water and its dissociation

$$[H_20] \rightleftarrows [H^+] + [OH^-]$$

$$Kw \times [H_20] = [H^+] \times [OH^-]$$

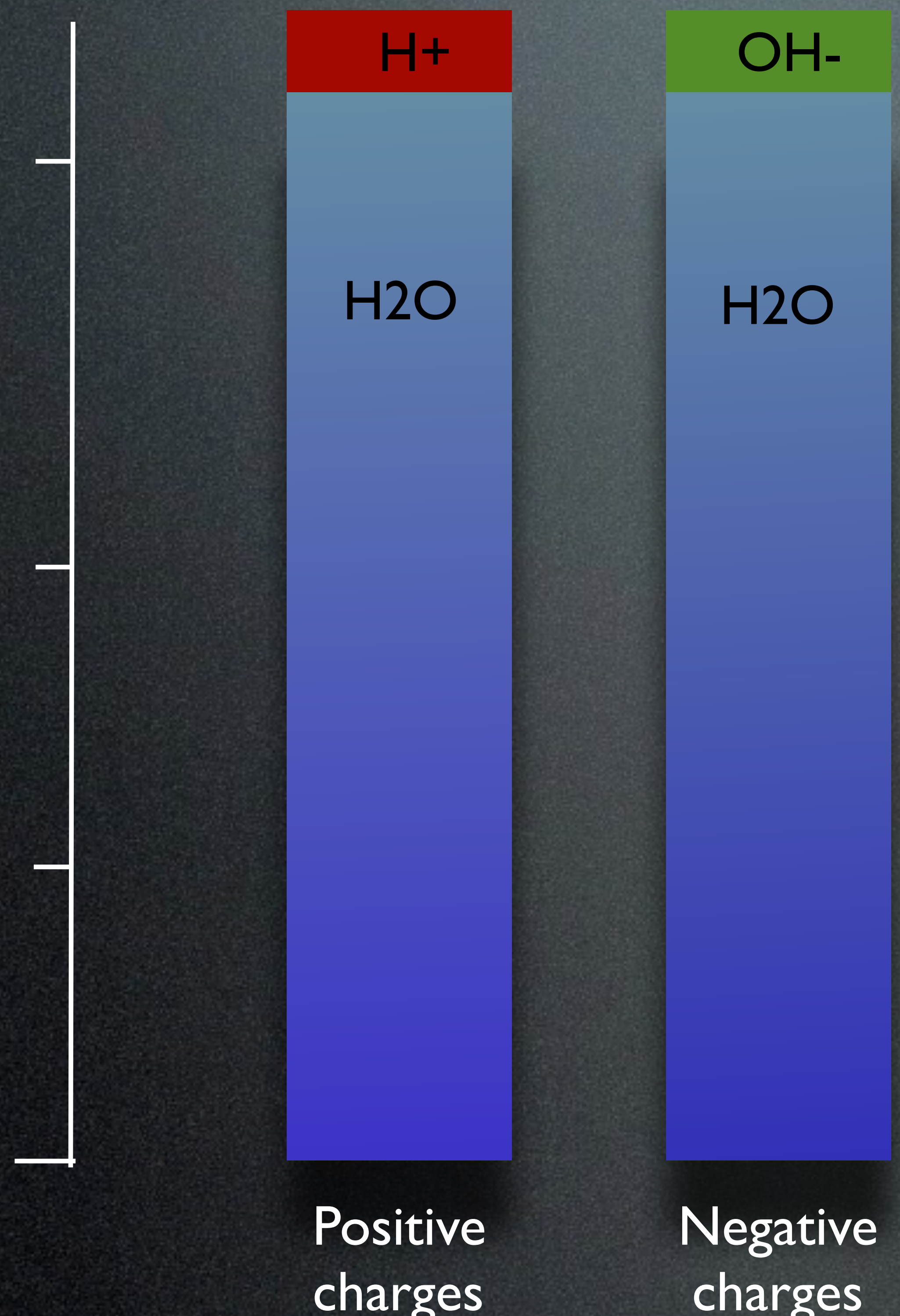
$$constant = [H^+] \times [OH^-]$$

Electric **neutrality** must be maintained

[H+] and [OH-] adjust to outside influences

<u>Independent</u> variables control acid base by influencing water dissociation

All acid-base states result from alterations in the **dissociation** of water



$$H_20 \rightleftarrows [H^+] + [OH^-]$$

$$Kw \times [H_20] = [H^+] \times [OH^-]$$

Electric **neutrality** must be maintained, so:

$$[H^+] = [OH^-]$$

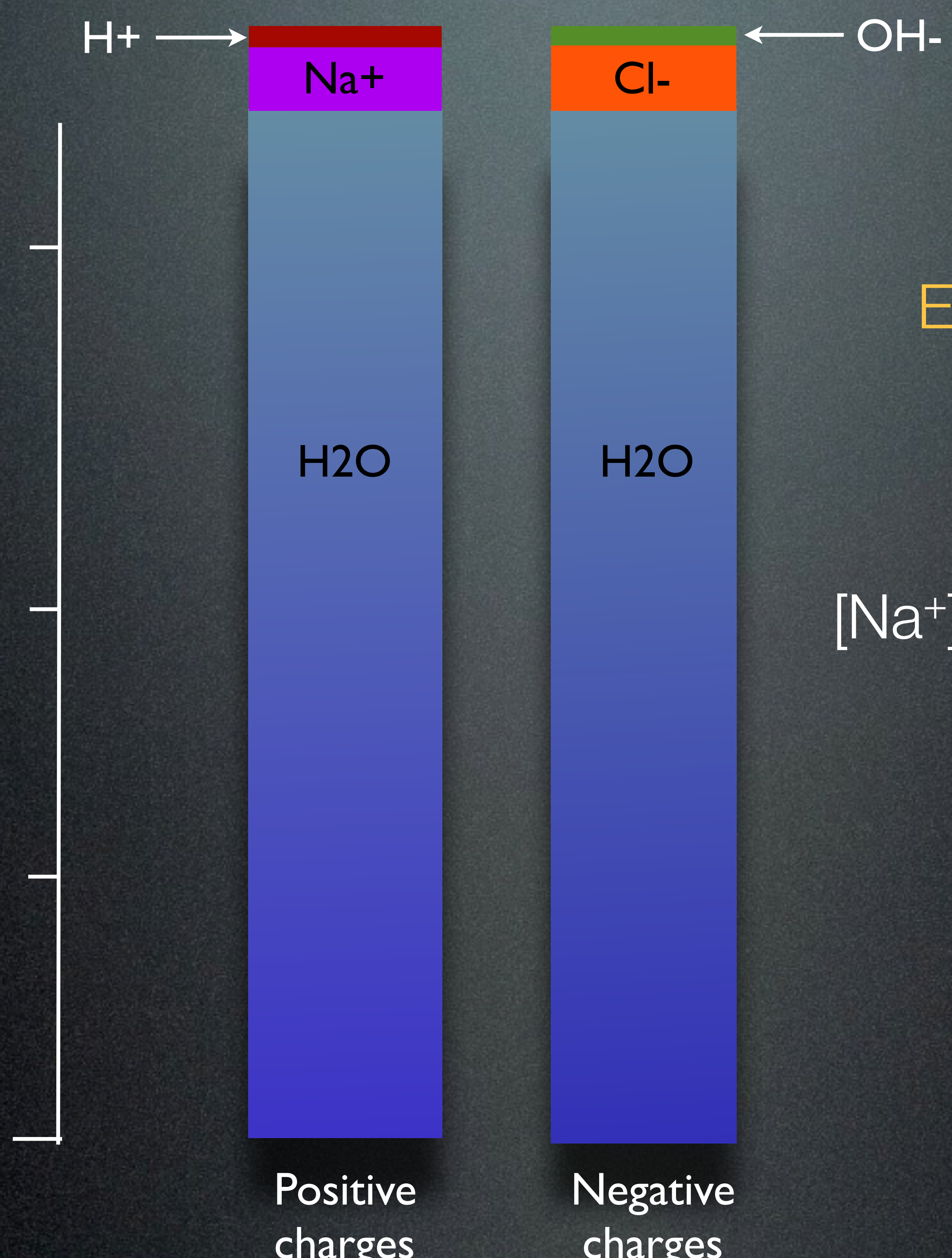
Pure Water

Solution	Temp	K'w	$[H^+]$	pH
Pure water	25°	1.0×10^{-14} (Eq/L)	1.0×10^{-7} (Eq/L)	7
Pure water	37°	4.4×10^{-14} (Eq/L)	2.1×10^{-7} (Eq/L)	6.7
Plasma	37°	-	40 nM/L	7.4

Physiological pH for ECF is 7.4, which is **alkaline**.

Conventionally we refer to relative acidity/alkalinity from this starting point

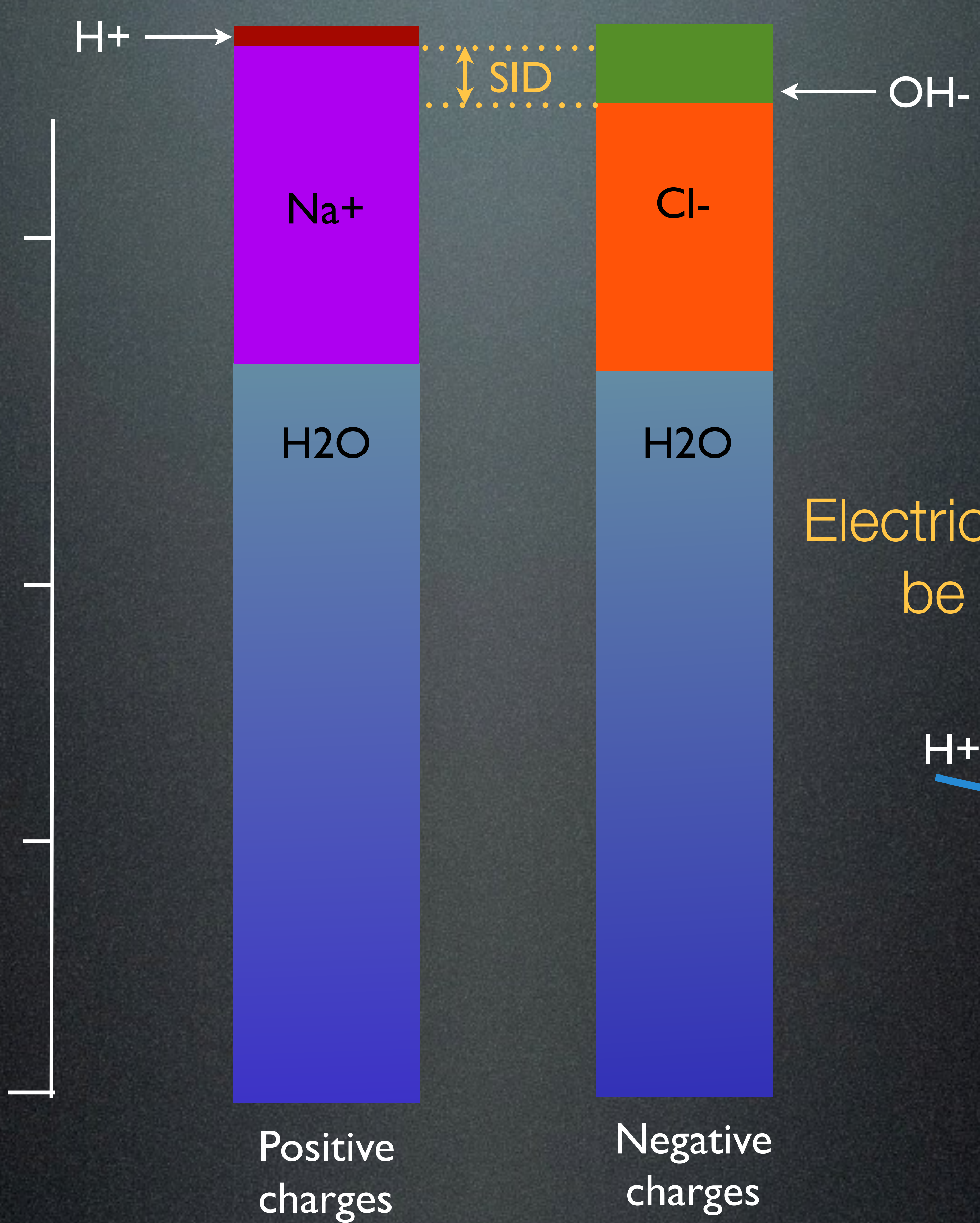
Add NaCl - a **fully dissociated** strong ion



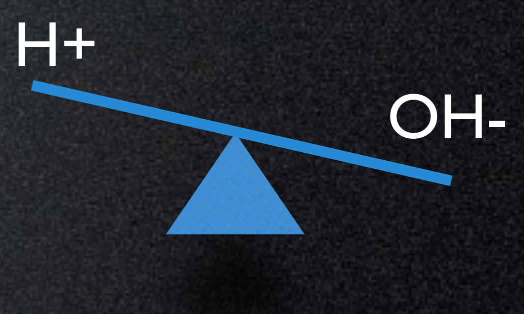
Electric neutrality must be maintained

$$[Na^+] + [H^+] = [Cl^-] + [OH^-]$$

Biological fluids - $[Na^+] > [Cl^-]$



Electric neutrality must be maintained, so :

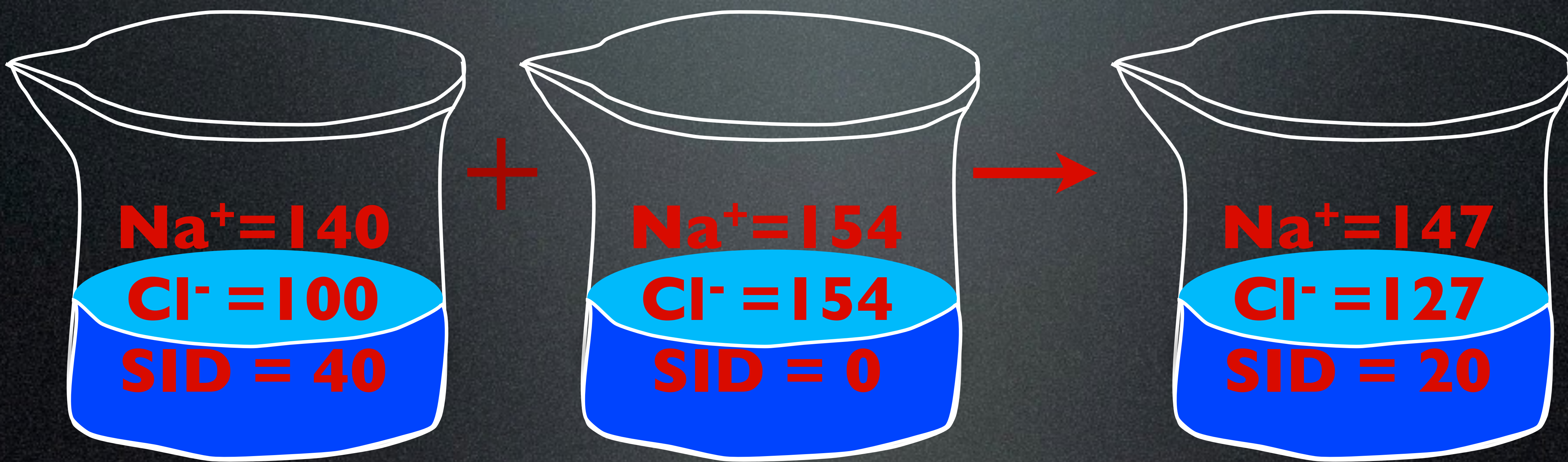


Strong Ion Difference

- Normal SID ⇒ ~ 40
- <u>Decreased</u> SID ⇒ <u>acidosis</u>
  - Hyperchloraemic acidosis
    - large volumes of saline
  - Free water excess
    - G5%, mannitol, alcohols
- <u>Increased</u> SID ⇒ <u>alkalosis</u>
  - Chloride loss
    - Diuretics
    - Gastric suctioning
  - Free water deficit

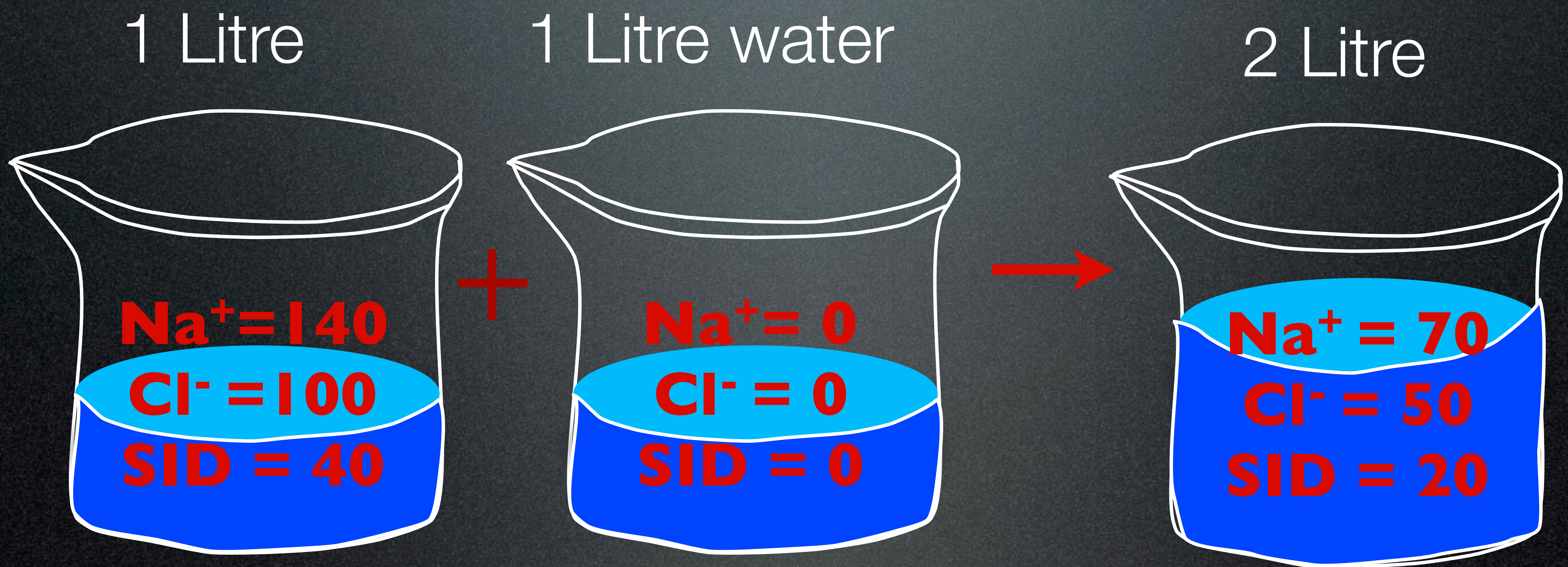
Strong ion difference after adding saline to ECF

1 Litre ECF　　1 Litre saline　　1 Litre ECF



Hyperchloraemic acidosis

Strong ion difference after adding water to ECF



Strong ion difference affected by:

- Sodium bicarbonate
  - makes solution alkaline by adding [Na^+] without accompanying strong anion

    ⇒ increased SID

    ⇒ alkalotic

- KCl
  - If wish to acidify, KCl adds [Cl^-] without K^+ (goes intracellular)

    ⇒ decreased SID

    ⇒ acidotic

Clinical Case

Severe asthma

pH	**6.75**	pCO2	**22**
$HCO3^-$	**21**	Base deficit	**0.9**
Na^+	**144**	Cl^-	**106**
Albumin (g/L)	**37**		

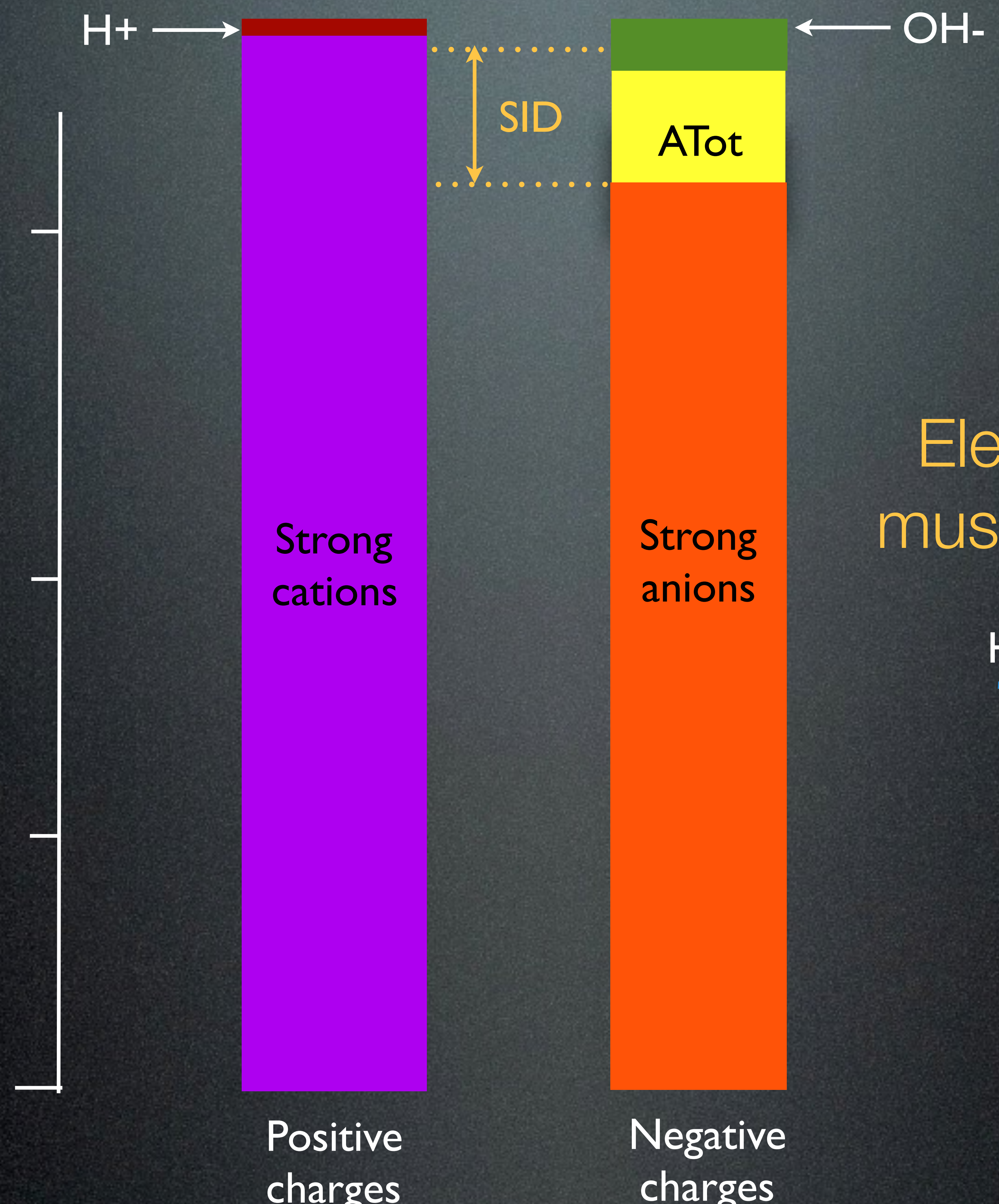
200 mls NaBicarb 8.4%

pH	**6.84**	pCO2	**Unrecordable**
$HCO3^-$	**Unrecordable**	Base deficit	**0.9**

Frusemide 10 mg/hr ⇒ 200 mL/hr

pH	**7.23**	pCO2	**10.13**
$HCO3^-$	**24**	Base deficit	**1**

Add weak acid



Electric neutrality must be maintained

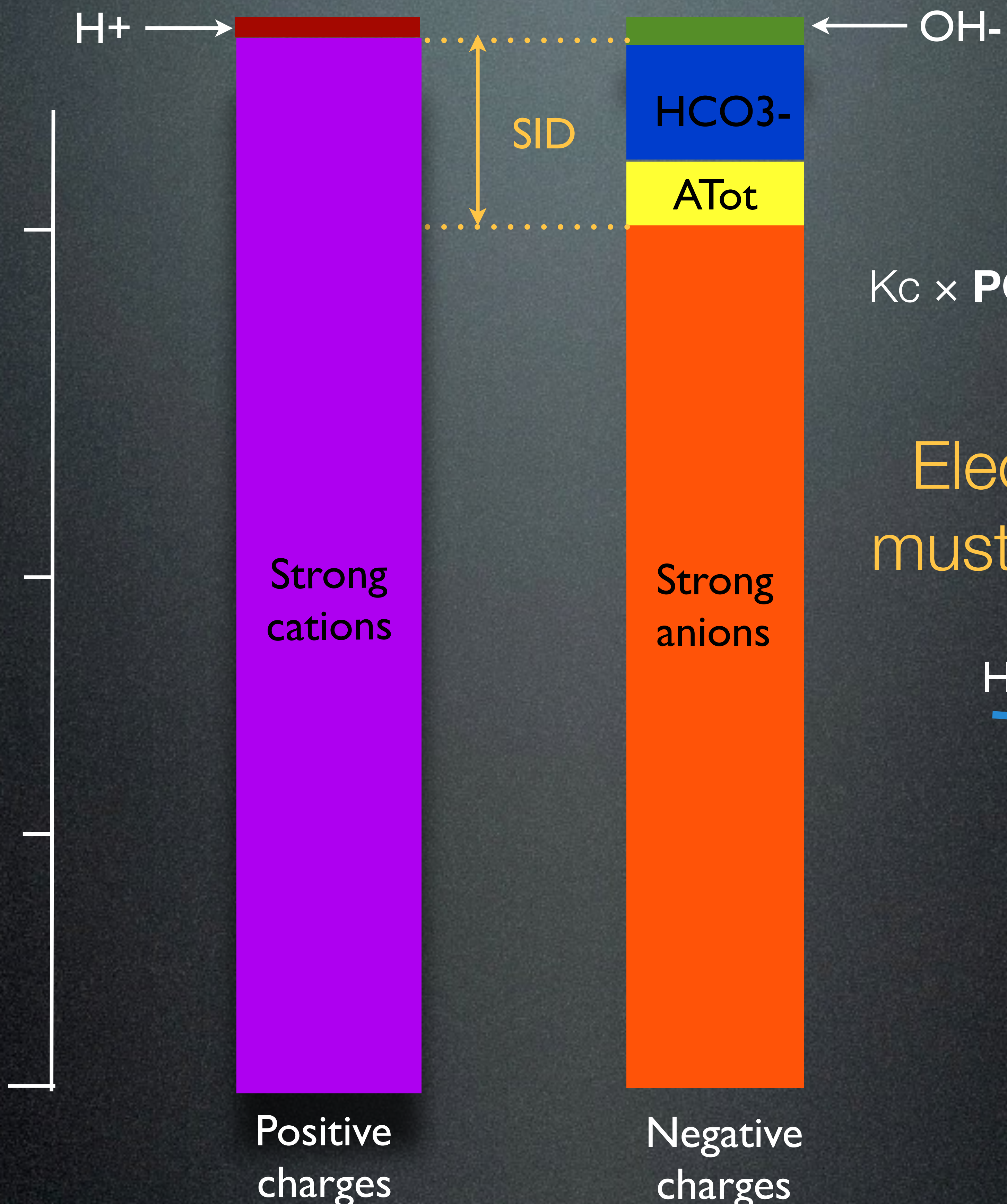
Weak anions (= "ATot")

- Decreased ATot ⇒ alkalosis
  - Hypoalbuminaemia

    Common in the critically ill
  - Hypophosphataemia

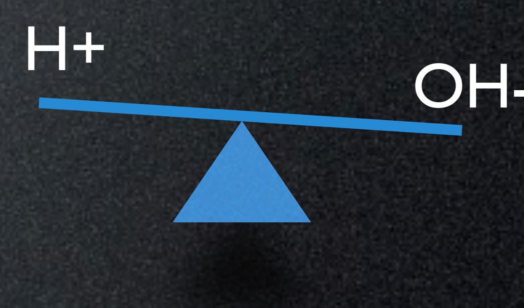
- Increased ATot ⇒ acidosis
  - Hyperphosphataemia

Add CO2



$K_C \times \mathbf{PCO2} \rightleftarrows [H^+] \times [HCO_3^-]$

Electric neutrality must be maintained



CO_2

- CO_2 (independent variable) $\Rightarrow$ $[HCO_3^-]$ (dependent)
- Increased pCO_2 $\Rightarrow$ Respiratory acidosis
- Decreased pCO_2 $\Rightarrow$ Respiratory alkalosis
- Metabolic acidosis $\Rightarrow$ respiratory compensation

  $\Delta\ pCO_2 = \Delta$ base excess/deficit

- Metabolic alkalosis $\Rightarrow$ respiratory compensation

  $\Delta\ pCO_2 = 0.6 \times \Delta$ base excess/deficit

- **Care** if metabolic acidosis and IPPV $\Rightarrow$

  must **hyperventilate** to compensate

3 **Independent** variables determining acid base status

- Strong Ion Difference
- Weak Anions
- pCO_2

Other variables are <u>dependent</u>

(ex. pH, $[H^+]$, $[HCO_3^-]$)

To calculate using Stewart's method

you need to answer the following polynomial equations:

water dissociation : $[H^+] \times [OH^-] = K'w$

weak acid dissociation : $[H^+] \times [A^-] \rightleftarrows Ka \times [HA]$

weak acid conservation of mass : $[ATot] = [H^+] + [A^-]$

bicarbonate ion formation equilibrium : $[H^+] \times [HCO_3^-] = Kc \times PCO2$

carbonate ion formation equilibrium : $[H^+] \times [CO_3^{2-}] = K_3 \times [HCO_3^-]$

electric neutrality : $([SID] + [H^+]) – ([HCO_3^-] – [A^-] – [CO_3^{2-}] – [OH^-]) = 0$

$\downarrow$

$[SID] + [H^+] - Kc \times PCO2/[H^+] - Ka - [ATot] / (Ka + [H^+]) - K_3 \times Kc\ PCO2/[H^+]^2 - K'w/[H^+] = 0$

Or ....

Simplified approach to Stewart Derivation

Four variables are determined:

(1) standard **base deficit** from a blood gas machine

(2) **sodium-chloride effect (SID)** = ($[Na^+]$ - $[Cl^-]$) - 40

(3) **albumin** effect = 0.25 X [42- albumin]

(4) **lactic** acid = measured lactate

(5) **unmeasured ion** effect

= base deficit - (sodium-chloride effect) - albumin effect- lactate

Quantifies the metabolic effects of Stewart's independent variables.

British Journal of Anaesthesia 92 (1): 54±60 (2004)

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Clinical Case

Multiple trauma, ARDS, Sepsis

pH	7.32	pCO2	5.5
HCO_3^-	21	Base deficit	4
Na^+	133	Cl^-	86
Albumin (g/L)	8	Lactate	18

the severity of the acidosis is greatly underestimated

(1) standard base deficit = 4

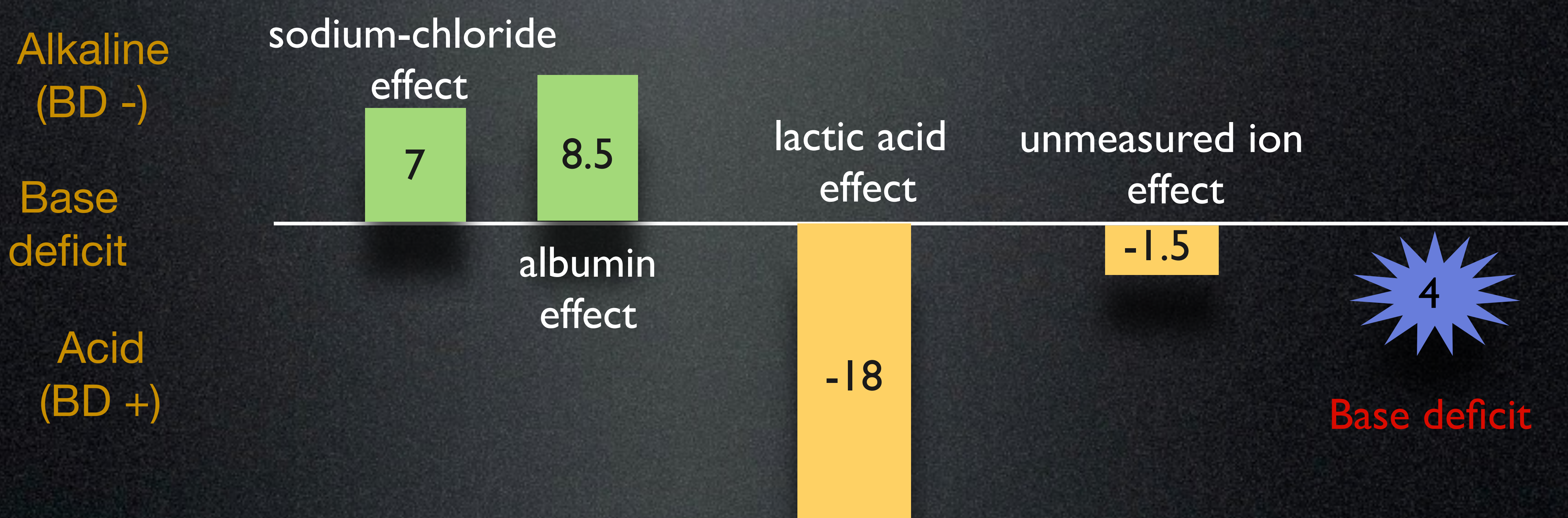
(2) sodium-chloride effect = $([Na^+] - [Cl^-]) - 40 = (133-86) - 40 = 7$

(3) albumin effect = $0.25 \times [42 - \text{albumin}] = 0.25 \times [42 - 8] = 8.5$

(4) lactic acid effect = -18

(5) unmeasured ion effect

= *base deficit - (sodium-chloride effect) - albumin effect - lactate = -4 - (7) - 8.5 - (-18) = -1.5*



Clinical Case

Assessment of a patient 2 hours post operatively. Patient was given 4 l of normal saline.

pH	7.28	pCO2	5.3
HCO_3^-	21	Base deficit	6.7
Na^+	144	Cl^-	115
Albumin (g/L)	28	Lactate	0.8

Explained by a decrease in the strong ion difference, partly offset by a decrease in total albumin.

(1) standard base deficit = 6.7

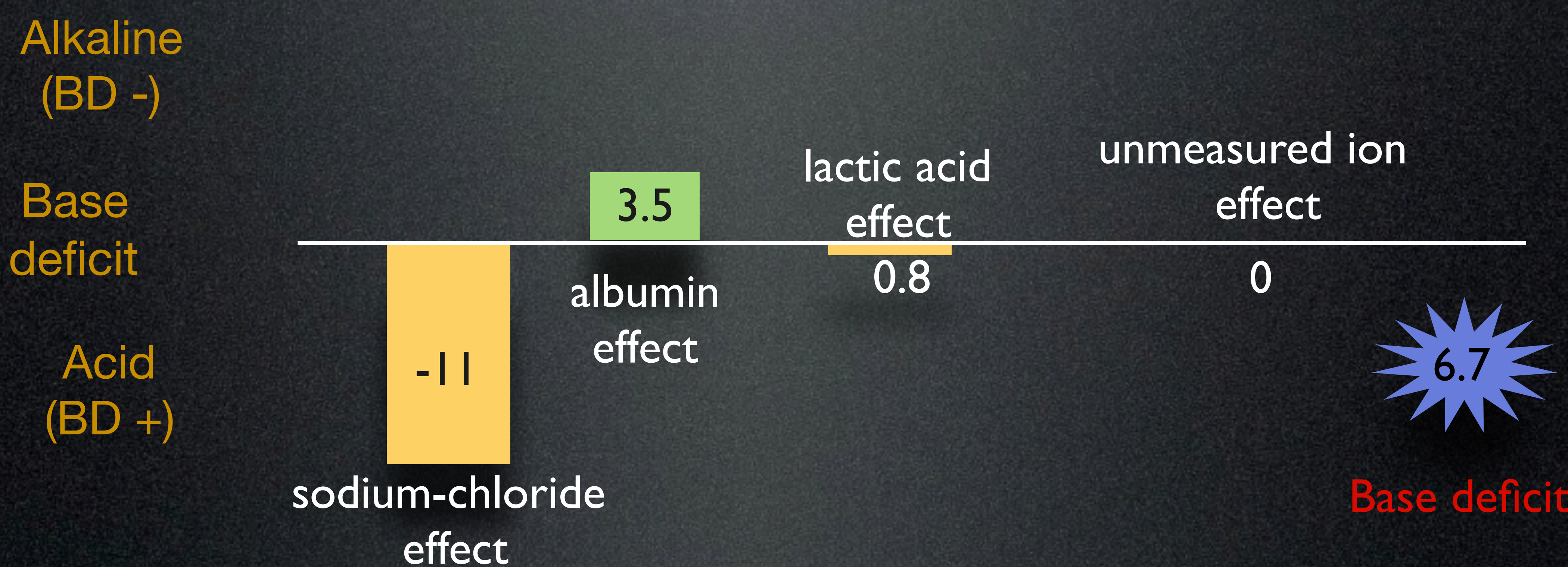
(2) sodium-chloride effect = ($[Na^+]$ - $[Cl^-]$) - 40 = (144-115) - 40 = -11

(3) albumin effect = 0.25 X [42- albumin] = 0.25 X [42 - 28] = 3.5

(4) lactic acid effect = 0.8

(5) unmeasured ion effect = 0

= base deficit - (sodium-chloride effect) - albumin effect - lactate = - 6.7 - (-11) - 3.5 - (-0.8) = 0



Clinical Case

52 yr old man with acute pancreatitis after fluid resuscitation with saline.

pH	7.205	pCO2	3.47
HCO_3^-	10	Base deficit	16
Na^+	142	Cl^-	112
Albumin (g/L)	28	Lactate	1.0

Explained by a decrease in the strong ion difference and unmeasured anions, partly offset by a decrease in total albumin.

(1) standard base deficit = 16

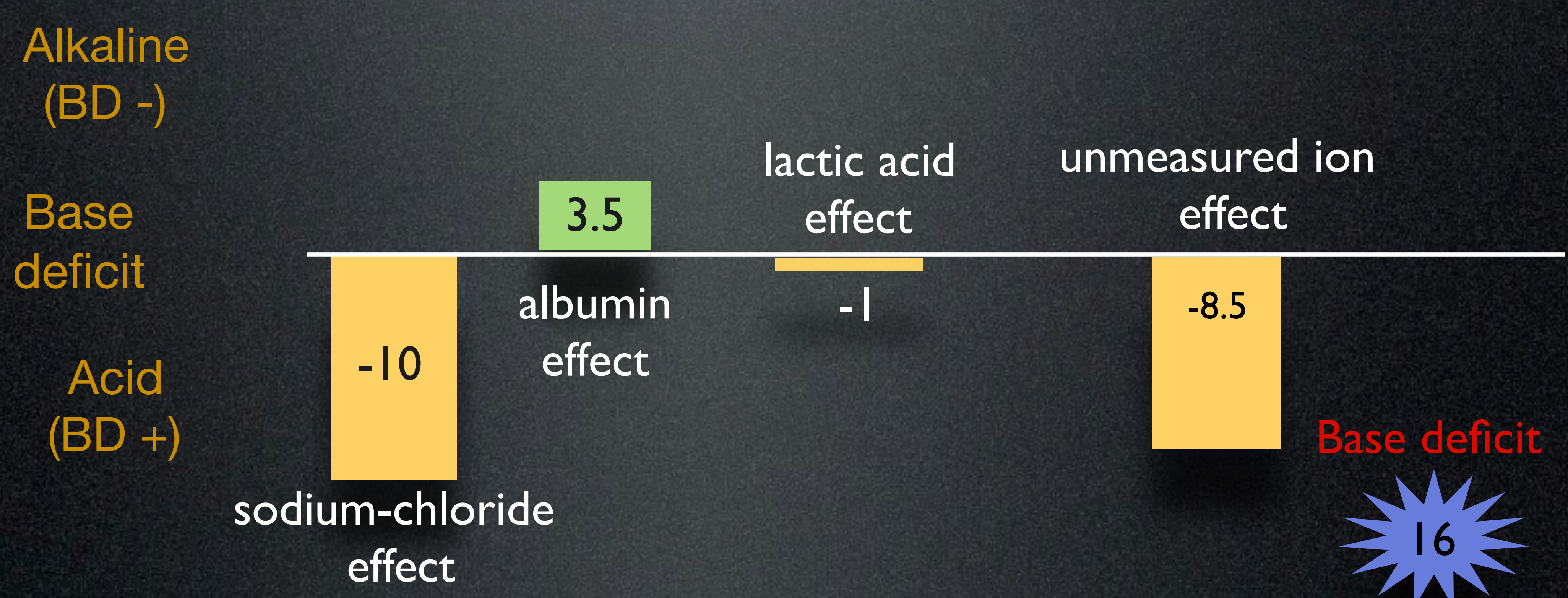
(2) sodium-chloride effect = ($[Na^+]$ - $[Cl^-]$) - 40 = (142-112) - 40 = -10

(3) albumin effect = 0.25 X [42- albumin] = 0.25 X [42 - 28] = 3.5

(4) lactic acid effect = 1.0

(5) unmeasured ion effect = -1

= base deficit - (sodium-chloride effect) - albumin effect - lactate = -16 - (-10) - 3.5 -(-1.0) = -8.5



Clinical Case

Postoperative multiple organ failure

pH	7.40	pCO2	5.2
HCO_3^-	24	Base deficit	0
Na^+	139	Cl^-	102
Albumin (g/L)	6	Lactate	5

This acidosis is exactly matched by the alkalinizing hypoalbuminemia, so that both BD and [HCO3-] are within normal limits; a severe metabolic acidosis is missed

(1) standard base deficit = 0

(2) sodium-chloride effect = ($[Na^+]$ - $[Cl^-]$) - 40 = (139-102) - 40 = -3

(3) albumin effect = 0.25 X [42- albumin] = 0.25 X [42 - 6] = 9

(4) lactic acid effect = measured lactate = -5

(5) unmeasured ion effect

= base deficit - (sodium-chloride effect) - albumin effect - lactate = 0 - (-3) - 9 -(-5)= - 1

Clinical Case

Liver cirrhosis, bleeding varices

pH	7.4	pCO_2	5.2
HCO_3^-	24	Base deficit	0
Na^+	127	Cl^-	94
Albumin (g/L)	13	lactate	0

This low-SID acidosis is exactly matched by hypoalbuminemic alkalosis. BD and [HCO3-] are normal.

Both traditional diagnostic approaches miss this metabolic acidosis.

(1) standard base excess -> 0

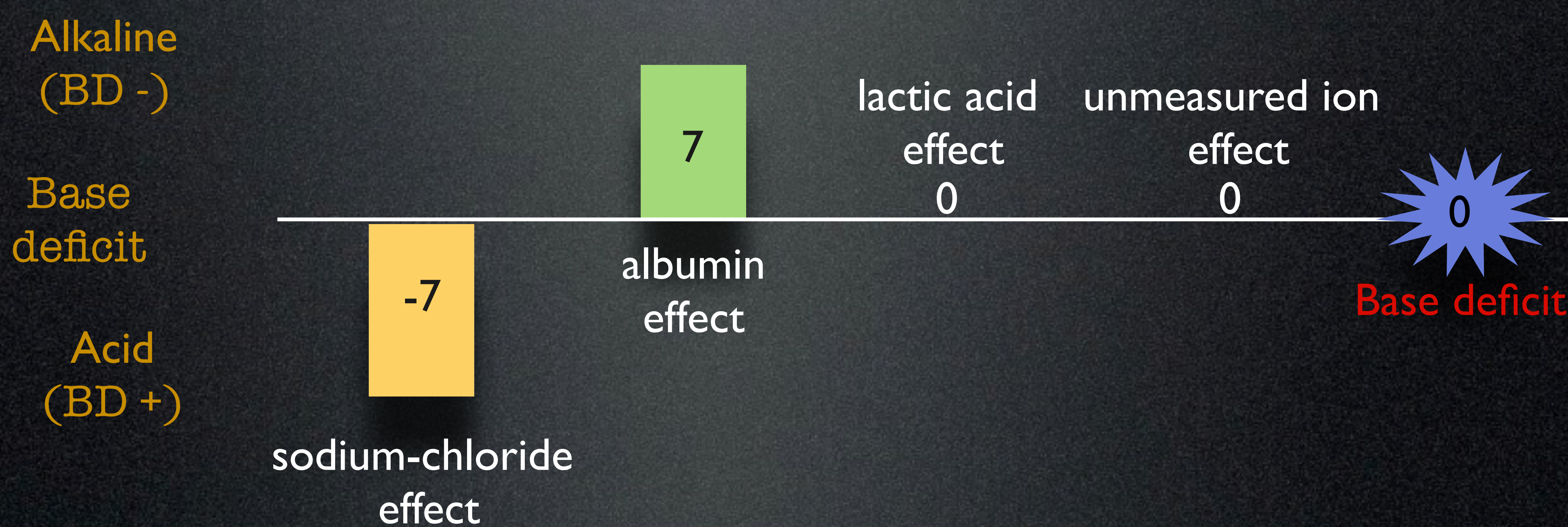
(2) sodium-chloride effect = $([Na^+] - [Cl^-]) - 40 = (127 - 94) - 40 = -7$

(3) albumin effect = $0.25 \times [42 - \text{albumin}] = 0.25 \times [42 - 13] = 7$

(4) lactic acid effect = 0

(5) unmeasured ion effect

= *base deficit - (sodium-chloride effect) - albumin effect - lactate= 0 - (-7) - 7 - 0 = 0*



Recap - Stewart’s model

- Alterations in the **dissociation of water** lead to all acid-base abnormalities
- **3 independent** variables affect acid-base balance
    - Strong ion difference (SID)
    - Weak acids (ATOT)
    - $PaCO_2$
- Metabolic **acidosis** is caused by:
    - Decreased SID
        - accumulation of metabolic anions
        - free water excess
    - Increased ATOT
- Metabolic **alkalosis** is caused by :
    - SID increases
    - Decreased ATOT (ex. hypoalbuminemia)

Did you know........

Some interesting facts

- Control of acid base

  Lungs ⇒ CO_2 (~17,000 mEq/day)

  Kidney ⇒ Cl (~60 mEq/day)

  Liver ⇒ Albumin

- Kidney maintains ECF's SID ⇒ $[Cl^-]$ excretion (accompanied by NH_4^+)

  Diuretics ⇒ alkalosis (chloride loss) ⇒ increased SID

- $NaHCO_3$ corrects acidosis by supplying only $[Na^+]$

  ⇒ increasing SID (not $[HCO_3^-]$ a dependent variable)

- Saline (SID = 0) ⇒ hyperchloremic metabolic acidosis
  - Its not the absolute value of chloride
  - it's the <u>strong ion</u> <u>difference</u> between Na and Cl

- Hypotonic NaCl solutions (SID = 0) ⇒ acidosis

- Water (SID=0) ⇒also acidosis

Some interesting facts

- What can the body use to regulate H^+
  - Na^+ must be kept **constant** to regulate volume
  - **Proteins** concentration is important for oncotic pressure
- **pCO2** can be altered for **rapid** adjustment
- **Cl^-** can be altered for **longer** term changes

Thus Cl^- is the major factor for long term Acid Base regulation

Conclusions

- Cause of acid base disturbance influences prognosis
- Uncomplicated cases ⇒ traditional methods
- In complex cases ⇒ Stewarts method
- Acid-base determined by independent variables acting on water dissociation
- **Independent** variables
    - Strong ion difference
    - Weak anions (albumin)
    - CO_2
- pH, $[H^+]$, $[HCO_3^-]$, are **dependent** variables

???

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http://www.jvsmedicscorner.com

(Mallory / Everest2013)