ACID-BASE

Jon Palmer

Chief, Neonatal Intensive Care Service

Director of Neonatal and Perinatal Programs

New Bolton Center, University of Pennsylvania

Acid-Base

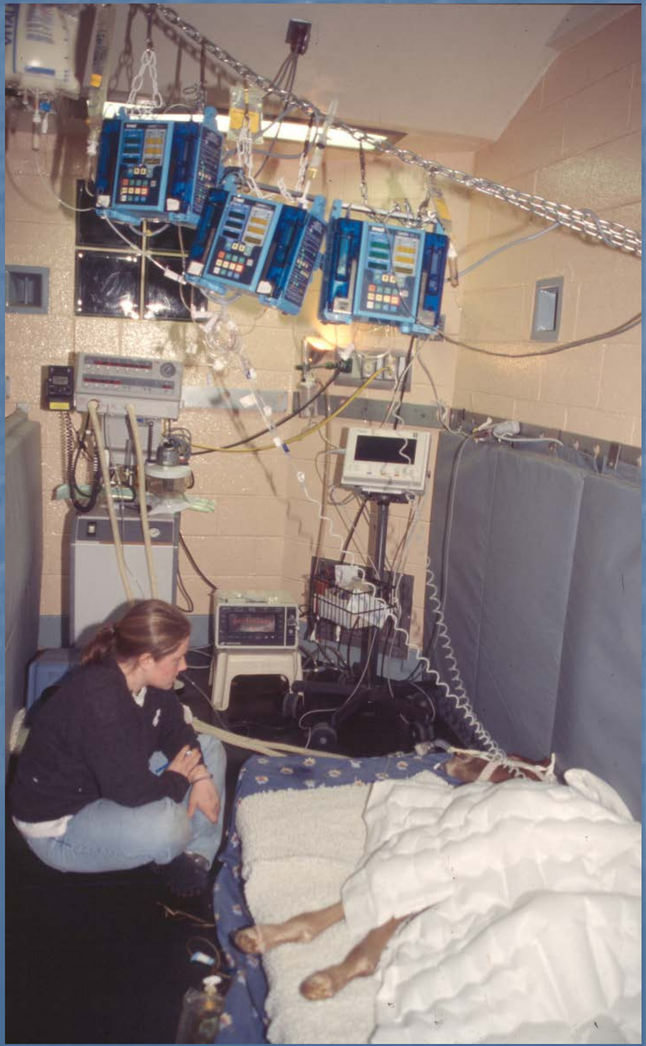
- Introduction/ historic perspective
- Tools for acid-base analysis
  - Base Excess
  - Buffer base – weak acid buffers
  - Anion Gap
  - Strong ions – SID, SIG
  - Modified Base Excess
- Metabolic acid-base abnormalities
  - Albumin level, Phosphate level
  - Free water
    - Reflected in [Na]
  - Chloride – inorganic SID
  - Organic anions, Organic cations
- Differential diagnosis of metabolic disturbances

Acid–Base Disorders

Acid-Base Abnormalities

Alterations in acid-base balance

Less important than the pathologic abnormalities causing them



Acid-Base Abnormalities

- Fatal disorders
  - Extreme (eg, pH <7.0 or >7.7)
  - Develops quickly
  - Direct cause of organ dysfunction
- Harm because of the patient’s response
  - Respiratory muscle fatigue
  - Diversion of blood flow from vital organs
  - Acidemia - increased adrenergic tone
  - Increase myocardial oxygen demand

Acid Production

- Primarily CO_2
  - 150 to 250 mEq/kg/d of carbonic acid
  - Hemoglobin is major buffer
    - "Haldane" effect - H^+ bond, HCO_3 to plasma (Cl shift) – 65%
    - CO_2 bound to protein – 27%
    - Pco_2 – 8%
- Strong organic acids
  - 30 to 40 mEq/kg/d
  - Variety of acids
    - Lactic acid
    - Tricarboxylic acids
    - Keto acids
  - Produced/ metabolized to CO_2

Acid Production

- Inorganic acids
  - H_2SO_4
  - H_3PO_4
- Urinary excretion acid
  - 1 to 2 mEq/kg/d anions

William O'Shaughnessy
Thomas Latta
1832

History Acid-Base Analysis

- Henderson 1909

$$H^{+} \propto \frac{HCO_3^-}{H_2CO_3}$$

- Hasselbalch 1916

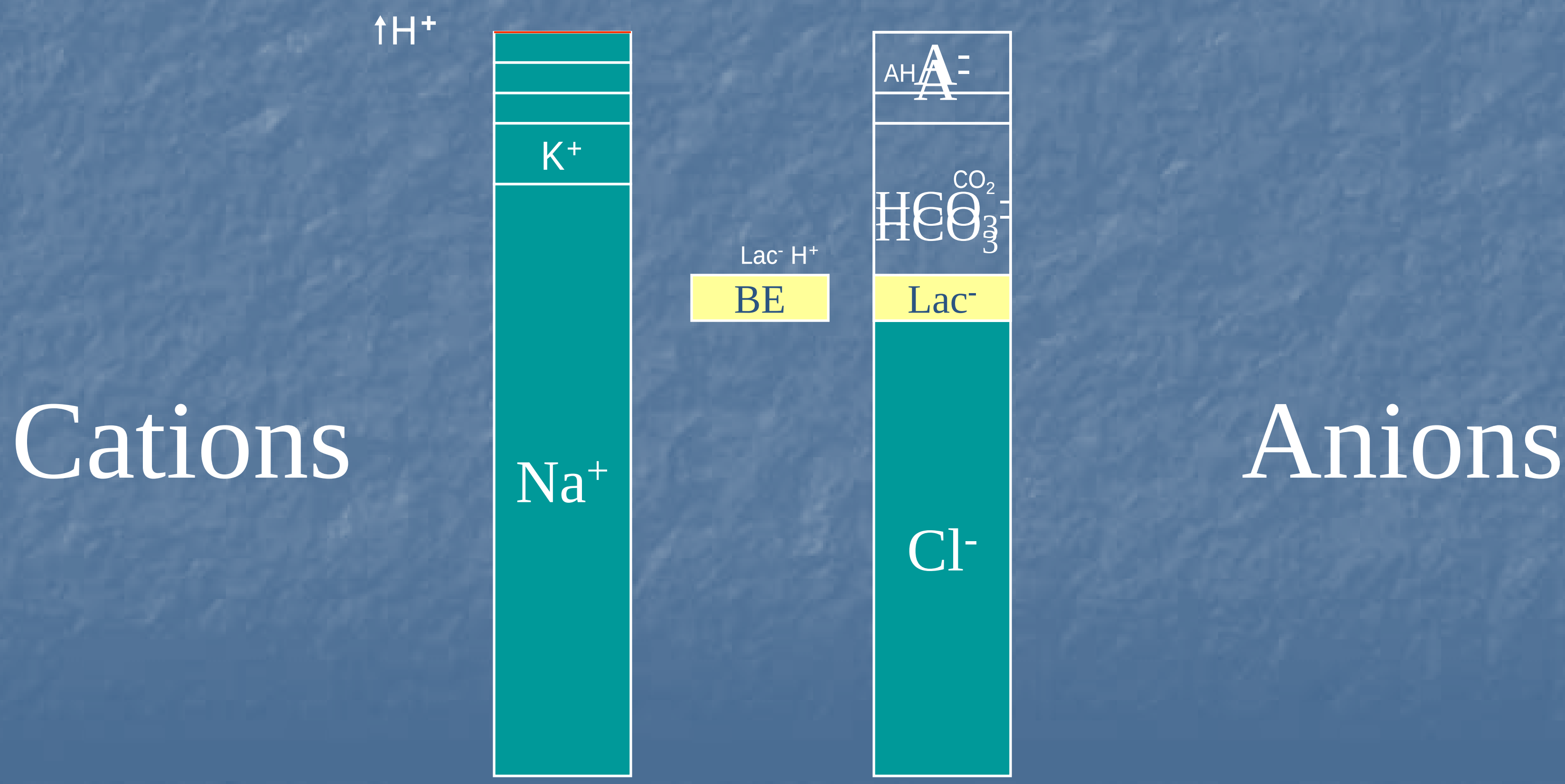
$$pH = 6.1 + \log\left[\frac{HCO_3^-}{P_{co_2} \times 0.03}\right]$$

- 1948 – Buffer Base
- 1957, 1958 – Standard Bicarbonate; Base Excess
- 1977 – Anion Gap
- 1981 – Stewart - Physical Chemistry

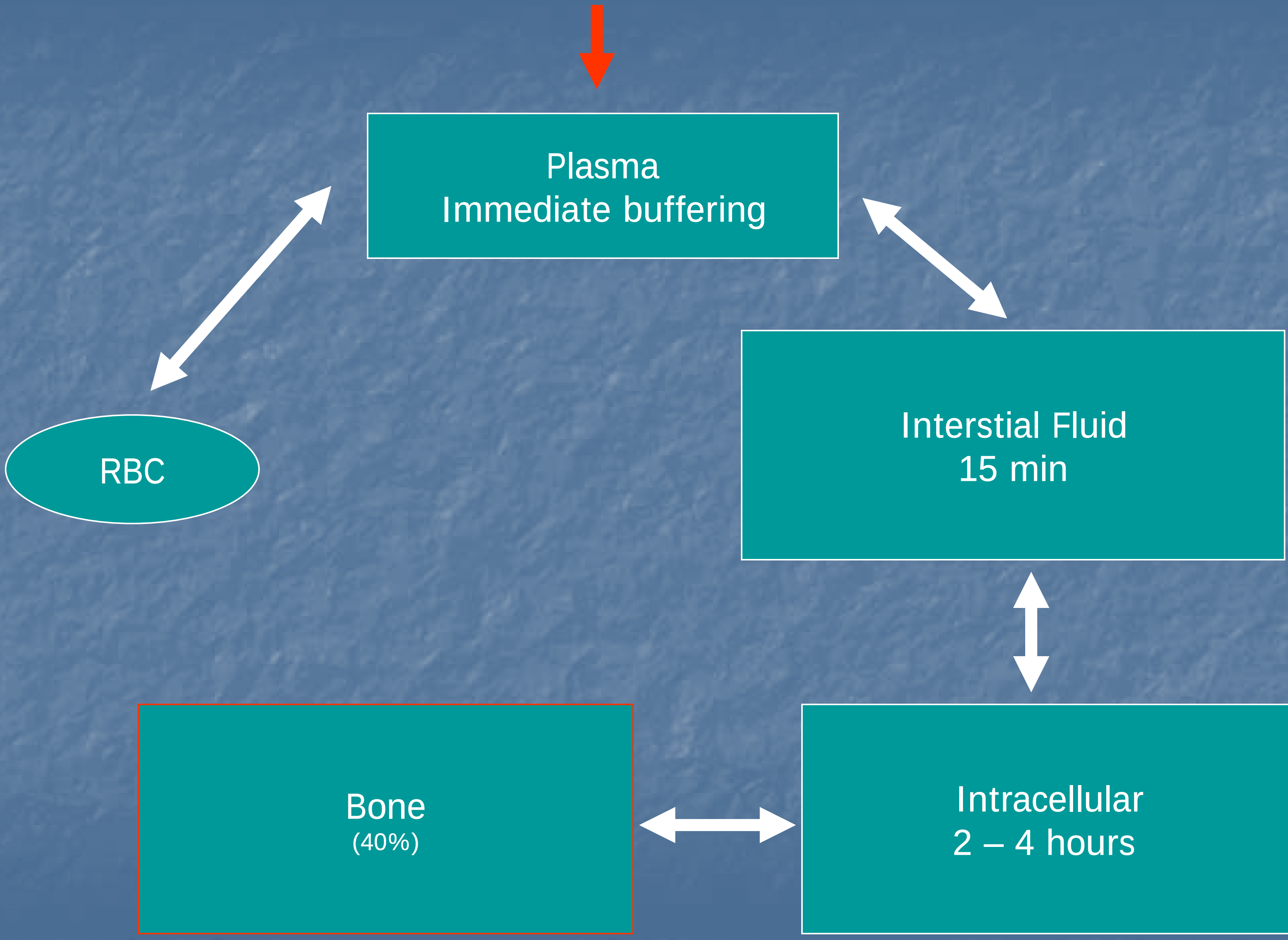
Base Excess

- Copenhagen Approach
  - Change in blood buffers
- Amount of acid/base added to whole blood
  - Return pH to 7.4
  - Assumptions
    - Pco_2 of 40 mm Hg
    - Temperature 37°C
    - Normal hemoglobin
    - Fully saturated blood
- Titration experiments
  - Nomograms
  - Formulas

BE
Lactic Acidosis



Acid Buffering

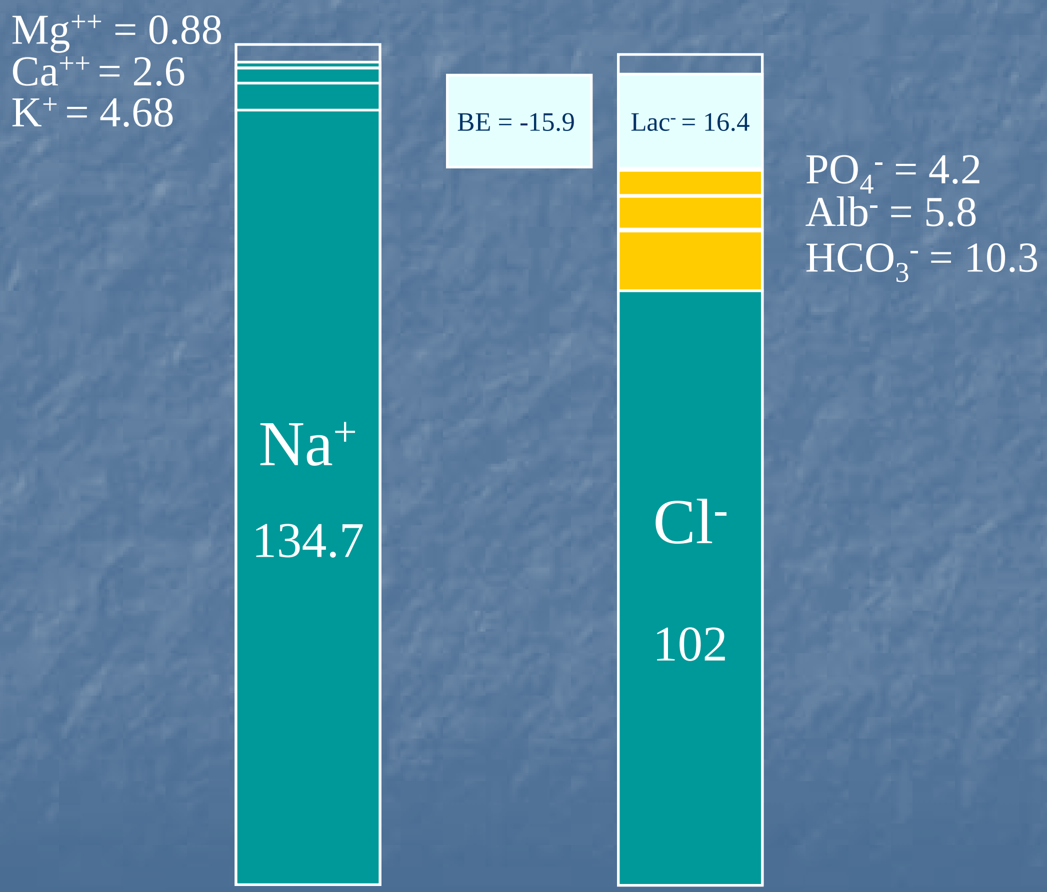


Standard Base Excess

- Buffer space
  - 1/3 normal hemoglobin
- Assumptions
  - Normal hemoglobin
  - Normal vascular/ECF ratio
  - Normal nonvolatile buffer
    - SBE_{corr} – Albumin, PO_4

Base Excess

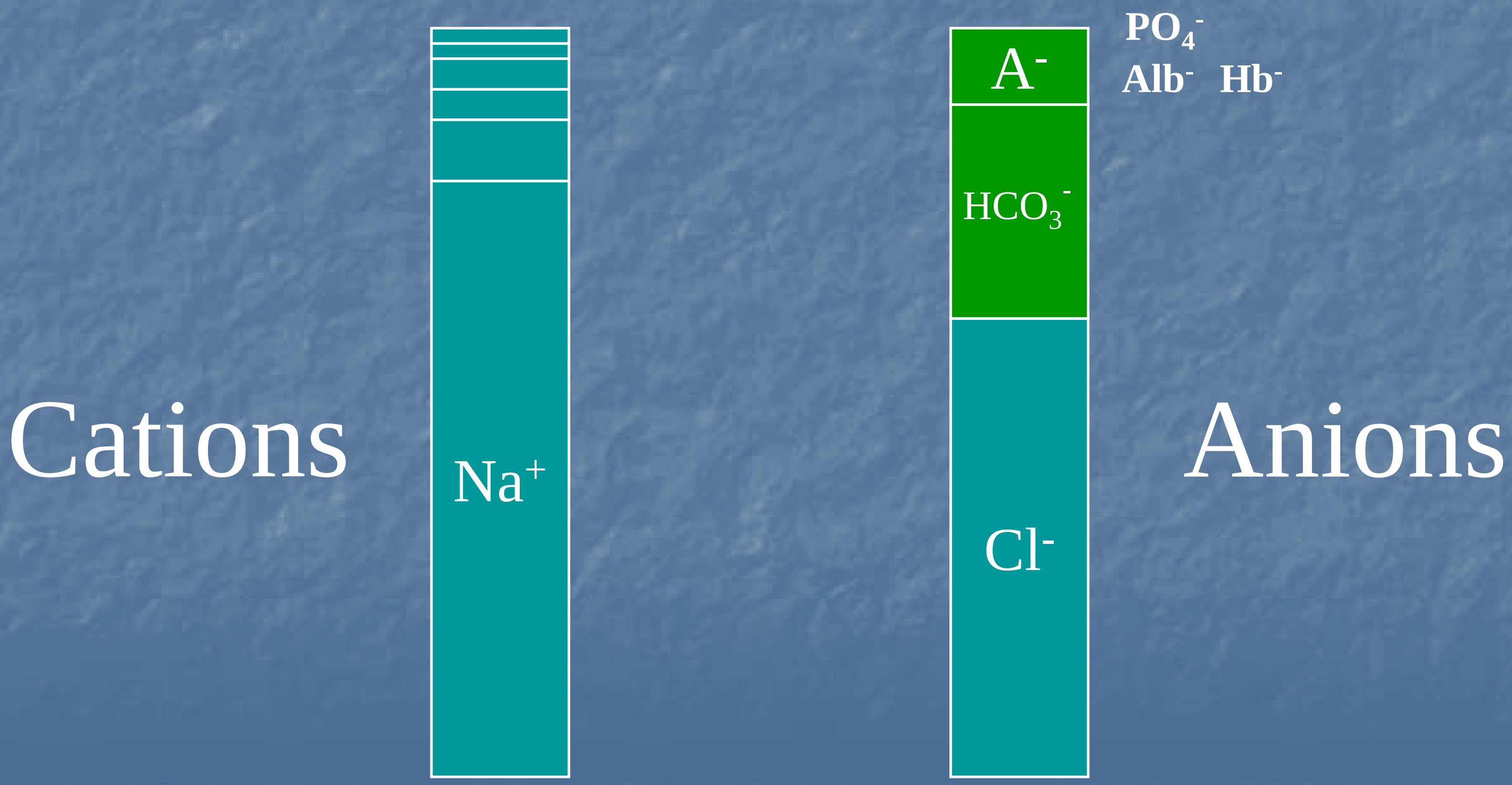
Septic shock, NE		mEq/l
pH	7.195	
Pco_2	26.4	
SBE	-15.9 mmol/l	-15.9
Na	134.7 mmol/l	134.7
K	4.68 mmol/l	4.68
Cl	102 mmol/l	102
Ca^{++}	5.31 mg/dl	2.6
Mg^{++}	1.08 mg/dl	0.88
Lac	16.4 mmol/l	16.4
PO_4	7.36 mg/dl	4.2
Alb	2.3 mg/dl	5.8
HCO_3	10.3 mmol/l	10.3



Buffer Base

- Weak Acid Buffer
- Volatile Weak Acid
  - $H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$
- Nonvolatile Weak Acids, A_{TOT}
  - Hemoglobin
  - Albumin
  - Inorganic phosphate
- Weak acids
  - pK_a act as buffers

Cations/Anions
Weak Ion Acid Buffer

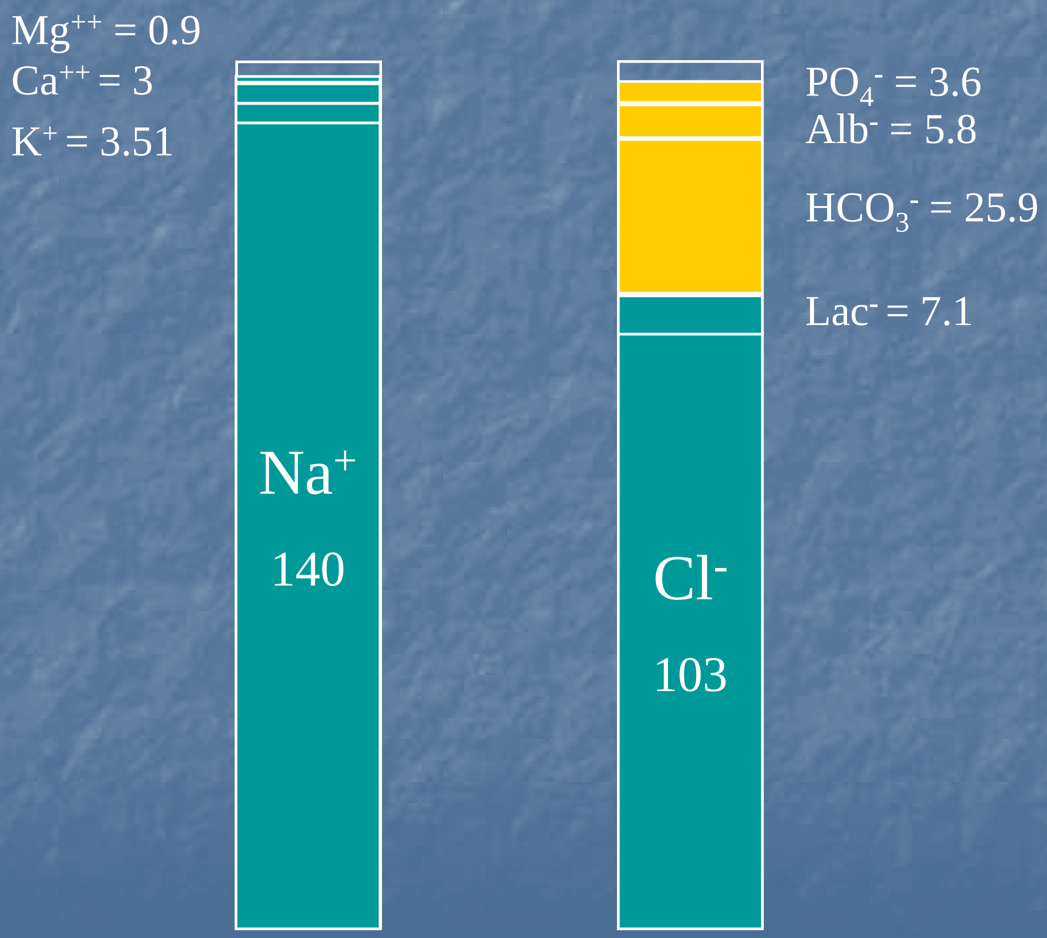


Calculating mEq/l

- $Alb^- = (Alb \times 10) \times ((0.123 \times pH) - 0.631)$
  - $Alb^- = 2.8 \times Alb$
- $PO_4^- = (PO_4 \times 0.323) \times ((0.309 \times pH) - 0.469)$
  - $PO_4^- = 0.58 \times PO_4$

Buffer Base

Neonatal Encephalopathy		mEq/l
pH	7.295	
Pco_2	52.7	
SBE	1.2	1.2
Na	140 mmol/l	140
K	3.51 mmol/l	3.51
Cl	103 mmol/l	103
Ca^{++}	6 mg/dl	3
Mg^{++}	1.1 mg/dl	0.9
Lac	7.1 mmol/l	7.1
PO_4	6.22 mg/dl	3.6
Alb	2.18 mg/dl	5.8
HCO_3	25.9 mmol/l	25.9



Anion Gap

Cations = Anions

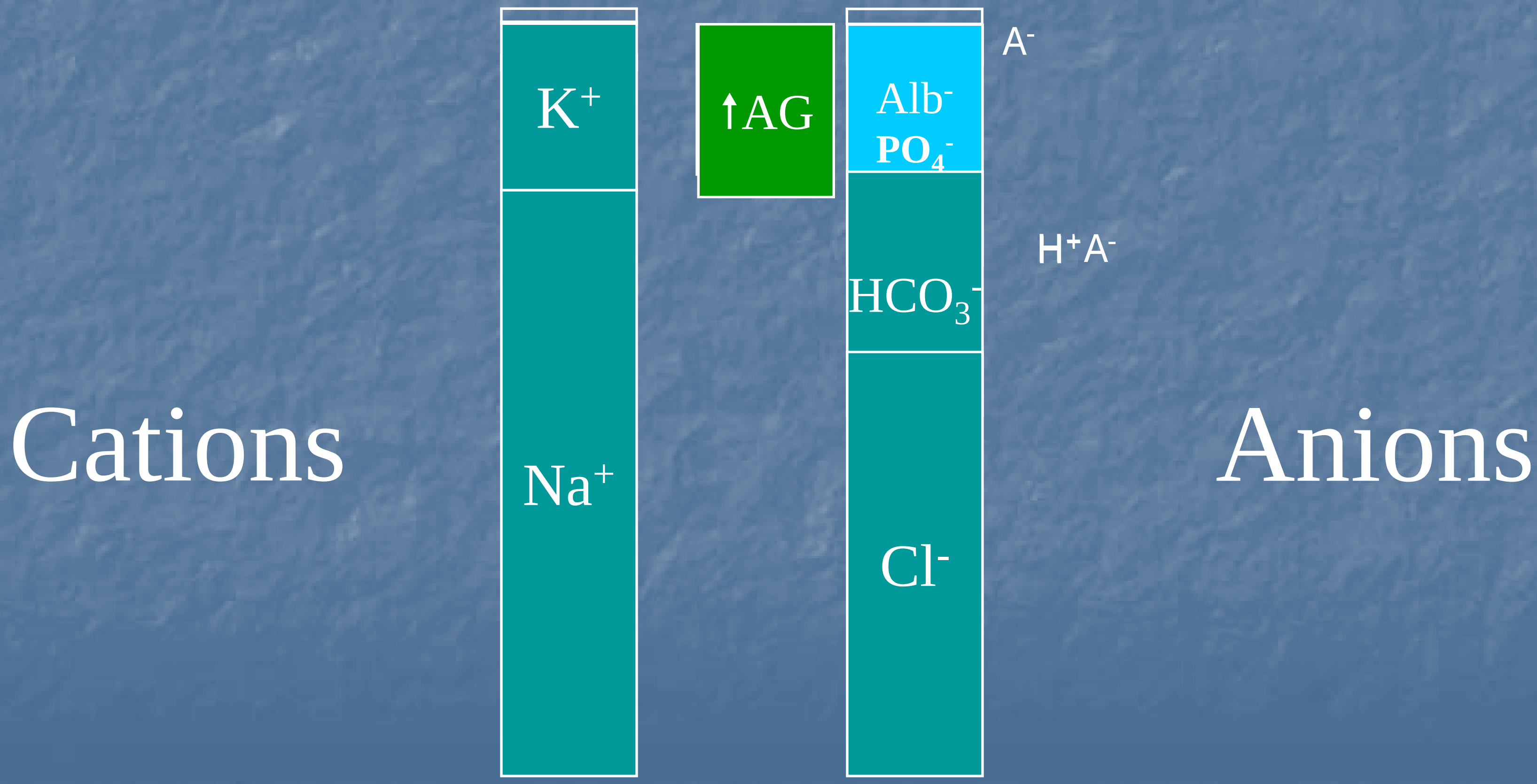
$$Na + K + Ca + Mg + UC = Cl + HCO_3 + Alb + PO_4 + UA$$

$$(Na + K) – (Cl+HCO_3) = (Alb + PO_4 + UA) – (Ca + Mg + UC)$$

$$(Na + K) – (Cl + HCO_3) = UA - UC$$

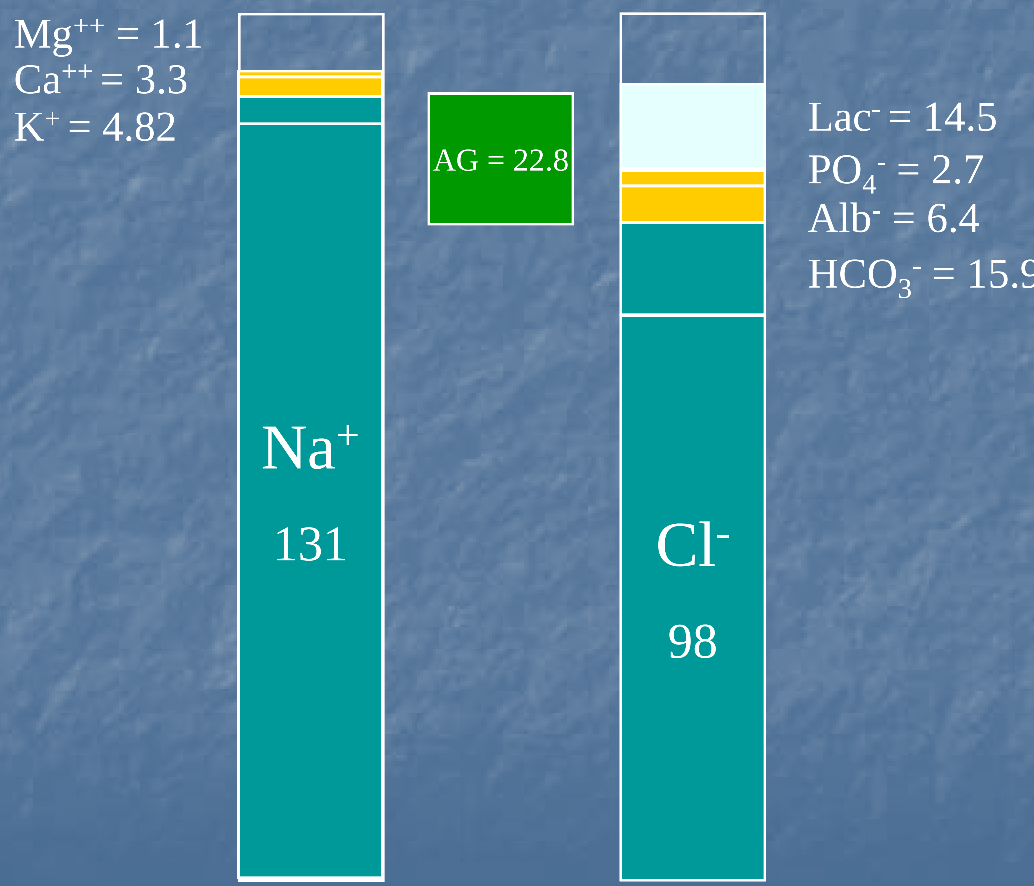
$$(Na + K) – (Cl + HCO_3) = AG$$

Cations/Anions
Anion Gap



Anion Gap

Birth Asphyxia		mEq/l
pH	7.009	
Pco2	62.4	
AG	22.8 mmol/l	
Na	131 mmol/l	131
K	4.82 mmol/l	4.82
Cl	98 mmol/l	98
Ca^{++}	6.58 mg/dl	3.3
Mg^{++}	1.3 mg/dl	1.1
Lac	14.5 mmol/l	14.5
PO_4	4.99 mg/dl	2.7
Alb	2.78 mg/dl	6.4
HCO_3	15.9 mmol/l	15.9
SBE	-13.3	



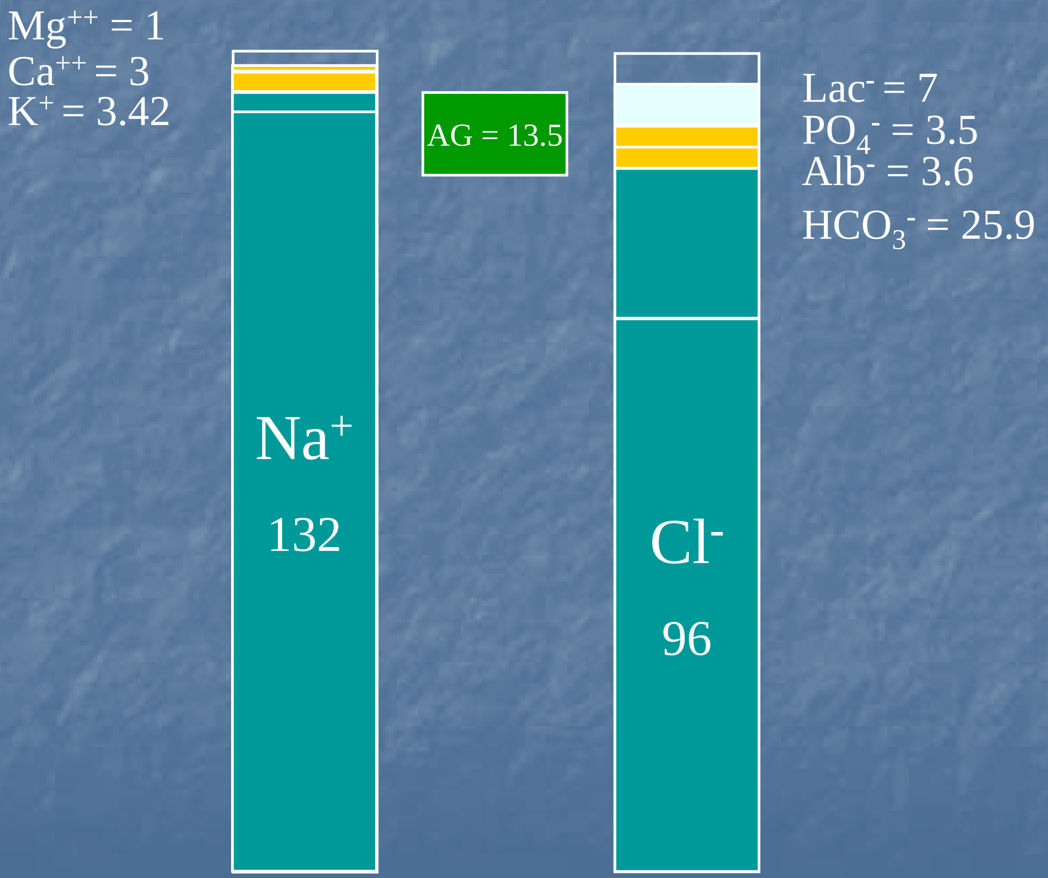
Anion Gap

- Unidentified cations
  - Ca^{++}, Mg^{++}
  - Amines, many drugs
- Unidentified anions include Alb, PO_4
  - Low levels could mask presence of UA
  - High levels could mimic presence of UA
- Corrected AG
  - $AG_{Corr} = AG + 2.5 \times (Alb_{ref} - Alb_{measured})$
  - $AG_{corr} = AG – ((2 \text{ X } Alb) + (0.5 \text{ X } Pi))$
    - Acid pH

Anion Gap

Dystocia		mEq/l
pH	7.39	
Pco2	42.6	
AG	13.5 mmol/l	
Na	132 mmol/l	132
K	3.42 mmol/l	3.42
Cl	96 mmol/l	96
Ca^{++}	6.13 mg/dl	3
Mg^{++}	1.4 mg/dl	1
Lac	7 mmol/l	7
PO_4	4.19 mg/dl	3.5
Alb	1.28 mg/dl	3.6
HCO3	26 mmol/l	26
SBE	1.3	

$AG_{corr} = AG - (Alb^-) + (PO_4^-)) = 6.4$



Anion Gap

- HCO_3^-
  - Respiratory influence
- Delta-delta
  - $\Delta AG = AG_{Corr} - AG_{ref}$
  - $\Delta HCO_3^- = HCO_3^-{}_{ref} - HCO_3^-{}_{measured}$
  - $\Delta AG = \Delta HCO_3^-$ if no respiratory influence
  - But ...
    - Non-bicarbonate buffers
    - Volume of distribution
    - Duration of acidosis
  - Normal – (1 to 1.6):1
    - Lactate - 0.8:1 to 1.8:1
    - Ketoacids - 0.8:1 to 1:1
  - Range may hide confounding abnormalities

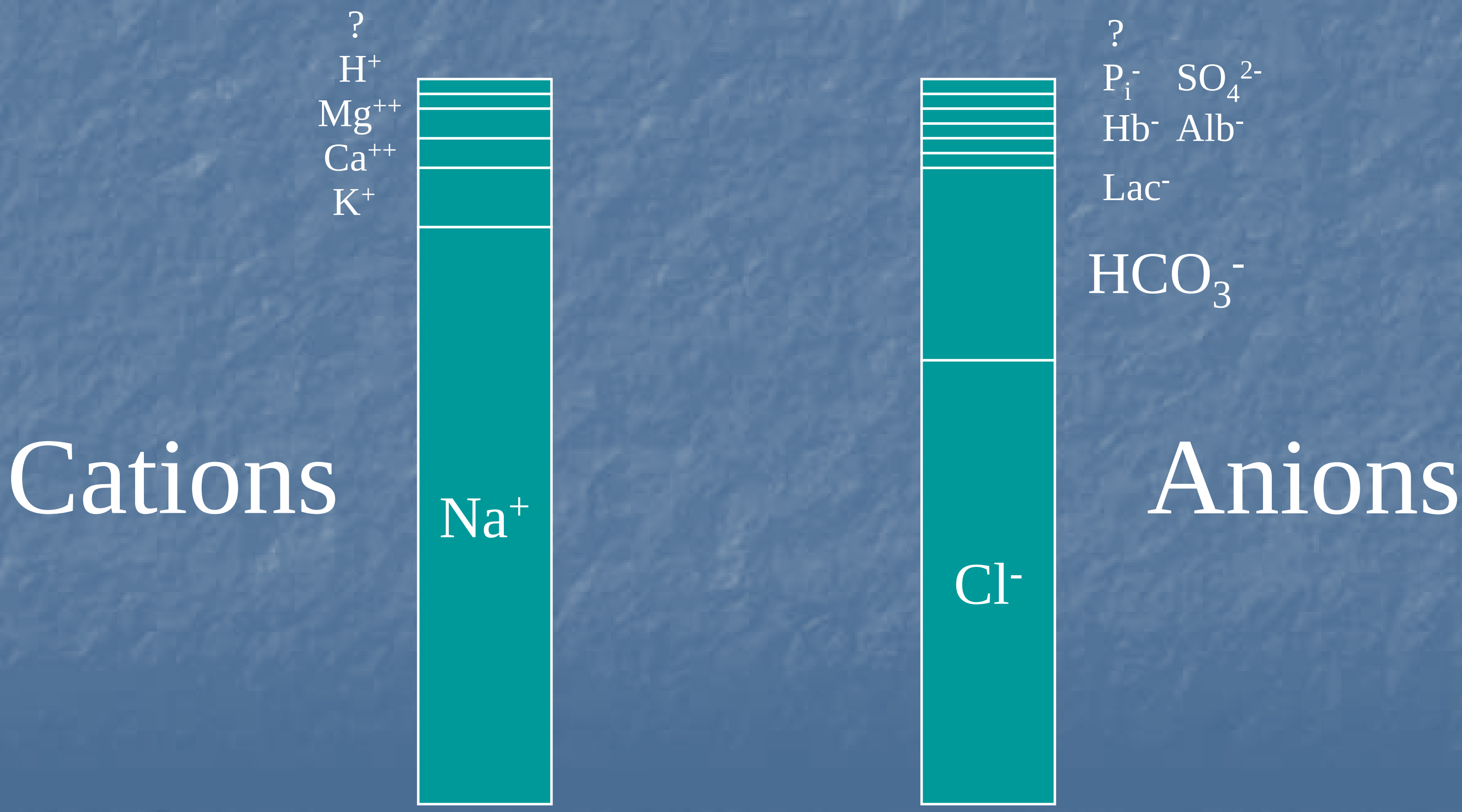
Stewart Approach

- Principles of physical chemistry
  - Electrical neutrality
  - Dissociation equilibriums
  - Conservation of mass
- Independent variables
  - SID
  - Weak acids (A_{TOT}) – buffer base
  - P_{CO2}

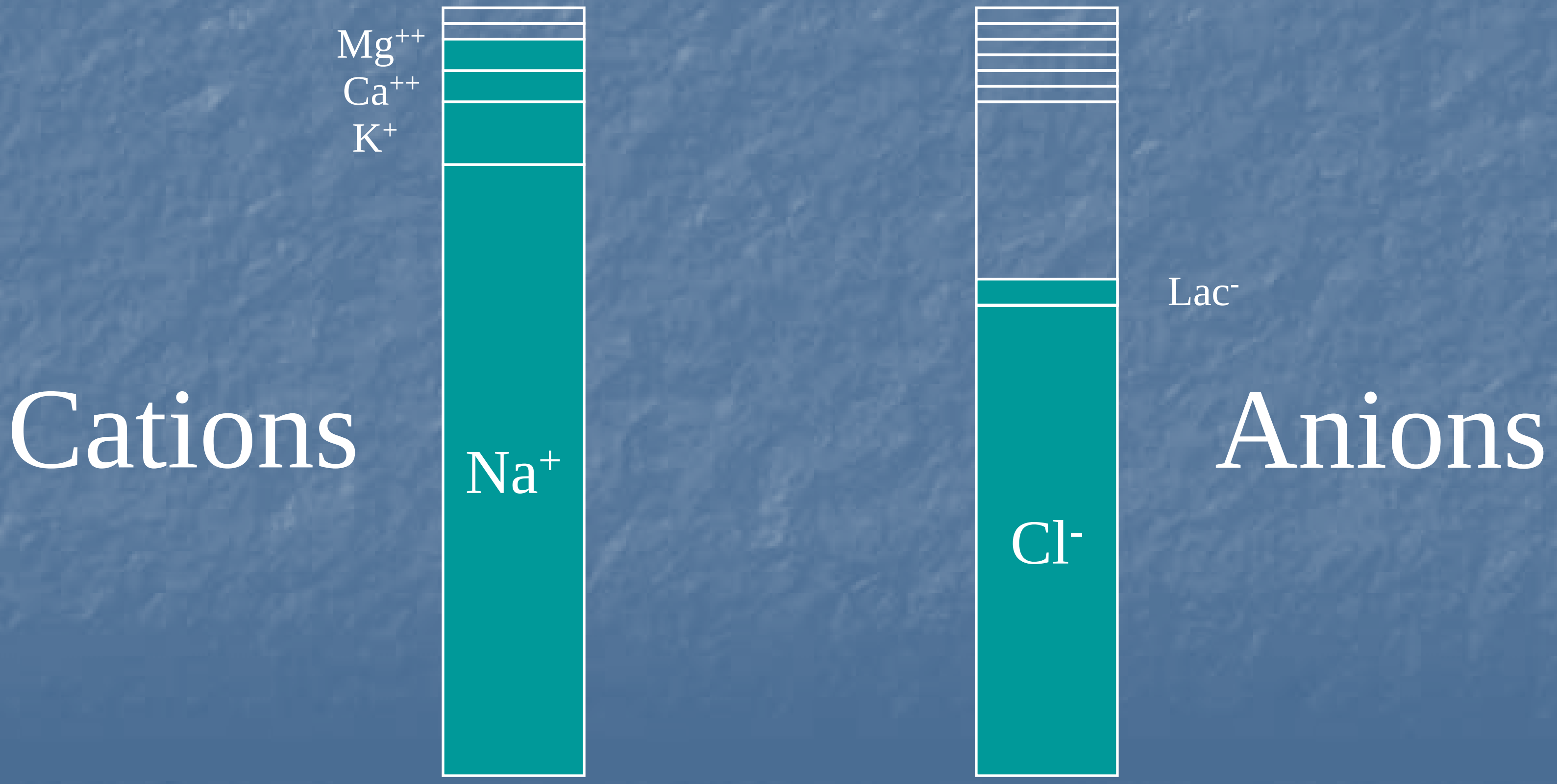
Strong Ions

- Inorganic
  - Na^+, Cl^-, K^+, $SO4^{--}$, Ca^{++}, and Mg^{++}
- Organic
  - Lactic acids
  - Tricarboxylic acids
  - Keto acids
- Strong organic anion
  - “footprint” or “ghost” of the strong acid

Cations/Anions

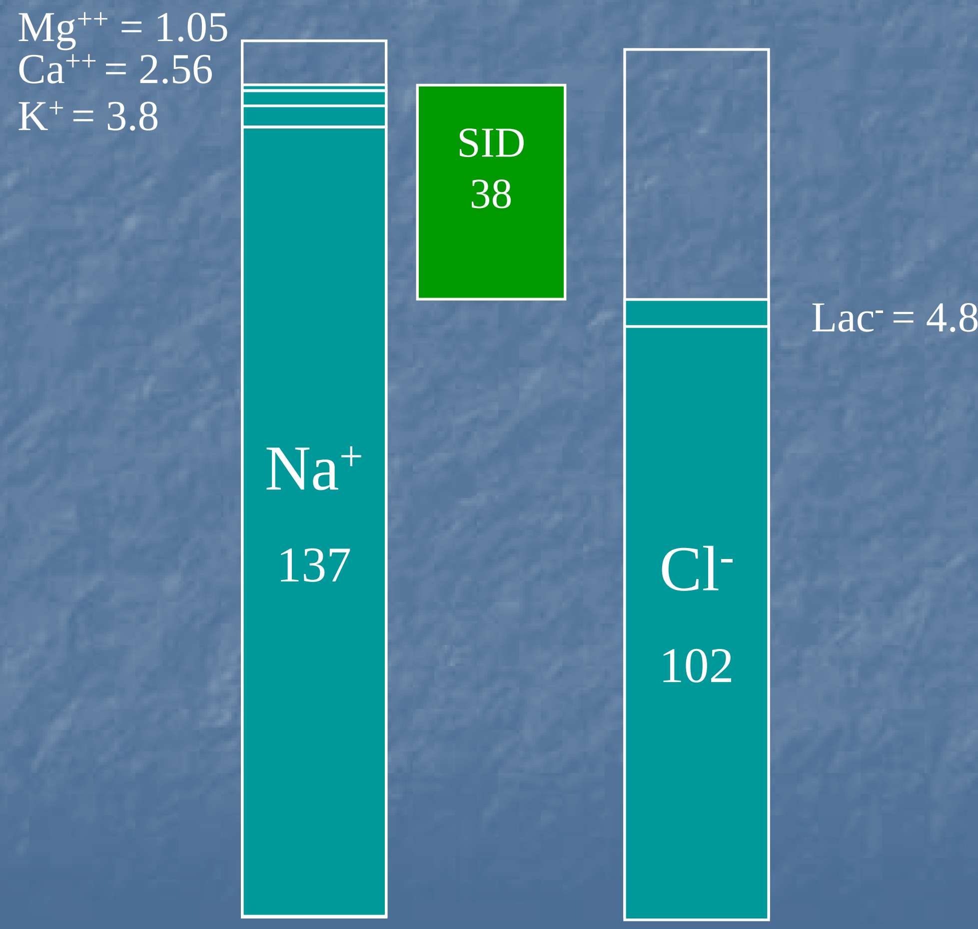


Strong Ions



Strong Ions

FIRS, Sepsis		mEq/l
pH	7.46	
Pco_2	39.8	
SID	38	
Na	137 mmol/l	137
K	3.8 mmol/l	3.8
Cl	102 mmol/l	102
Ca^{++}	5.11 mg/dl	2.56
Mg^{++}	1.28 mg/dl	1.05
Lac	4.8 mmol/l	4.8
PO_4	4.14 mg/dl	2.46
Alb	4.9 mg/dl	14
HCO_3	28.6 mmol/l	28.6
SBE	4.7	

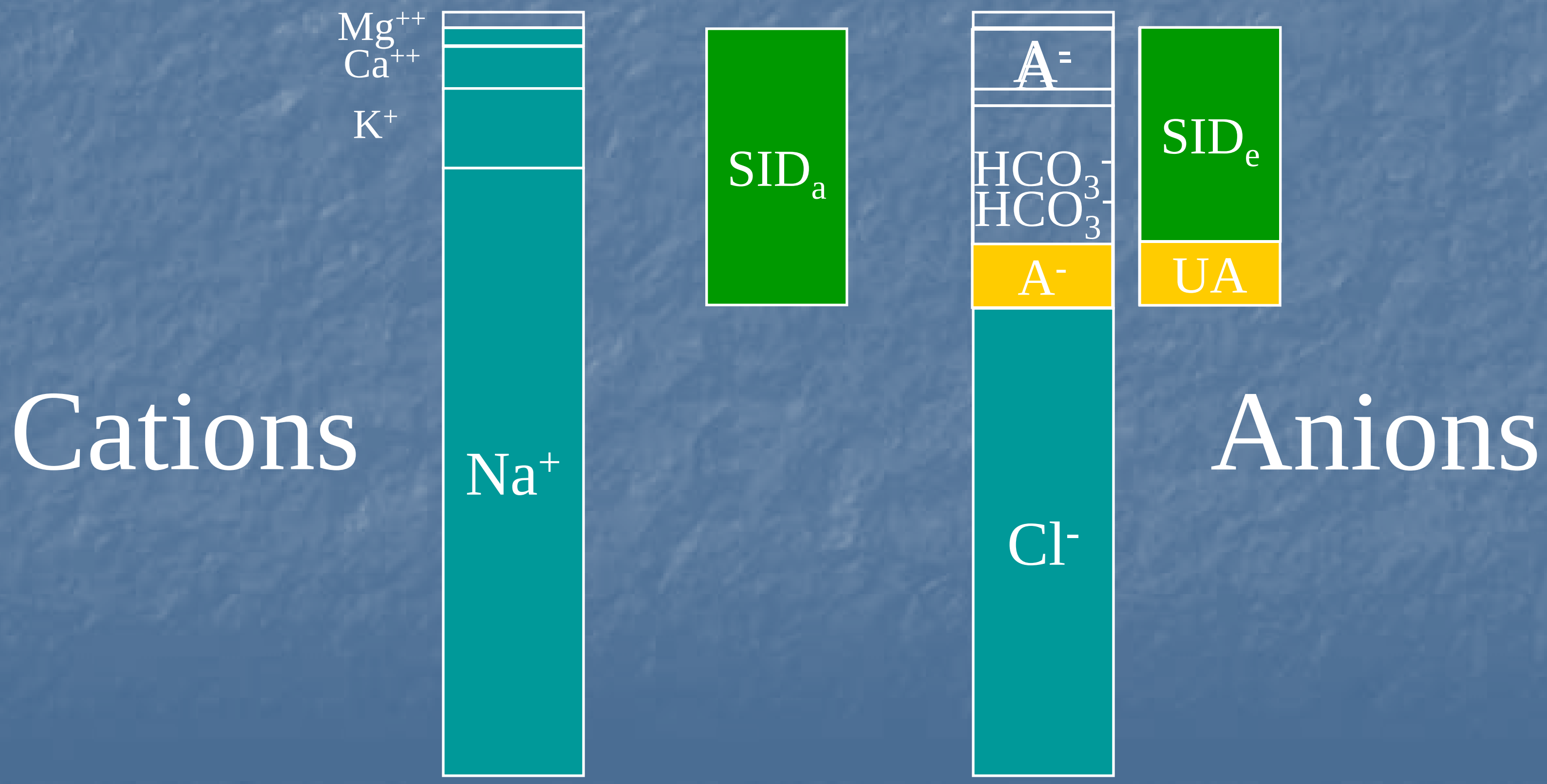


SIG

SID_a = (Na + K + Ca + Mg) – (Cl + Lac)

$SID_e = Alb^- + PO_4^- + HCO_3^-$

SIG = SID_a – SID_e = UC – UA = 0

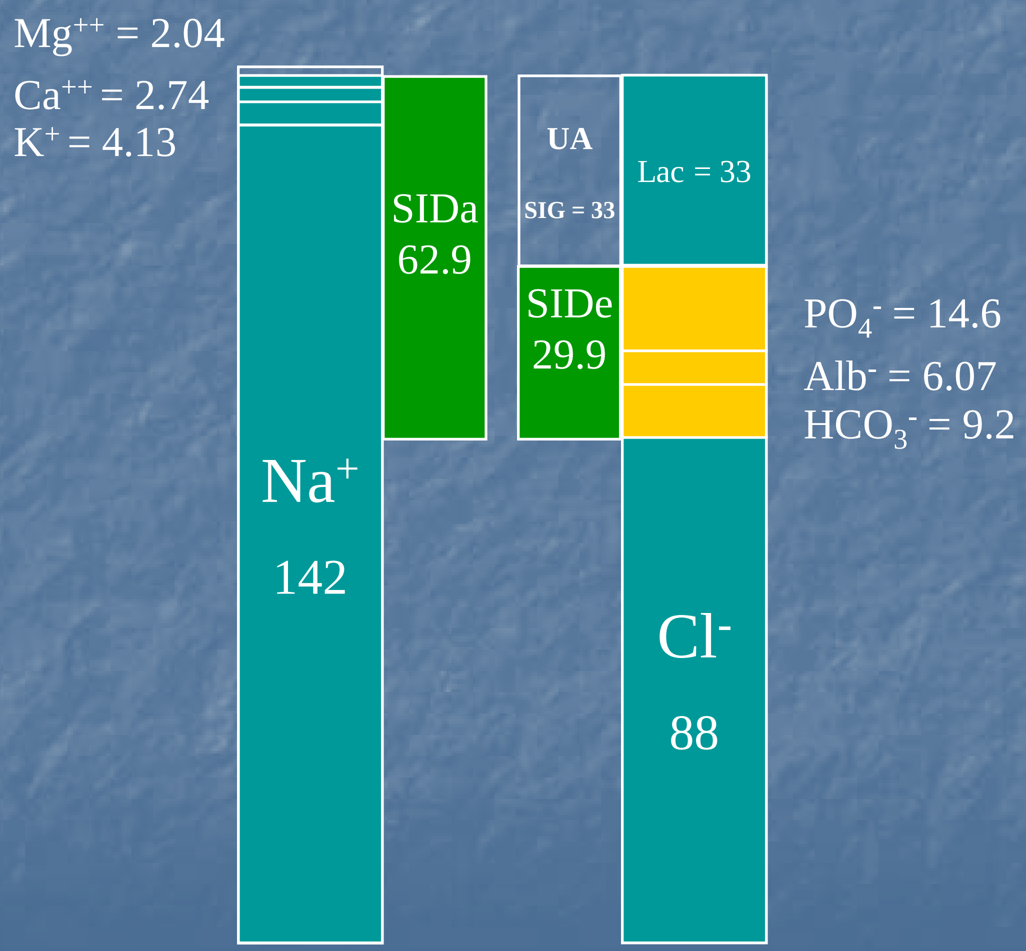


SIG

- SIG = SIDa – SIDe
- SIG > 0 – unmeasured anions
  - Sepsis
  - Liver disease
  - If lactate is not part of SIDa, D-Lac
    - Most common cause of SIG > 0
    - Lactate mmol/l = SIG
- SIG < 0 – increased unidentified cations
- Can have mixed picture but UC very rare
- SIG does not change with
  - pH, Pco_2 changes
  - Changes in albumin, phosphate

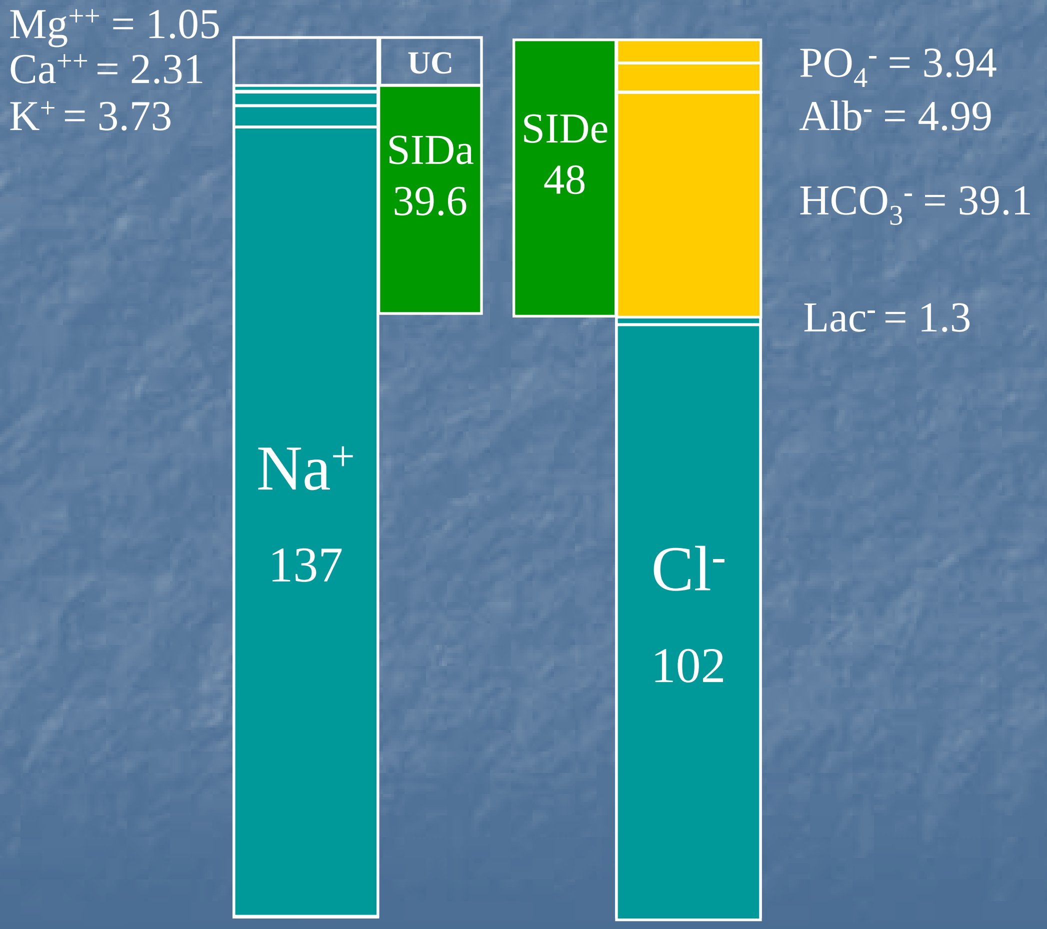
SIG – UA

Intrauterine distress Birth asphyxia		mEq/l
pH	6.791	
Pco_2	59.6	
SIDa	62.9	
SIDe	29.9	
SIG	33	
Na	142 mmol/l	142
K	4.13 mmol/l	4.13
Cl	88 mmol/l	88
Ca^{++}	5.49 mg/dl	2.74
Mg^{++}	2.49 mg/dl	2.04
Lac	?? mmol/l	??
PO_4	27.8 mg/dl	14.6
Alb	2.97 mmol/l	6.07
HCO_3	9.2 mmol/l	9.2
SBE	-22.5 mEq/l	-22.5



SIG - UC

FIRS, Sepsis		mEq/l
pH	7.361	
Pco_2	68.3	
SIDa	39.6	
SIDe	48	
SIG	-8.4	
Na	137 mmol/l	137
K	3.73 mmol/l	3.73
Cl	102 mmol/l	102
Ca^{++}	4.62 mg/dl	2.31
Mg^{++}	1.03 mg/dl	0.84
Lac	1.3 mmol/l	1.3
PO_4	6.75 mg/dl	3.94
Alb	1.82 mg/dl	4.99
HCO_3	39.1 mmol/l	39.1
SBE	13.1	

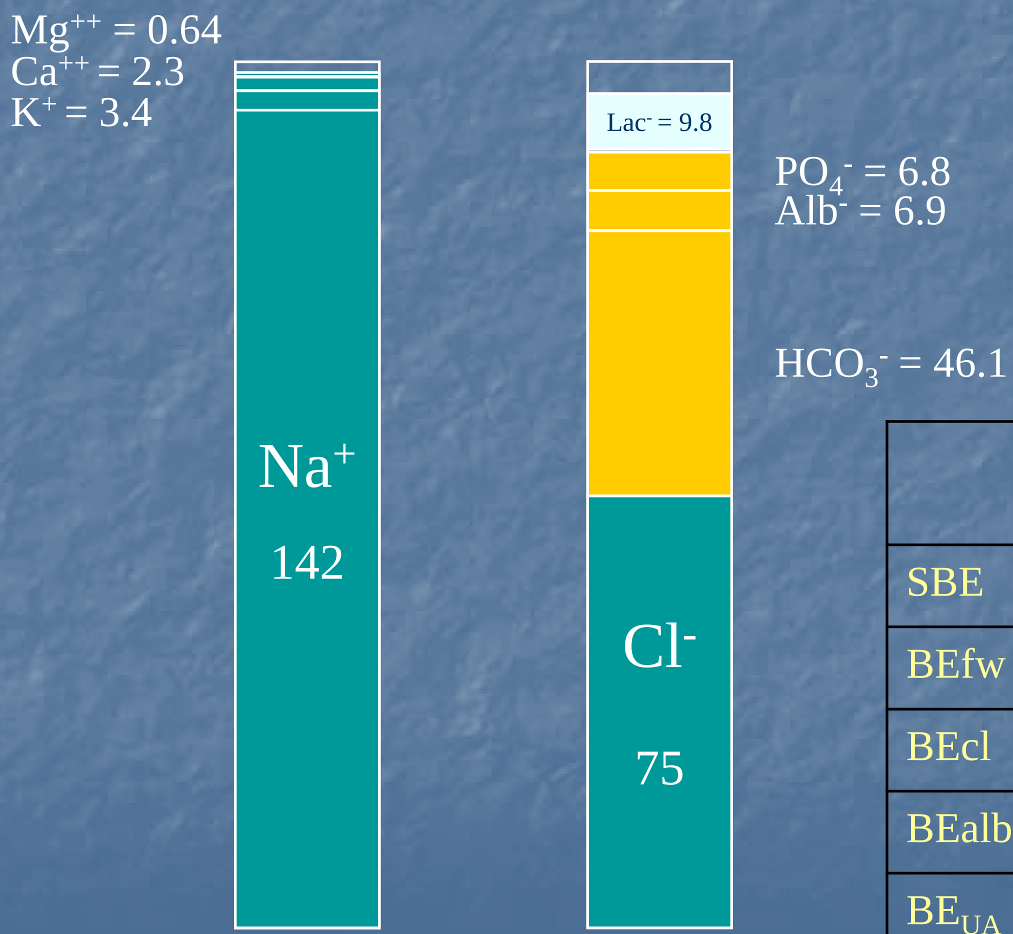


Modified BE Method

- Combining BE and Stewart's approach
  - Free water (deficit or excess)
  - Changes in Cl
  - Changes in A^- (Nonvolatile buffer base)
  - Presence of organic UA
- $BE_{lab} = BE_{fw} + BE_{Cl} + BE_{alb} + BE_{UA}$
  - $BE_{fw} = 0.3 \times (Na_{measured} – Na_{ref})$
  - $BE_{Cl} = Cl_{ref} – Cl_{Corr}$
    - $Cl_{corr} = (Na_{ref} / Na_{measured}) \times Cl^-_{measured}$
  - $BE_{alb} = 3.4 (Alb_{ref} - Alb_{measured})$
  - $BE_{UA} = BE_{lab} - (BE_{fw} + BE_{Cl} + BE_{alb})$

Modified Base Excess

IUGR, FIRS, NEC		mEq/l
pH	7.424	
Pco_2	69.8	
SBE	20.5	
Na	142	142
K	3.4	3.4
Cl	75	75
Ca^{++}	4.69	2.3
Mg^{++}	0.78	0.64
Lac	9.8	9.8
PO_4	11.5	6.8
Alb	2.45	6.9
HCO_3	46.1	46.1



BE	
SBE	20.5
BEfw	1.2
BEcl	27.1
BEalb	-0.51
BE_{UA}	-7.29


Metabolic Acid-Base Abnormalities

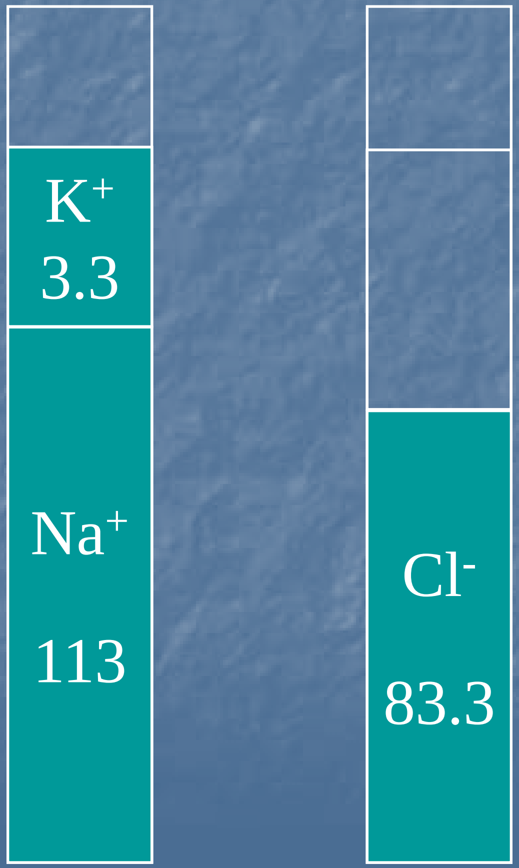
- Albumin/ Phosphate concentrations
- Free water
  - Dilutional Acidosis
  - Contraction Alkalosis
- Hypochloremia/ Hyperchloremia
- Unidentified Anions/ Unidentified Cations

Albumin/ Phosphate Concentrations

- A_{TOT}, Buffer Base, weak acids
- Metabolic acidosis
  - Hyperphosphatemia
    - Renal failure, catabolism
  - Hyperalbuminemia
    - Hemoconcentration
    - Plasma/ albumin therapy
- Metabolic alkalosis
  - Hypoalbuminemia
- Neonates
  - Hypoalbuminemia
  - Hyperphosphatemia

Dilutional Acidosis
Free Water

Na = 136
K = 4
Cl = 100
SID = 40



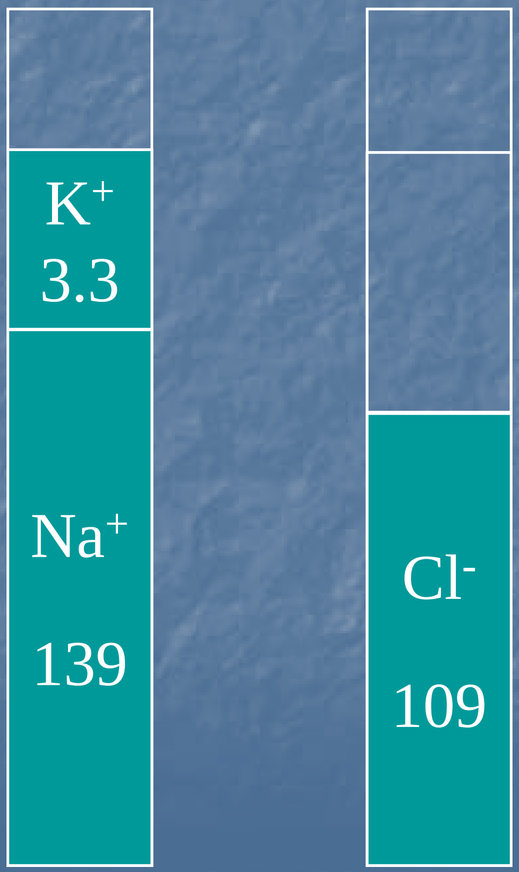
Add 20% water
Na = 113
K = 3.3
Cl = 83.3
SID = 33

Dilutional Acidosis

- Addition of free water (hyponatremia)
  - Will cause a decrease SID
  - Dilutional acidosis
    - Any osmotically active particle
      - Increase volume of ECF, no change in charge
      - Mannitol (before the diuresis)
      - Hyperglycemia
      - Ethylene glycol or methanol poisoning

Dilutional Acidosis
Saline

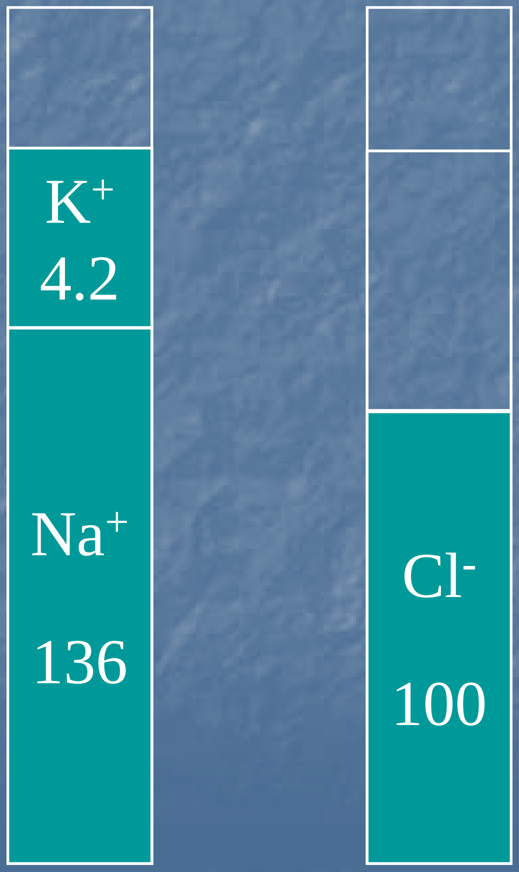
Na = 136
K = 4
Cl = 100
SID = 40



Add 20% saline
Na = 139
K = 3.3
Cl = 109
SID = 33.3

Dilutional Acidosis
Add SID balance fluid

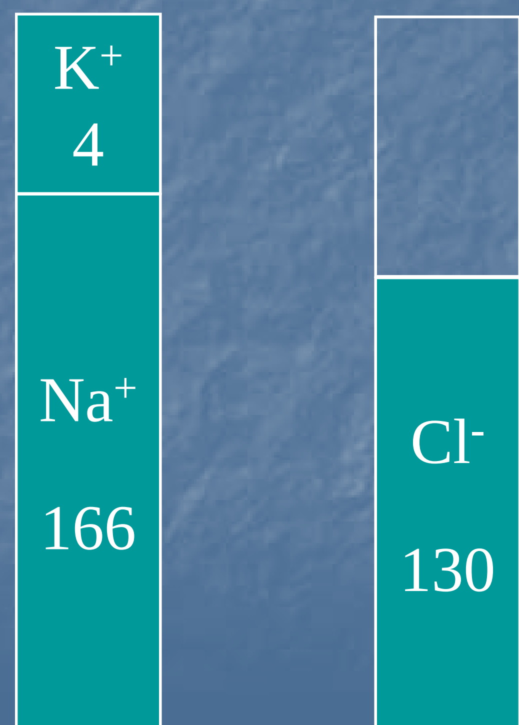
Na = 136
K = 4
Cl = 100
SID = 40



Add 20% Normisol R
Na = 137
K = 4.2
Cl = 100
SID = 41

Dilutional Acidosis
Add NaCl – no volume

Na = 136
K = 4
Cl = 100
SID = 40



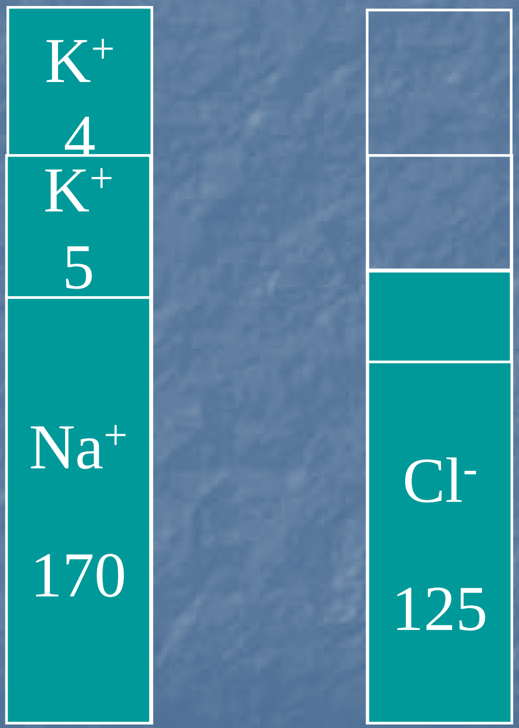
Add 30 mEq
Na = 166
K = 4
Cl = 130
SID = 40

Dilutional Acidosis

- Dilution effect
  - Depends on the SID of added fluid
  - Amount of fluid added
- How much of the SID is from free water?
- To correct for the free water effect
  - $Na_{ref}/Na_{measured}$
  - $Cl_{Corr} = (Na_{ref} / Na_{measured}) \times Cl^{-}_{measured}$
- Not that simple – in real life
  - Dilute Alb, PO_4
  - Alkalizing effect

Contraction Alkalosis

Na = 136
K = 4
Cl = 100
SID = 40



Contract 20%
Na = 170
K = 5
Cl = 125
SID = 50

Hypochloremia Hyperchloremia

- Normal renal handling of Cl
  - Renal acid-base control
  - Adjust SID by excreting Cl without Na
  - Diet – equal Na and Cl
- Abnormal renal handling of Cl
  - Renal Tubular Acidosis

Hypochloremia
Hyperchloremia

- Hyperchloremic acidosis – non-renal
  - GI losses Na
  - Excessive saline therapy
- Hypochloremic alkalosis
  - Chloriuresis (furosemide)
  - GI loss Cl
  - Contraction alkalosis (loss of free water)
    - Glucose diuresis

Unidentified Anions
Unidentified Cations

- Unidentified anions
  - L-lactate
  - D-lactate
  - Endogenous unidentified anions
    - Ketoacids
    - VFA
    - Sulfates
  - Exogenous organic unidentified anions
    - Salicylates
    - Methanol
    - Ethylene glycol

Unidentified Anions
Unidentified Cations

- Unidentified cations
  - Endogenous organic cations
    - Amines
  - Exogenous organic cations
    - Toxins
    - Drugs
- Detect unidentified anions/ cations
  - Numbers don't "add up"
  - "Gap"
    - AG
    - SIG
  - Occurrence of unidentified cations
    - Can mask the presence of unidentified anions

Differential Diagnosis Metabolic Acid-Base Disturbances

- Free water
  - Reflected in [Na]
- Chloride – inorganic SID
- Organic anions
- Organic cations
- Albumin level
- Phosphate level

Changes SID

- SID acidosis
  - Renal tubular acidosis
  - GIt - Diarrhea
  - Iatrogenic
- SID alkalosis
  - GIt
  - Diuretics/ diuresis
  - Compensation for respiratory acidosis
  - Pathologic renal loses
  - Na loading – iatrogenic

Metabolic Acid-Base Disturbances

Abnormality	**Acidosis**	**Alkalosis**
Abnormal SID		
Free water excess/deficit	Water excess = dilutional ↓ SID +↓$[Na^+]$	Water deficit = contraction ↑ SID ↑$[Na^+]$
Chloride	↓ SID ↑$[Cl^-]$	↑ SID +↓$[Cl^-]$
UA (e.g. D-lactate, keto acids)	↓ SID ↑$[UA^-]$	—
UC (e.g. organic cations)	—	↑ SID ↑$[UC^+]$
Abnormal Buffer Base		
Albumin [Alb]	↑[Alb]	↓[Alb]
Phosphate [Pi]	↑[Pi]	↓[Pi]