Dialysis Chemistries

NKF – CNNT
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I presently hold stock in and receive a pension from Baxter International Inc.

Chemistry Topics

- CO₂ in Dialysate – The mystery ingredient
- Hardness – What’s “as CaCO₃” mean?
- Urea vs. BUN – They aren’t the same
- Amino Acids – The Lego set for proteins
- The 1st Membrane – An explosive story
- Carbonate Precipitation – Why it happens

Terminology

- Mole
  - International measure of quantity
  - $6.023 \times 10^{23}$ (about 600 sextillion)
  - Known as Avogadro’s Number
  - Used to measure a quantity of atoms or molecules
  - Generally expressed in moles per liter for aqueous solutions


- Gram Atomic Weight
  - The weight of one mole of a particular atom expressed in grams.
  - Gram Atomic Weights of dialysate atoms:
    - Sodium (Na) = 23.00
    - Chlorine (Cl) = 35.45
    - Potassium (K) = 39.10
    - Carbon (C) = 12.01
    - Hydrogen (H) = 1.008
    - Oxygen (O) = 16.00
    - Magnesium (Mg) = 24.31
    - Calcium (Ca) = 40.08


- Gram Molecular Weight
  - The weight of one mole of a particular atom expressed in grams.
  - Molecular weights are the sum of the atomic weights of the atoms in the molecule.
  - Sodium Chloride (NaCl) molecular weight = Na + Cl = 23.00 + 35.45 = 58.45 grams
  - Sodium Bicarbonate (NaHCO₃) = 23.00 + 1.008 + 12.01 + 3(16.00) = 84.018 grams


- Equivalent (Eq):
  - One mole of charge – positive or negative.
  - Charges of the dialysate ions:
    - Na⁺, K⁺, Mg²⁺, Ca²⁺, Cl⁻, HCO₃⁻, CH₃COO⁻
  - One mole of Na⁺ ions = 1 Equivalent
  - One half mole of Ca²⁺ ions = 1 Equivalent
  - 1/1000 Equivalent = 1 miliEquivalent = mEq
  - 1 miliEquivalent/liter = mEq/L

College Chemistry, Donald C. Gregg, © 1967, Allyn and Bacon Inc., p 201.
Dialysate Concentrate

- Created to simplify the preparation of dialysate.
- Solution made as concentrated as possible to reduce shipping costs and ease of handling.
- Sodium and Chlorides must be within +/-2% of the container label.
- All other compounds must be within +/- 5% of the container label.

CSA Standards Z364.2.1 - 94

Why use bicarbonate instead of acetate dialysate?

- Bicarbonate is the natural buffer in the blood stream.
- When acetate dialysate was used, bicarbonate was dialyzed out of the blood and acetate was dialyzed in.
- Acetate dialysate contained no carbon dioxide so CO₂ diffused into the dialysate.
- Lower blood CO₂ resulted in lower breathing rates and reduced blood oxygen levels.

Concentrate Proportioning Ratios

<table>
<thead>
<tr>
<th>INITIAL COMPANY</th>
<th>PARTS ACID</th>
<th>PARTS BICARB</th>
<th>PARTS WATER</th>
<th>PARTS DIALYSATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drake - Willock</td>
<td>1.00</td>
<td>1.83</td>
<td>34.00</td>
<td>36.83X</td>
</tr>
<tr>
<td>Cobe Laboratories</td>
<td>1.00</td>
<td>1.72</td>
<td>42.28</td>
<td>45X</td>
</tr>
<tr>
<td>Fresenius</td>
<td>1.00</td>
<td>1.225</td>
<td>32.775</td>
<td>36.1X</td>
</tr>
</tbody>
</table>

Concentrate Dilution Factors

<table>
<thead>
<tr>
<th>INITIAL COMPANY</th>
<th>ACID DILUTION</th>
<th>BICARB DILUTION</th>
<th>BICARB CALCULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drake - Willock</td>
<td>36.83X</td>
<td>20.13X</td>
<td>36.83/1.83 = 20.13</td>
</tr>
<tr>
<td>Cobe Laboratories</td>
<td>45X</td>
<td>26.16X</td>
<td>45/1.72 = 26.16</td>
</tr>
<tr>
<td>Fresenius</td>
<td>35X</td>
<td>28.57X</td>
<td>35/1.225 = 28.57</td>
</tr>
</tbody>
</table>

The first proportioning ratio (3:1) for acetate dialysate was established by a Canadian Engineer, Albert L. Bab in 1963 at the University of Washington in Seattle.
Albert Leslie Babb

- Univ. of British Columbia – 1948
- B.S. Chemical Engineering
- Univ. of Illinois – 1951
- PhD Chemical Engineering
- Univ. of Washington – 1961-1981
- Head of Nuclear Engineering Dept.
- Created 1st Proportioning Dialysis Machine in 1963
- Created 1st Home Dialysis Machine in 1964
- Nominated for Noble Prize in 1977
- Professor Emeritus - 1992

Equipment Proportioning

(45X at $Q_D = 800 \text{ mL/min}$)

- **Water** (751.6 mL/min)
- **Bicarbonate Dialysate** (900 mL/min)

- **Acid Concentrate Pump 45X** (17.8 mL/min)
- **Bicarb Concentrate Pump 26.16X** (30.6 mL/min)

How much concentrate is used?

(Volume for 4 hours in liters)

<table>
<thead>
<tr>
<th>Flowrate (mL/min)</th>
<th>Acid 45X</th>
<th>Bicarb 26.16X</th>
<th>Acid 36.83X</th>
<th>Bicarb 20.13X</th>
<th>Acid 35X</th>
<th>Bicarb 28.57</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>2.66</td>
<td>4.58</td>
<td>3.26</td>
<td>5.95</td>
<td>3.43</td>
<td>4.20</td>
</tr>
<tr>
<td>600</td>
<td>3.19</td>
<td>5.50</td>
<td>3.91</td>
<td>7.15</td>
<td>4.10</td>
<td>5.04</td>
</tr>
<tr>
<td>700</td>
<td>3.74</td>
<td>6.43</td>
<td>4.56</td>
<td>8.35</td>
<td>4.80</td>
<td>5.88</td>
</tr>
<tr>
<td>800</td>
<td>4.27</td>
<td>7.34</td>
<td>5.21</td>
<td>9.53</td>
<td>5.49</td>
<td>6.72</td>
</tr>
</tbody>
</table>

Volumen = (Dialysate Flowrate x 240 minutes)/Dilution Ratio

The Control and Monitoring of Conductivity

- For each control function there needs to be an independent monitor function
- Four possibilities:
  - Control | Monitor | Patient
  - OK | OK | SAFE
  - OK | FAIL | SAFE
  - FAIL | OK | SAFE
  - FAIL | FAIL | UNSAFE
- If a control failure is one in a thousand and a monitor failure is the same, then the chance of a simultaneous failure is one in a million
- Never start a treatment without sufficient concentrate to do the entire treatment
- Never override conductivity alarms!

The Acid/Bicarbonate Reaction

When the Acetic Acid in the Acid concentrate mixes with the Bicarbonate ion in the Bicarb concentrate the following reaction occurs:

$$ \text{CH}_3\text{COOH} + \text{HCO}_3^- \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{CH}_3\text{COO}^- $$

- Acetic Acid
- Bicarb Ion
- Carbon Dioxide
- Water
- Acetate Ion

- 4 mM/L
- 4 mEq/L
- 4 mM/L
- 4 mM/L
- 4 mEq/L

For 45X concentrates the 37 mEq/L concentrate becomes 33 mEq/L in the final dialysate solution.

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How much CO₂ will be in the dialysate?

- The reaction with the acetic acid produced 4 mmol of carbon dioxide.
- That’s 1/250th (4/1000) of a mole/liter. (0.176 gm of CO₂/liter)
- From Avogadro’s law, one mole of a gas occupies 22.4 liters at one atmosphere of pressure (760 mmHg)
- Boyle’s Law: P₁ x V₁ = P₂ x V₂ hence
  - 760 mmHg x 22.4 liters = 17,024 mmHg x 1 liter
  - 17,024 mmHg / 250 = 68 mmHg
- Normal blood CO₂ pressure is 40 mmHg hence:
  - CO₂ will go from the dialysate into the blood
  - This is a good thing because CO₂ levels promote breathing and as a result, proper Oxygen levels.

### Variable Sodium and Bicarbonate

- For variable Sodium, only the Acid concentrate is changed to keep the bicarbonate constant.
- For variable Bicarbonate, both the Acid and Bicarbonate concentrates are changed:
  - The Bicarb is adjusted to the desired level.
  - The Acid is changed to correct the Sodium level due to the bicarb change.
  - The adjustments must be slightly corrected for the acid/bicarb reaction that occurs.
- When both Sodium and Bicarb are to be changed, both concentrates are adjusted as necessary.
- When the acid concentrate is changed, all the other ions in the acid bath are also changed!

### 45X Acid Concentrate

<table>
<thead>
<tr>
<th>Molecule</th>
<th>G. M. W. (Grams)</th>
<th>Acid Amount (Grams/L)</th>
<th>mM/L</th>
<th>mEq/L</th>
<th>Dilute 45X mEq/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>58.45</td>
<td>263.02</td>
<td>4500</td>
<td>4500</td>
<td>100.0</td>
</tr>
<tr>
<td>KCl</td>
<td>74.55</td>
<td>6.71</td>
<td>90.0</td>
<td>90.0</td>
<td>2.00</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>110.98</td>
<td>6.24</td>
<td>56.2</td>
<td>112.5</td>
<td>2.50</td>
</tr>
<tr>
<td>MgCl₂</td>
<td>95.21</td>
<td>1.61</td>
<td>16.9</td>
<td>33.82</td>
<td>0.75</td>
</tr>
<tr>
<td>CH₃COOH</td>
<td>60.05</td>
<td>10.80</td>
<td>180.0</td>
<td>180.0</td>
<td>4.00</td>
</tr>
<tr>
<td>C₃H₆O₆</td>
<td>180.16</td>
<td>67.6</td>
<td>375.2</td>
<td></td>
<td>8.34 mEq/L</td>
</tr>
</tbody>
</table>

### Bicarbonate: Concentrate to Dialysate

- Sodium Bicarbonate = NaHCO₃
- GMW = 84.00 grams = 1 mole
- Liquid bicarbonate contains:
  - 81.25 grams/L = 81.25/84.02 = 0.967 mole
    - (650 gram packet makes 8 liters)
  - Bicarb has one charge, hence:
    - 0.967 mole/L = 0.967 Eq/L = 967 mEq/L
    - The dilution factor for the Bicarb is 26.16X:
      - 967 mEq/L / 26.16 = 37.0 mEq/L

### Conductivity

- Unit of Measure: millisiemens/centimeter (mS/cm)
- Used to measure total ion concentration
- Factors that determine conductivity:
  - Total ions in solution (Total Ionic Strength = TIS)
  - Each ion’s mobility (Conductance Factor)
  - Non ionic molecules decrease conductivity (Dextrose)
  - Increases as temperature increases (Reference 25°C)
- Typical value for dialysate is 14.0 mS/cm at 25°C
- For any electrolyte solution, the number of positive and negative ions are always equal.
**Conductivity Temperature Compensation**

- The conductivity of an electrolyte solution, such as dialysate, varies with temperature.
- For dialysate, this change is about 1.80 – 2.20% per degree Centigrade.
- For the conductivity values to reflect total ion concentration, all values must be corrected to the same temperature, which is 25°C.
- All dialysate machines utilize a temperature measuring device (normally a thermistor) to measure the dialysate temperature and correct the conductivity reading for the difference between the actual conductivity at the dialysate temperature and 25°C.

**Conductivity Temperature Compensation Table for 14.00 mS/cm @ 25°C**

<table>
<thead>
<tr>
<th>Temperature (degrees Celsius)</th>
<th>Uncompensated Cond. (mS/cm)</th>
<th>% Change from 25.0°C</th>
<th>Compensated by Thermistor</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.0</td>
<td>16.83</td>
<td>20.2</td>
<td>14.00</td>
</tr>
<tr>
<td>35.0</td>
<td>17.18</td>
<td>22.7</td>
<td>14.00</td>
</tr>
<tr>
<td>36.0</td>
<td>17.64</td>
<td>25.3</td>
<td>14.00</td>
</tr>
<tr>
<td>37.0</td>
<td>17.90</td>
<td>27.8</td>
<td>14.00</td>
</tr>
<tr>
<td>38.0</td>
<td>18.27</td>
<td>30.5</td>
<td>14.00</td>
</tr>
<tr>
<td>39.0</td>
<td>18.65</td>
<td>33.2</td>
<td>14.00</td>
</tr>
<tr>
<td>40.0</td>
<td>19.03</td>
<td>36.0</td>
<td>14.00</td>
</tr>
</tbody>
</table>

**Compensation @ 2.07%/°C**

**Ionic Strength = Valence² x Molarity**

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Symbol</th>
<th>Valence²</th>
<th>Molarity (mmol/L)</th>
<th>Ionic Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>Na⁺</td>
<td>1</td>
<td>137.00</td>
<td>137.00</td>
</tr>
<tr>
<td>Calcium</td>
<td>Ca²⁺</td>
<td>4</td>
<td>0.25</td>
<td>1.00</td>
</tr>
<tr>
<td>Potassium</td>
<td>K⁺</td>
<td>1</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg²⁺</td>
<td>4</td>
<td>0.375</td>
<td>1.50</td>
</tr>
<tr>
<td>Chloride</td>
<td>Cl⁻</td>
<td>1</td>
<td>105.25</td>
<td>105.25</td>
</tr>
<tr>
<td>Acetate</td>
<td>C₂H₃O₂⁻</td>
<td>4</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>HCO₃⁻</td>
<td>1</td>
<td>33.00</td>
<td>33.00</td>
</tr>
<tr>
<td><strong>Total Ionic Strength (TIS)</strong></td>
<td></td>
<td></td>
<td>287.75</td>
<td></td>
</tr>
<tr>
<td><strong>Total Ionic Strength / 2</strong></td>
<td></td>
<td></td>
<td>143.88</td>
<td></td>
</tr>
</tbody>
</table>

**Conductance Factor**

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Factor for TIS/2 x 157</th>
<th>Factor for TIS/2 x 160</th>
<th>Factor per mmol/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Chloride</td>
<td>104.51</td>
<td>103.40</td>
<td>0.04826</td>
</tr>
<tr>
<td>Potassium Chloride</td>
<td>126.49</td>
<td>125.47</td>
<td>0.04435</td>
</tr>
<tr>
<td>Calcium Chloride</td>
<td>103.36</td>
<td>101.52</td>
<td>0.08000</td>
</tr>
<tr>
<td>Magnesium Chloride</td>
<td>106.29</td>
<td>105.23</td>
<td>0.04609</td>
</tr>
<tr>
<td>Sodium Acetate</td>
<td>70.17</td>
<td>69.03</td>
<td>0.04857</td>
</tr>
<tr>
<td>Sodium Bicarbonate</td>
<td>73.97</td>
<td>72.28</td>
<td>0.07348</td>
</tr>
</tbody>
</table>

**Factors from the Drake-Willock Conductance Tables**

**Conductivity Calculation**

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>(#1) Conductance Factor</th>
<th>(#2) Charge mmol/L</th>
<th>(#3) Multiply by #2</th>
<th>Divide #3 by 1000</th>
<th>Conductivity mS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>104.178</td>
<td>100.00</td>
<td>10.418</td>
<td>10.418</td>
<td></td>
</tr>
<tr>
<td>KCl</td>
<td>126.185</td>
<td>2.00</td>
<td>252.4</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td>CaCl₂</td>
<td>102.810</td>
<td>2.50</td>
<td>257.6</td>
<td>0.027</td>
<td></td>
</tr>
<tr>
<td>MgCl₂</td>
<td>105.973</td>
<td>0.75</td>
<td>79.3</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Na₂C₂H₃O₂</td>
<td>69.823</td>
<td>4.00</td>
<td>279.3</td>
<td>0.029</td>
<td></td>
</tr>
<tr>
<td>NaHCO₃</td>
<td>73.464</td>
<td>33.00</td>
<td>2,424.3</td>
<td>0.024</td>
<td></td>
</tr>
<tr>
<td><strong>Total Dialysate Conductivity without Dextrose</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>13.710</strong></td>
</tr>
</tbody>
</table>

**Compensating for Dextrose**

- Dextrose decreases conductivity because it doesn’t ionize.
- Final conductivity with dextrose ($C_{\text{final}}$) = $C_0 - (0.00105 \times \text{Dex}) + (0.0000574 \times \text{Dex} \times C_0)$
  
  Where:
  
  $\text{Dex} =$ Dextrose in mg/dL = 150.0 (1.5 g/L)
  
  $C_0 =$ Dialysate conductivity without dextrose (mS/cm) = 13.710

  Example:
  
  $C_{\text{final}} = 13.710 - (0.00105 \times 150.07) + (0.0000574 \times 150.0 \times 13.710)$
  
  $= 13.710 - (0.157) + (0.118)$
  
  $= 13.67$ mS/cm
When more is less!

- When a component in the dialysate bath is increased, the conductivity doesn’t always go up.
- If the total positive charge of a bath remains constant and one of the negatively charged ions is increased, the other negatively charged ions must decrease to maintain the balance of charge.
- If the increased negative ion has a lower conductance factor than the others, the net effect is a drop in conductivity for the final dialysate solution.

The Case of the Increasing Bicarbonate

Bath fixed components: Ca\(^{++}\) (1.5 mmol/L), K\(^{+}\) (2 mmol/L), Mg\(^{++}\) (0.5 mmol/L), CH\(_3\)COO\(^-\) (3.0 mmol/L), C\(_6\)H\(_{12}\)O\(_6\) (8.33 mmol/L)

Conductance factors: NaCl = 104.51, NaHCO\(_3\) = 73.97

### Table

<table>
<thead>
<tr>
<th>Bicarb (mmol/L)</th>
<th>30.0</th>
<th>31.0</th>
<th>32.0</th>
<th>33.0</th>
<th>34.0</th>
<th>35.0</th>
<th>36.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride (mmol/L)</td>
<td>110.0</td>
<td>109.0</td>
<td>108.0</td>
<td>107.0</td>
<td>106.0</td>
<td>105.0</td>
<td>104.0</td>
</tr>
<tr>
<td>Conductivity (mS/cm)</td>
<td>13.87</td>
<td>13.84</td>
<td>13.81</td>
<td>13.78</td>
<td>13.74</td>
<td>13.71</td>
<td>13.68</td>
</tr>
</tbody>
</table>

Dialysate Modification using Additives

- **Additives:**
  - Added as a liquid (slightly dilutes concentrate)
    - Potassium Chloride (30 mL vial)
  - Added as a powder (increases ion only)
    - Potassium Chloride
    - Calcium Chloride
    - Magnesium Chloride
    - Dextrose

Acid Concentrate Modification

Potassium – 30 mL raises 4.5 liter of acid concentrate by 0.5 mmol/L

<table>
<thead>
<tr>
<th>No Spike</th>
<th>1 Spike</th>
<th>2 Spikes</th>
<th>3 Spikes</th>
<th>4 Spikes</th>
<th>5 Spikes</th>
<th>6 Spikes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>100</td>
<td>99.54</td>
<td>99.06</td>
<td>98.54</td>
<td>98.02</td>
<td>97.50</td>
</tr>
<tr>
<td>K</td>
<td>1</td>
<td>1.49</td>
<td>1.99</td>
<td>2.48</td>
<td>2.97</td>
<td>3.47</td>
</tr>
<tr>
<td>Ca</td>
<td>1.5</td>
<td>1.49</td>
<td>1.48</td>
<td>1.47</td>
<td>1.46</td>
<td>1.45</td>
</tr>
<tr>
<td>Mg</td>
<td>0.5</td>
<td>0.497</td>
<td>0.493</td>
<td>0.490</td>
<td>0.487</td>
<td>0.484</td>
</tr>
<tr>
<td>Cl</td>
<td>105</td>
<td>104.86</td>
<td>104.62</td>
<td>104.44</td>
<td>104.27</td>
<td>104.11</td>
</tr>
<tr>
<td>C(<em>6)H(</em>{12})O(_6)</td>
<td>3</td>
<td>2.98</td>
<td>2.96</td>
<td>2.94</td>
<td>2.92</td>
<td>2.90</td>
</tr>
</tbody>
</table>

Key thoughts on Dialysate

- Dialysate is a prescription drug
- Never start a treatment without enough concentrate to finish the treatment
- Dialysate is an evolving chemistry
- If possible, use only one dilution type of concentrate in your facility
- Never adjust a conductivity monitor to correct an alarm condition

What is hardness?

- Hardness is defined by the various minerals of Calcium and Magnesium dissolved in water.
- There are 8 specific compounds:
  - Calcium Carbonate: CaCO\(_3\)
  - Calcium Bicarbonate: Ca(HCO\(_3\))\(_2\)
  - Calcium Sulfate: CaSO\(_4\)
  - Calcium Chloride: CaCl\(_2\)
  - Magnesium Carbonate: MgCO\(_3\)
  - Magnesium Bicarbonate: Mg(HCO\(_3\))\(_2\)
  - Magnesium Sulfate: MgSO\(_4\)
  - Other elements such as Iron and Manganese also add to total hardness when in high concentrations which is rare.
The hardness unit: Grain per gallon (gpg)

- A grain is 1/7000 of a pound = 0.0648 of a gram. (453.6 gm = 1 lb.)
- There’s about 25,000 grains of rice to a pound.
- A gallon of water weights 8.34 pounds.
- 1 grain/gallon = 0.000143/8.34 = 1.71 x 10^{-5}
- To convert this ratio to parts per million (ppm) multiply by 1 million:
  - (1.71 x 10^{-5}) x 10^6 = 1.71 x 10^1 = 17.1 ppm.
  - 1 ppm = 1 mg/L

Grains per gallon as CaCO₃

- Rather than list each mineral in water for its individual contribution to hardness, the minerals are converted to the equivalent amount of Calcium Carbonate and then added together.
- This conversion is done using the gram equivalent weights of the minerals.
- For Calcium and Magnesium compounds the equivalent weight of each compound is half its gram molecular weight because both Calcium (Ca++) and Magnesium (Mg++) have double charges.

Molecular and Equivalent Weights

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Molecular Weight</th>
<th>Equivalent Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium carbonate</td>
<td>100.090</td>
<td>50.045</td>
</tr>
<tr>
<td>Calcium bicarbonate</td>
<td>162.114</td>
<td>81.057</td>
</tr>
<tr>
<td>Calcium sulfate</td>
<td>136.142</td>
<td>68.071</td>
</tr>
<tr>
<td>Calcium chloride</td>
<td>110.986</td>
<td>55.493</td>
</tr>
<tr>
<td>Magnesium carbonate</td>
<td>84.322</td>
<td>42.161</td>
</tr>
<tr>
<td>Magnesium bicarbonate</td>
<td>146.346</td>
<td>73.173</td>
</tr>
<tr>
<td>Magnesium sulfate</td>
<td>120.374</td>
<td>60.187</td>
</tr>
<tr>
<td>Magnesium chloride</td>
<td>95.218</td>
<td>47.609</td>
</tr>
</tbody>
</table>

Equivalent Conversion Example

- The formula:
  \[
  \text{Amt. Of Mineral} = \frac{\text{Eqw. Wt. (CaCO}_3\text{)} \times \text{Eqw. Wt. (Mineral)}}{\text{Mineral of Amt.}}
  \]

- Convert 10.0 gpg of Magnesium sulfate to gpg as Calcium carbonate.
  \[
  10 \text{ gpgMgSO}_4 \times \left( \frac{50.045}{60.187} \right) = 8.31 \text{ gpg as CaCO}_3
  \]

Nitrogen Compounds

- Ammonia – NH₃
  Subtract a Hydrogen and add a Chlorine and you get:
- Mono-Chloramine – NH₂Cl
- Di-Chloramine – NHCl₂
- Nitrogen Trichloride – NCl₃

Chloramines

- Chloramines are less active, but more stable than free Chlorine
- Toxicity is not an issue
- Primary use is to control disinfectant byproducts in extended regions of municipal water systems
- Trihalomethanes (THMs) - MCL** = 80 µg/L
- Haloacetic Acids (HAAs) – MCL** = 60 µg/L
- Municipal Dosage: 1.5 mg/L to 5 mg/L.
- EPA limit for chloramines (as Cl₂): MRDL* = 4.0 mg/L

* Maximum Residual Disinfection Level
** Maximum Concentration Level

https://www3.epa.gov/region9/water/chloramine.html
Organic Chemistry - α–Amino Acids

- All amino acids must have an amino group and a carboxyl group

\[
\begin{align*}
\text{AMINO} & \quad (\text{NH}_2) \\
\text{CARBOXYL} & \quad (\text{COOH}^-)
\end{align*}
\]

- There are 20 amino acids used to build all human proteins.
  - 9 are essential (You must eat them.)
  - 11 are nonessential (You can make them.)

Proteins are...

- Complex organic compounds containing carbon, hydrogen, oxygen, nitrogen and sulfur.
- The main ingredient in the protoplasm of all living cells.
- High molecular weight molecules consisting of α – amino acids in peptide linkages.
- Each has a genetically defined sequence of amino acids which determine its shape and function.
- Water/salt solution soluble types:
  - Albumins, globulins, histones, protamines
- Water insoluble types:
  - Collagens, elastins, keratins, actins, myosin

Amino Acid Possibilities

<table>
<thead>
<tr>
<th>Amino Acid Chain</th>
<th>Combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>3</td>
<td>8,000</td>
</tr>
<tr>
<td>4</td>
<td>160,000</td>
</tr>
<tr>
<td>10</td>
<td>$1.024 \times 10^{13}$</td>
</tr>
<tr>
<td>100</td>
<td>$1.2675 \times 10^{130}$</td>
</tr>
</tbody>
</table>

The α–Amino Acids

<table>
<thead>
<tr>
<th>Essential</th>
<th>Non-essential</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Histidine</td>
<td></td>
</tr>
<tr>
<td>- Isoleucine</td>
<td></td>
</tr>
<tr>
<td>- Leucine</td>
<td></td>
</tr>
<tr>
<td>- Lysine</td>
<td></td>
</tr>
<tr>
<td>- Methionine</td>
<td></td>
</tr>
<tr>
<td>- Phenylalanine</td>
<td></td>
</tr>
<tr>
<td>- Threonine</td>
<td></td>
</tr>
<tr>
<td>- Tryptophan</td>
<td></td>
</tr>
<tr>
<td>- Valine</td>
<td></td>
</tr>
<tr>
<td>- Alanine</td>
<td></td>
</tr>
<tr>
<td>- Arginine</td>
<td></td>
</tr>
<tr>
<td>- Asparagine</td>
<td></td>
</tr>
<tr>
<td>- Aspartic Acid</td>
<td></td>
</tr>
<tr>
<td>- Cysteine</td>
<td></td>
</tr>
<tr>
<td>- Glutamic Acid</td>
<td></td>
</tr>
<tr>
<td>- Glutamine</td>
<td></td>
</tr>
<tr>
<td>- Glycine</td>
<td></td>
</tr>
<tr>
<td>- Proline</td>
<td></td>
</tr>
<tr>
<td>- Serine</td>
<td></td>
</tr>
<tr>
<td>- Tyrosine</td>
<td></td>
</tr>
</tbody>
</table>

WHAT IS UREA?

A compound formed in the liver by the process known as the urea cycle. Gram Molecular Weight = 60 Daltons

For the smallest amino acid, Glycine, R = CH - H

Formation of a peptide (miniature protein) is called peptide linking. Note that each middle amino acid in the chain has lost a water molecule (H₂O)

WHAT IS UREA?

- Principal end product of protein catabolism.
- Constitutes about half of the total urinary solids.
- Elevated level in blood = Azotemia

Friedrich Wöhler – 1828 – Silver Cyanate + Ammonium chloride = Urea + Silver chloride

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The Conversion Equation -
Protein to Urea Nitrogen

\[ PCR = 9.35 \, G + 11.04 \]

or

\[ G = \frac{PCR - 11.04}{9.35} \]

- **PCR**: Protein Catabolic rate (grams/day)
- **G**: Generation rate of urea nitrogen (milligrams/minute)

1 Gram of protein yields 128 milligrams of BUN

---

BUN Build-up in a Patient

- Patient’s Weight = 70 kg
- Assume 58% of weight is fluid volume = 40.6 liters
- Patient’s Volume = 40.6 liters = 406 deciliters
- If DPI = PCR = 84 g/day (1.2 g/kg/day x 70 kg), then:
  - \[ G = \frac{(84 - 11.04)}{9.35} = 7.80 \text{ mg/min.} \]
  - 7.80 mg/min x 60 min/hr = 468 mg/hr.
  - 468 mg/hr x 24 hr/day = 11,232 mg/day
  - 11,232 mg/day / 406 dL = 27.7 mg/dL/day.

---

**pH**

- Unit of measure that describes the degree of acidity or alkalinity of a solution
- Represented as the negative logarithm of the Hydrogen ion concentration or activity in moles/L

\[ \text{H}_3\text{O}^+ + \text{OH}^- \rightarrow 2\text{H}_2\text{O} \]

Hydronium Ion  Hydroxyl Ion  Water

- When the Hydronium and Hydroxyl ion concentrations are equal, the solution is neutral and has a pH of 7.
- pH of 7.0 = \(10^{-7} = 0.0000001\) mole/liter
- In pure water, for every Hydronium ion there are 555,000,000 water molecules.

---

**pH**

- Acids have a pH below 7.0 (Higher \(\text{H}_3\text{O}^+\))
- Bases have a pH above 7.0 (Lower \(\text{H}_3\text{O}^+\))
- A pH increase of only 0.3 means the concentration of \(\text{H}_3\text{O}^+\) has doubled
- The pH of various solutions:
  - Blood = 7.35 – 7.45
  - Dialysate = 7.00 – 7.40
  - Urine = 6.5 – 8.0
  - Baking Soda = 8.4
  - Bleach = 12.6
  - Sea Water = 8.0
  - Vinegar = 2.9

- Measurement of pH
  - pH paper color indicators – limited accuracy
  - pH electrodes – AAMI recommended
Blood pH and the Bicarbonate Ion

- Blood pH is directly related to the concentrations of bicarbonate and carbon dioxide in the blood.
- The relationship is defined by the Henderson-Hasselbalch Equation:

\[
\text{pH} = \text{pK} + \log \left( \frac{\text{HCO}_3^-}{0.03 \times \text{pCO}_2} \right)
\]

- Where: pK = the blood pH from acids in the blood
  \( \text{HCO}_3^- = \) bicarb concentration (mEq/L)
  \( \text{pCO}_2 = \) carbon dioxide pressure (mmHg)

Solving the equation

- Blood normal values for pK, \( \text{HCO}_3^- \), and \( \text{pCO}_2 \) are:
  - pK = 6.1, \( \text{HCO}_3^- = 24 \text{ mEq/L} \), and \( \text{pCO}_2 = 40 \text{ mmHg} \)
- Placing these values in the equation yields:

\[
\text{Blood pH} = 6.1 + \log \left( \frac{24 \text{ mEq/L}}{0.03 \times 40 \text{ mmHg}} \right)
\]

\[
\text{Blood pH} = 6.1 + \log \left( \frac{24}{1.2} \right)
\]

\[
\text{Blood pH} = 6.1 + \log(20) = 6.1 + 1.3 = 7.4
\]

Flame Emission Photometry

- Used to measure concentrations of Sodium and Potassium in solutions.
- The solution to be tested is atomized and injected into a burner flame.
- The Na and K atoms when heated produce specific colors which identify the atom type.
  - Sodium = 589.0 nm (Yellow)
  - Potassium = 766.5 nm (Infrared)
- The intensity of the light determines the amount of the element present.

Osmolality

- A measure of osmotic pressure interpreted as a measure of total concentration of solute particles per liter
- Solute + Solvent = Solution
- Unit of measure is the osmole
  - 1 mole of particles/liter
  - Osmotic pressure = 17,008 mmHg (330 psi)
- The freeze point of a solution is lowered by 1.86°C per osmole.
  - Blood Serum = 275-295 mOsm
  - Dialysate = 280-290 mOsm
  - Urine = 300-1100 mOsm

Osmometer

- Thermistor: feed/dost circuit
- Freezing bath
- Insulation
- Sample
- Stirrer/Bracket wire
Atomic Absorption Spectrophotometry

• Works by measuring the absorption of light as opposed to a flame photometer that measures light emission.
• Used in clinical labs to measure the concentration of Magnesium and Calcium in solution.
• Requires a special light source to generate monochromatic light to match the element to be measured.
  o Calcium = 422.7 nanometers
  o Magnesium = 285.2 nanometers