Chemical Reactions in Dialysis

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Terminology

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

McGraw Hill Dictionary of Scientific and Technical Terms, 2nd edition, Editor - Daniel N. Lapedes, © 1978, McGraw Hill Book Company, ISBN 0-07-045258-X, p 1041, 132.

Terminology

- **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

Handbook of Chemistry and Physics, 58th Edition, Editor - Robert C. West, Ph D, © 1977-78, CRC Press Inc., ISBN 0-8493-0458-X, p F-106

Terminology

- **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 ($NaHCO_3$) =

    23.00 + 1.008 + 12.01 + 3(16.00) = 84.018 grams

Handbook of Chemistry and Physics, 58th Edition, Editor - Robert C. West, Ph D, © 1977-78, CRC Press Inc., ISBN 0-8493-0458-X, p F-106

Terminology

- **Equivalent (Eq):**
  - One mole of charge – positive or negative.
  - Charges of the dialysate ions:

    Na^{+}, K^{+}, Mg^{++}, Ca^{++}, Cl^{-}, HCO_3^{-}, CH_3COO^{-}

  - One mole of Na^{+} ions = 1 Equivalent
  - One half mole of Ca^{++} ions = 1 Equivalent
  - 1/1000 Equivalent = 1 milliEquivalent = mEq
  - 1 milliEquivalent/liter = mEq/L

College Chemistry, Donald C. Gregg, © 1961, Allyn and Bacon Inc., p 220.

Chemistry Topics

- CO_2 in Dialysate – The mystery ingredient
- Hardness – What’s “as $CaCO_3$” mean?
- Urea vs. BUN – They aren’t the same
- Amino Acids – The Lego set for proteins
- The 1st Membrane – An explosive story

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:

$$CH_3COOH + HCO_3^- \longrightarrow CO_2 + H_2O + CH_3COO^-$$

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 bicarbonate concentrate becomes 33 mEq/L in the final dialysate solution.

How much CO_2 pressure 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. (0.1.76 gm of CO_2 /liter)
- From Avogadro's law, one mole of a gas occupies 22.4 liters at one atmosphere of pressure (760 mmHg)
- Boyle's Law: $P_1 \times V_1 = P_2 \times V_2$ hence

  760 mmHg x 22.4 liters = 17,024 mmHg x 1 liter

  17,024 mmHg / 250 = 68 mmHg
- Normal blood CO_2 pressure is 40 mmHg hence:
- CO_2 will go from the dialysate to the blood
- This is a good thing because CO_2 levels promote breathing and as a result, proper Oxygen levels.

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:

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

- Where: pK = the blood pH from acids in the blood

  HCO_3^- = bicarb concentration (mEq/L)

  pCO_2 = carbon dioxide pressure (mmHg)

Solving the equation

- Blood normal values for pK, HCO_3^- , and pCO_2 are:

  pK = 6.1, HCO_3^- = 24 mEq/L, and pCO_2 = 40 mmHg
- Placing these values in the equation yields:

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

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

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

What is hardness?

- **Hardness is defined by the various minerals of Calcium and Magnesium dissolved in water.**
- **There are 8 specific compounds:**
  - **Calcium Carbonate - $CaCO_3$ – chalk, limestone, marble**
  - **Calcium Bicarbonate – $Ca(HCO_3)_2$**
  - **Calcium Sulfate – $CaSO_4$ - gypsum**
  - **Calcium Chloride – $CaCl_2$**
  - **Magnesium Carbonate - $MgCO_3$ – chalk, limestone, marble**
  - **Magnesium Bicarbonate - $Mg(HCO_3)_2$**
  - **Magnesium Sulfate - $MgSO_4$ – Epsom salts**
  - **Magnesium Chloride - $MgCl_2$**
- **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 = 64.8 milligrams (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 = 1.71×10^{-5}
- To convert this ratio to parts per million (ppm) multiply by 1 million:

  $$(1.71 \times 10^{-5}) \times 10^{6} = 1.71 \times 10^{1} = 17.1 \text{ ppm.}$$

- 1 ppm = 1 mg/L

How hard is hard?

Hardness Level*	Grains per Gallon	Parts per Million
Soft	0 – 3.5	0 - 60
Medium	3.5 – 7.0	61 - 120
Hard	7.0 – 10.5	121 - 180
Very Hard	Over 10.5	181 +

* Defined by the United States Geological Survey

Grains per gallon as $CaCO_3$

- 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 it’s gram molecular weight because both Calcium (Ca^{++}) and Magnesium (Mg^{++}) have double charges.

Molecular and Equivalent Weights

	Molecular Weight	Equivalent Weight
Calcium carbonate	**100.090**	**50.045**
Calcium bicarbonate	**162.114**	**81.057**
Calcium sulfate	**136.142**	**68.071**
Calcium chloride	**110.986**	**55.493**
Magnesium carbonate	**84.322**	**42.161**
Magnesium bicarbonate	**146.346**	**73.173**
Magnesium sulfate	**120.374**	**60.187**
Magnesium chloride	**95.218**	**47.609**

Equivalent Conversion Example

- The formula:

$$\text{Amt. of Mineral} \times \frac{\text{Eqv. Wt. }(CaCO_3)}{\text{Eqv. Wt. }(\text{Mineral})} = \text{Amt. Of Mineral as } CaCO_3$$

- Convert 10.0 gpg of Magnesium sulfate to gpg as Calcium carbonate.

$$10\text{ gpg } MgSO_4 \times \left(\frac{50.045}{60.187}\right) = 8.31\text{ gpg as } CaCO_3$$

Urea vs. BUN

- Urea - A compound formed in the liver by the process known as the urea cycle. It's formula and gram molecular weight is:

$$CO(NH_2)_2$$

12.01 + 16.00 + [14.008 + (1.008 x 2)] x 2 = 60.058 Daltons

- BUN = Blood Urea Nitrogen = Amount of nitrogen from the urea in the blood.
- Ratio: Urea/Urea Nitrogen =

60.058/2 x 14.008 = 60.058/28.016 = 2.14

Dorland's Illustrated Medical Dictionary, Editor: Elizabeth J. Taylor, 27th Edition,1988, W. B. Saunders Company, pp 59, 1789.

Other Nitrogen Compounds

- Ammonia – NH_3
- Subtract a Hydrogen and add a Chlorine and you get:
- Mono-Chloramine – NH_2Cl
- Subtract a Hydrogen and add a Chlorine and you get:
- Di-Chloramine – $NHCl_2$
- Subtract a Hydrogen and add a Chlorine and you get:
- Nitrogen Trichloride – NCl_3

Organic Chemistry - α–Amino Acids

- All amino acids must have an amino group and an carboxyl group
  - AMINO CARBOXYL
    - (NH_2^-) ($COOH^+$)
- 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.)

Dorland's Illustrated Medical Dictionary, Editor: Elizabeth J. Taylor, 27th Edition,1988, W. B. Saunders Company, pp 59, 1370.

The α–Amino Acids

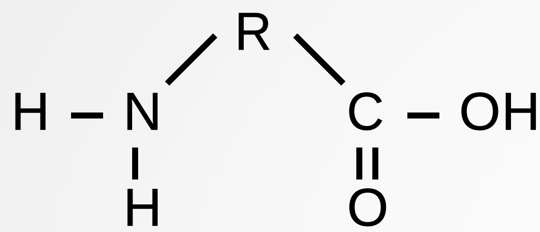
- Essential
  - Histidine
  - Isoleucine
  - Leucine
  - Lysine
  - Methionine
  - Phenylalanine
  - Threonine
  - Tryptophan
  - Valine

- Non-essential
  - Alanine
  - Arginine
  - Asparagine
  - Aspartic Acid
  - Cysteine
  - Glutamic Acid
  - Glutamine
  - Glycine
  - Proline
  - Serine
  - Tyrosine

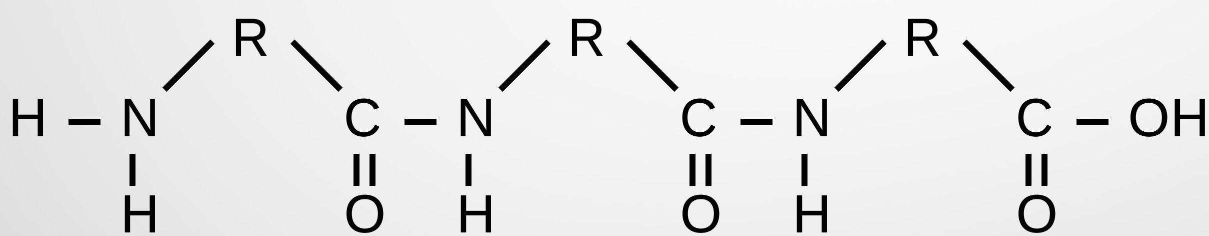
Proteins are…

- 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 Structure/Bonding



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 (H_2O)

Organic Chemistry, M. A. Fox and J. K. Whitesell, Copyright 1994, Jones and Bartlett, pp 619-621

Amino Acid Possibilities

Amino Acid Chain	Combinations
2	400
3	8,000
4	160,000
10	1.02×10^{13}
100	1.27×10^{130}

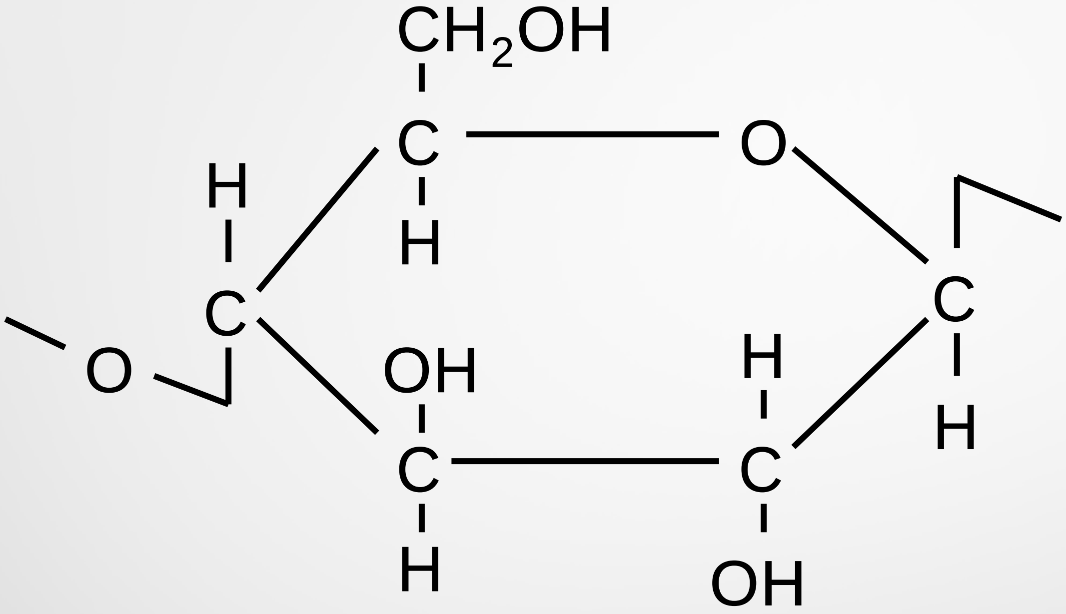
The first practical membrane

- 1845 – Friedrich Schoenbeim spills a combination of nitric and hydrochloric acids and wipes it up with his wife's cotton apron.
- The reaction synthesizes cellulose trinitrate (gun cotton).
- He patents the process and forms his own company making the product which proved to be a fairly safe explosive for construction and mining.
- Adapted by Alfred Nobel of Sweden into a controlled explosive called dynamite.
- Nobel uses his wealth to create the Nobel Prizes.
- Schoenbeim also discovered cellulose dinitrate which could be dissolved in ether and then dried to make thin films of the material.

The development of Collodion

- Sheets of cellulose dinitrate were used as surgical dressings and the basis for photographic film until 1935.
- The material was called “collodion” from the Greek word “*Kolla*” for glue like substance.
- In the laboratory it became known as a good semipermeable membrane and was used by Fick to study diffusion.
- 1913 – It was used by Able, Roundtree, and Turner to perform the first in vivo studies of blood. They made the collodion into tubes by dipping glass rods into the collodion solution.
- 1924 - Haas dialyzed patients using collodion for two years but none of the patients lived.
- 1929 - Collodion was replaces by cellulose acetate when the Visking company in Chicago started making tubes of cellulose acetate for sausage casing.

Cellulose – $(C_6H_{10}O_5)_N$



The main polysaccharide of plant cell walls. It's a polymer of β–D-glucose with a water molecule removed to form links between units resulting in chains of between 2000 and 4000 units long.

McGraw Hill page 263