METROLOGY FOR BIOMEDS

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WHY ARE UNITS OF MEASURE IMPORTANT?

- Accurate Communication
  - Which statement maximizes understanding?
    - “This dialysate is a 2 K.”
    - “This dialysate has a Potassium of 2 mEq/L.”
  - Which statement sounds professional?
    - “The water was running around 8 this morning.”
    - “The water TDS was about 8 ppm this morning.”
- Standard values needed internationally
    - Known as the International System of Units and abbreviated SI (Le Systeme International d’unites)
    - In the United States the system is managed by the National Institute of Standards and Technology (NIST)

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST)

- Founded in 1901 as a non-regulatory federal agency of the Department of Commerce
- Presently has an operating budget of about $843 million annually
- The Weights and Measures Division
  - Promotes uniformity standards of U.S. weights and measure laws
  - Enables equality between buyers and sellers in the marketplace
  - Works at the state and local level to provide training for metrologists
  - Develops procedures for various weight and measurement testing devices
- In 2015 $8.7 trillion dollars of products and services (≈50% of the US Gross Domestic Product) were impacted by the NIST

ISO 9000 STANDARDS

- ISO = International Organization for Standardization
- The first standards ever published where done by the U. S. Military to specify a quality assurance system for their suppliers. (MIL-I-Q9858 and MIL-I45208)
- The British developed their own Defense Standards in 1979 entitled BS5750: 1979 parts 1, 2, and 3.
- In 1987, after much deliberation and arguments, ISO 9001, ISO 9002, and ISO9003 were published to establish an international standard for quality. These standards were then adapted by each country in the coming years
- Today, additional revisions have resulted in a single document: ISO 9001: 2000

REQUIREMENTS OF ISO 9001: 2000

- The organization shall identify the measurements to be made and the measuring and monitoring devices required to assure conformity of product to specified requirements.
- Measuring and monitoring devices shall be used and controlled to ensure that measurement capability is consistent with the measurement requirements.
- Measurement and monitoring shall be calibrated and adjusted periodically or prior to use, against devices traceable to international or national standards; where no such standards exist the basis used for calibration shall be recorded

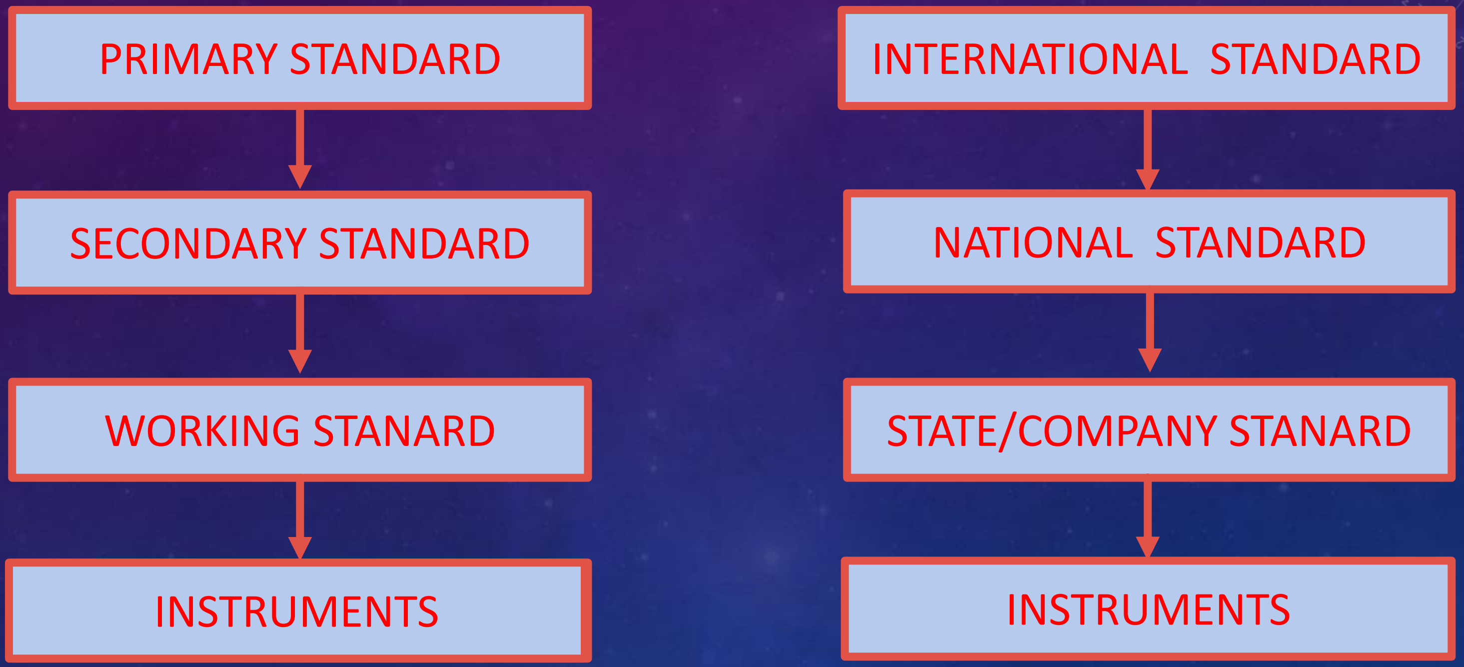
REQUIREMENTS OF ISO 9001: 2000

- Where applicable measuring and monitoring devices shall:
  - Be safeguarded from adjustments that would invalidate the calibration
  - Be protected from damage and deterioration during handling, maintenance, and storage
  - Have the results of their calibrations recorded
  - Have the validity of previous results reassessed if they are subsequently found to be out of calibration, and corrective action taken.

CONCEPTS OF MEASUREMENT

- Measurand – the specific quantity determined in a measurement process
- Influence quantity – any quantity that may affect the Measurand such as temperature (conductivity at 25^{0} C)
- True value – a quantity defined (mmHg) if there was no error in measurement. It cannot be determined experimentally.
- Nominal value – the approximate or rounded off value for a measurement or device.
- Conventional true value – the “exact” value as measured by a device that has a greater accuracy that the measured value.
- Error – the difference between a measured value and it’s conventional true value.
- Accuracy – the difference between a higher standard value and the measured value.
- Precision – The standard deviation of a series of measurements against the final mean value

HIERARCHY OF STANDARDS



SI – A BRIEF HISTORY

- The metric system was conceived by a group of scientists including Lavoisier known as the "father of modern chemistry" who were commissioned by King Louis XVI.
- The base units were first established in 1795.
    - Meter – 1/10,000,000 of the distance between the equator and the north pole through the meridian of Paris.
    - Second – 1/86,400 of a day. Later it became 1/31,622,400 of the year 1900.
    - Kelvin – 1/100 of the difference between the freezing and boiling points of water
    - Kilogram – the mass of one liter of water at 0^{o} Centigrade. Changed to a reference temp of 4^{o} C later the same year. The platinum "Kilogramme des Archives" was created in 1799.
- The system is a living system and continually evolves.

THE SI BASE UNITS TODAY

Length	**meter**	**m**
Mass	**kilogram**	**kg**
Time	**second**	**s**
Electric Current	**ampere**	**A**
Temperature	**Kelvin**	**K**
Luminous intensity	**candela**	**cd**
Amount of substance	**mole**	**mol**

- The 1st six were established by the 10th General Conference of Weights and Measures (CGPM) in 1954
- The mole was added as a 7th base unit by the 14th CGPM in 1971

DEFINITIONS

- Meter – the length traveled by light in a vacuum in 1/299,792,458 of a second. In the lab, it's measured as 1,579,800.298728 wavelengths of a helium-neon laser.
- Kilogram – a platinum-iridium mass kept in Sevres, France and used as a reference world wide. Known as the international prototype kilogram
- Second – the duration of 9,192,631,770 periods of radiation of the ground state of Cesium-133 atom
- Ampere - the current in two infinite parallel wires one meter apart that produces a force of 2×10^{-7} newtons. A coulomb of charge/second.
- Kelvin – temperature scale defined by various elements change of state. Triple point of water = 273.16 K, Sulfur liquid-gas equilibrium = 717.75 K, gold solid-liquid equilibrium = 1336.15 K
- Candela – the light from a black body with a surface area of 1/600,000 of a square meter at the solidification temperature of platinum (2045 K)

DERIVED UNITS
M = MASS, L = LENGTH, T = TIME, Q = CHARGE

- Units made from combinations of the fundamental units.
  - Force = Newton = mass x acceleration = kilogram x meter/second^2 = MLT^{-2}
  - Pressure = Pascal = Force/area = newton/meter^2 = $ML^{-1}T^{-2}$
  - Energy = Joule = force x length = newton x meter = ML^2T^{-2}
  - Power = Watt = energy/time = joule/second = ML^2T^{-3}
  - Potential Difference = Volt = power/current = joule/ampere = $ML^2T^{-2}Q^{-1}$
  - Conductance = Siemens = current/potential difference = ampere/volt = $M^{-1}L^{-2}TQ^2$
  - Conductivity = conductance/length = Siemens/meter = $M^{-1}L^{-3}TQ^2$

WHO ARE THOSE GUYS?

- Andre Marie Ampere (1775–1836) – French physicist and mathematician. Founder of electrodynamics. Related current to magnetic field strength.
- Kelvin, William Thompson (1824-1907) – British mathematician and physicist. Contributed to thermodynamics, related size of particles to dissolving rate.
- Isaac Newton (1642–1727) – English mathematician. Dynamic theory of gravity, laws of motion, Calculus.
- Blaise Pascal (1623-1662) – French physicist and mathematician. Defined pressure distribution in a liquid, probability theory.
- Alessandro Volta (1745-1827) – Italian physicist. Developed the first battery, theory of electrical current.

PREFIXES FOR UNITS

Power of 10	Prefix	Symbol	Power of 10	Prefix	Symbol
+1	deca	da	-1	deci	d
+2	hecto	h	-2	centi	c
+3	kilo	k	-3	milli	m
+6	mega	M	-6	micro	μ
+9	giga	C	-9	nano	n
+12	tera	T	-12	pico	p
+15	exa	E	-15	femto	f
+18	peta	P	-18	atto	a
+21	zetta	Z	-21	zepto	z
+24	yotta	Y	-24	yocto	y

CHEMISTRY UNITS

- **Mole**
  - International measure of amount of substance
  - The number of atoms in 12 grams of carbon-12.
  - $6.02214179 \times 10^{23}$ mol^{-1}(about 600 septillion)
  - Known as Avogadro's Number, N_A
  - Amedeo Avogadro (1776-1856)
  - 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.

CHEMISTRY UNITS

- **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

CHEMISTRY UNITS

- **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.
  - Calcium Carbonate ($CaCO_3$) molecular weight =

    Ca + C + 3(O) = 40.08 + 12.01 + 3(16.00) = 100.09 grams
  - Magnesium Chloride ($MgCl_2$) molecular weight =

    Mg + 2(Cl) = 24.31 + 2(35.45) = 95.21 grams

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CHEMISTRY UNITS

- **Equivalent (Eq):**
  - One mole of charge – positive or negative.
  - Charges of common ions:
    - Na^{+}, K^{+}, Mg^{++}, Ca^{++}, Cl^{-}, HCO_3^{-}, CO_3^{-}, SO_4^{--}
  - One mole of Ca^{++} ions = 2 Equivalents = 40.08 grams
  - One half mole of Ca^{++} ions = 1 Equivalent = 20.08 grams
  - One third mole of Al^{+++} ions = 1 Equivalent = 8.994 grams
  - One half mole of $CaCO_3$ = 1 Equivalent = 50.045 grams
  - 1/1000 of an Equivalent = 1 milliEquivalent = 1 mEq
  - 1 mEq per liter of solution = 1 mEq/L

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

CHEMISTRY UNITS - 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

$$H_3O^+ \quad + \quad OH^- \rightleftharpoons 2H_2O$$

Hydronium Ion **Hydroxyl Ion** **Water**

- In a glass of pure water, there is one hydronium and one hydroxyl ion for every 550,000,000 water molecules!
- When the Hydronium and Hydroxyl ion concentrations are equal, the solution is neutral and has a pH of 7.0 (0.0000001 moles/liter)
- In water, when the concentration of Hydronium goes up, the concentration of Hydroxyl goes down in proportion and visa versa.

CHEMISTRY UNITS - pH

- Acids have a pH below 7.0 (Higher H_3O^+)
- Bases have a pH above 7.0 (Lower H_3O^+)
- The pH of various solutions:

  Blood = 7.35 – 7.45   Dialysate = 7.00 – 7.40

  Vinegar = 2.9   Bleach = 12.6

  Baking Soda = 8.4   Sea Water = 8.0
- Measurement of pH
  - pH paper color indicators - limited accuracy
  - pH electrodes – AAMI recommended

PRESSURE RELATIONSHIPS

	Pascal (Pa)	Atmosphere (atm)	mmHg (torr)	P.S.I.
Pascal (Pa)	1	9.869233 X 10^{-6}	7.500617 X 10^{-3}	1.450377 X 10^{-4}
Atmosphere (atm)	101325	1	760	14.69595
mmHg	133.3224	1.3157895 X 10^{-3}	1	0.01933678
P.S.I.	6894.757	0.06804596	51.71493	1

1 inch Hg = 25.4 mmHg, 1 P.S.I. = 0.0703 kg/cm^2, 1 bar = 100,000 Pa

1 P.S.I. = 1 P.S. I. G. = 1 P.S.I. A. + 1 Atmosphere

THE HARDNESS UNIT: GRAIN PER GALLON (GPG)

- A grain is 1/7000 of a pound = 0.0648 of a gram.
- There's about 25,000 grains of rice to a pound.
- Hardness is generally measured in grains per gallon.
- A gallon of water weights 8.33 pounds.
- 1 grain/1 gallon = 0.000143/8.33 = 1.71×10^{-5}
- To convert this ratio to parts per million (ppm) multiply by 1 million:

  $1.71 \times 10^{-5} \times 10^{6} = 17.1$ ppm.

HARD WATER IN THE UNITED STATES

- The range of hardness in the USA is from 1 to 350 gpg. (17.1 ppm – 6,000 ppm).
- Most water is in the range of 3 to 50 gpg.
- New York city water runs between 1 and 3 grains of hardness as does Oregon and Washington
- California hardness is generally in the 3.5 to 7 gpg range except its east central area which has hardness above 10 grains
- Arizona and New Mexico are also areas of 10+ gpg.

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 are also considered hardness when in high concentrations which is rare.

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 molecular weight because both Calcium (Ca^{++}) and Magnesium (Mg^{++}) are double charged.

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:

$$\text{Amount of mineral x } \frac{\text{Equivalent wt. of } CaCO_3}{\text{Equivalent wt. of mineral}}$$

$$= \text{Amount of mineral as } CaCO_3$$

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

$$10.0 \text{ gpg } MgSO_4 \text{ x } \frac{50.045}{60.187} = 8.31 \text{ gpg as } CaCO_3$$

HOW IMPORTANT IS METROLOGY?

- OCTOBER 1st , 1999
- NASA's $125 million dollar Mars Climate Orbiter was lost.
- NASA (Jet Propulsion Lab) exchanged critical data for the launch using the Metric system.
- Lockheed Martin Astronautics, the designer of the Orbiter, used the English system to provide acceleration data.
- The JPL engineers mistook the data from Lockheed Martin to be in Metric system units of measure resulting in the launch failure.