Electrolyte Solutions: Milliequivalents, Millimoles, and Milliosmoles

12

PHARMACEUTICAL CALCULATIONS
LECTURE 2
LEVEL1 (2022/2023)

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Objectives

Upon successful completion of this chapter, the student will be able to:

- Calculate the milliequivalent weight from an atomic or formula weight.
- Convert between milligrams and milliequivalents.
- Calculate problems involving milliequivalents.
- Calculate problems involving millimoles and milliosmoles.

As noted in Chapter 11, the molecules of chemical compounds in solution may remain intact, or they may dissociate into particles known as ***ions,*** which carry an electric charge. Substances that are not dissociated in solution are called ***nonelectrolytes***, and those with varying degrees of dissociation are called ***electrolytes***. Urea and dextrose are examples of nonelectrolytes in body water; sodium chloride in body fluids is an example of an electrolyte.

Sodium chloride in solution provides Na^+ and Cl^- ions, which carry electric charges. If electrodes carrying a weak current are placed in the solution, the ions move in a direction opposite to the charges. Na^+ ions move to the negative electrode (*cathode*) and are called *cations*. Cl^- ions move to the positive electrode (*anode*) and are called *anions*.

Electrolyte ions in the blood plasma include the cations Na^+, K^+, Ca^{++}, and Mg^{++} and the anions Cl^-, HCO_3^-, HPO_4^{--}, SO_4^{--}, organic acids$^-$, and protein$^-$. Electrolytes in body fluids play an important role in maintaining the acid-base balance in the body. They play a part in controlling body water volumes and help to regulate body metabolism.

Applicable Dosage Forms

Electrolyte preparations are used in the treatment of disturbances of the electrolyte and fluid balance in the body. In clinical practice, they are provided in the form of oral solutions and syrups, as dry granules intended to be dissolved in water or juice to make an oral solution, as oral tablets and capsules and, when necessary, as intravenous infusions.

Milliequivalents

A *chemical unit*, the ***milliequivalent (mEq),*** is now used almost exclusively in the United States by clinicians, physicians, pharmacists, and manufacturers to express the concentration of electrolytes in solution. This unit of measure is related to the total number of ionic charges in solution, and it takes note of the valence of the ions. In other words, it is a unit of measurement of the amount of *chemical activity* of an electrolyte. In the International System (SI), which is used in European countries and in many others throughout the world, molar concentrations [as millimoles per liter (mmol/L) and micromoles per liter (μmol/L)] are used to express most clinical laboratory values, including those of electrolytes.

TABLE 12.1 BLOOD PLASMA ELECTROLYTES IN MILLIEQUIVALENTS PER LITER (mEq/L)

CATIONS	mEq/L	ANIONS	mEq/L
Na^{+}	142	HCO_3^{-}	24
K^{+}	5	Cl^{-}	105
Ca^{++}	5	HPO_4^{--}	2
Mg^{++}	2	SO_4^{--}	1
		Org. Ac.$^{-}$	6
		Proteinate^{-}	16
	154		154

CALCULATIONS CAPSULE

Milliequivalents

To convert milligrams (mg) to milliequivalents (mEq):

$$mEq = \frac{mg \times Valence}{Atomic,\ formular,\ or\ molecular\ weight}$$

To convert milliequivalents (mEq) *to milligrams (mg):*

$$\text{mg} = \frac{\text{mEq} \times \text{Atomic, formula, or molecular weight}}{\text{Valence}}$$

To convert milliequivalents per milliliter (mEq/mL) *to milligrams per milliliter (mg/mL):*

$$mg/mL = \frac{mEq/mL \times Atomic,\ formula,\ or\ molecular\ weight}{Valence}$$

Milliequivalents

What is the concentration, in milligrams per milliliter, of a solution containing 2 mEq of potassium chloride (KCl) per milliliter?

$$\text{Molecular weight of KCl} = 74.5$$
$$\text{Equivalent weight of KCl} = 74.5$$
$$1 \text{ mEq of KCl} = \tfrac{1}{1000} \times 74.5 \text{ g} = 0.0745 \text{ g} = 74.5 \text{ mg}$$
$$2 \text{ mEq of KCl} = 74.5 \text{ mg} \times 2 = 149 \text{ mg/mL, } \textit{answer.}$$

Or, by using the preceding equation:

$$\text{mg/mL} = \frac{2 \text{ (mEq/mL)} \times 74.5}{1} = 149 \text{ mg/mL, } \textit{answer.}$$

Milliequivalents

To convert milligrams (mg) to milliequivalents (mEq):

$$mEq = \frac{mg \times Valence}{\text{Atomic, formular, or molecular weight}}$$

To convert milliequivalents (mEq) to milligrams (mg):

$$\text{mg} = \frac{\text{mEq} \times \text{Atomic, formula, or molecular weight}}{\text{Valence}}$$

To convert milliequivalents per milliliter (mEq/mL) to milligrams per milliliter (mg/mL):

$$mg/mL = \frac{mEq/mL \times \text{Atomic, formula, or molecular weight}}{\text{Valence}}$$

What is the concentration, in grams per milliliter, of a solution containing 4 mEq of calcium chloride ($CaCl_2{\cdot}2H_2O$) per milliliter?

Recall that the equivalent weight of a binary compound may be found by dividing the formula weight by the *total valence* of the positive or negative radical.

$$\text{Formula weight of } CaCl_2{\cdot}2H_2O = 147$$
$$\text{Equivalent weight of } CaCl_2{\cdot}2H_2O = \tfrac{147}{2} = 73.5$$
$$1 \text{ mEq of } CaCl_2{\cdot}2H_2O = \tfrac{1}{1000} \times 73.5 \text{ g} = 0.0735 \text{ g}$$
$$4 \text{ mEq of } CaCl_2{\cdot}2H_2O = 0.0735 \text{ g} \times 4 = 0.294 \text{ g/mL, } \textit{answer.}$$

Note: The water of hydration molecules does not interfere in the calculations as long as the correct molecular weight is used.

Milliequivalents

What is the percent (w/v) concentration of a solution containing 100 mEq of ammonium chloride per liter?

$$\text{Molecular weight of } NH_4Cl = 53.5$$
$$\text{Equivalent weight of } NH_4Cl = 53.5$$
$$1 \text{ mEq of } NH_4Cl = \tfrac{1}{1000} \times 53.5 = 0.0535 \text{ g}$$
$$100 \text{ mEq of } NH_4Cl = 0.0535 \text{ g} \times 100 = 5.35 \text{ g/L or}$$

0.535 g per 100 mL, or 0.535%, *answer.*

A solution contains 10 mg/100 mL of K^+ ions. Express this concentration in terms of milliequivalents per liter.

$$\text{Atomic weight of } K^+ = 39$$
$$\text{Equivalent weight of } K^+ = 39$$
$$1 \text{ mEq of } K^+ = \tfrac{1}{1000} \times 39 \text{ g} = 0.039 \text{ g} = 39 \text{ mg}$$
$$10 \text{ mg/100 mL of } K^+ = 100 \text{ mg of } K^+ \text{ per liter}$$
$$100 \text{ mg} \div 39 = 2.56 \text{ mEq/L, } \textit{answer.}$$

Or, by the equation detailed previously:

$$\text{mEq/L} = \frac{100 \text{ (mg/L)} \times 1}{39}$$
$$= 2.56 \text{ mEq/L, } \textit{answer.}$$

Milliequivalents

To convert milligrams (mg) to milliequivalents (mEq):

$$mEq = \frac{mg \times Valence}{\text{Atomic, formular, or molecular weight}}$$

To convert milliequivalents (mEq) to milligrams (mg):

$$mg = \frac{mEq \times \text{Atomic, formula, or molecular weight}}{Valence}$$

To convert milliequivalents per milliliter (mEq/mL) to milligrams per milliliter (mg/mL):

$$mg/mL = \frac{mEq/mL \times \text{Atomic, formula, or molecular weight}}{Valence}$$

Milliequivalents

A solution contains 10 mg/100 mL of Ca^{++} ions. Express this concentration in terms of milliequivalents per liter.

$$\text{Atomic weight of } Ca^{++} = 40$$
$$\text{Equivalent weight of } Ca^{++} = {}^{40}\!/_{2} = 20$$
$$1 \text{ mEq of } Ca^{++} = {}^{1}\!/_{1000} \times 20 \text{ g} = 0.020 \text{ g} = 20 \text{ mg}$$
$$10 \text{ mg/100 mL of } Ca^{++} = 100 \text{ mg of } Ca^{++} \text{ per liter}$$
$$100 \text{ mg} \div 20 = 5 \text{ mEq/L}, \textit{ answer.}$$

A magnesium (Mg^{++}) level in blood plasma is determined to be 2.5 mEq/L. Express this concentration in terms of milligrams.

$$\text{Atomic weight of } Mg^{++} = 24$$
$$\text{Equivalent weight of } Mg^{++} = {}^{24}\!/_{2} = 12$$
$$1 \text{ mEq of } Mg^{++} = {}^{1}\!/_{1000} \times 12 \text{ g} = 0.012 \text{ g} = 12 \text{ mg}$$
$$2.5 \text{ mEq of } Mg^{++} = 30 \text{ mg}$$
$$30 \text{ mg/L}, \textit{ answer.}$$

Milliequivalents

To convert milligrams (mg) to milliequivalents (mEq):

$$mEq = \frac{mg \times Valence}{\text{Atomic, formular, or molecular weight}}$$

To convert milliequivalents (mEq) to milligrams (mg):

$$\text{mg} = \frac{\text{mEq} \times \text{Atomic, formula, or molecular weight}}{\text{Valence}}$$

To convert milliequivalents per milliliter (mEq/mL) to milligrams per milliliter (mg/mL):

$$mg/mL = \frac{mEq/mL \times \text{Atomic, formula, or molecular weight}}{\text{Valence}}$$

Milliequivalents

How many milliequivalents of potassium chloride are represented in a 15-mL dose of a 10% (w/v) potassium chloride elixir?

$$\text{Molecular weight of KCl} = 74.5$$
$$\text{Equivalent weight of KCl} = 74.5$$
$$1 \text{ mEq of KCl} = \tfrac{1}{1000} \times 74.5 \text{ g} = 0.0745 \text{ g} = 74.5 \text{ mg}$$
$$\text{15-mL dose of 10\% (w/v) elixir} = 1.5 \text{ g or } 1500 \text{ mg of KCl}$$
$$\frac{74.5 \text{ (mg)}}{1500 \text{ (mg)}} = \frac{1 \text{ (mEq)}}{x \text{ (mEq)}}$$
$$x = 20.1 \text{ mEq, } \textit{answer.}$$

How many milliequivalents of magnesium sulfate are represented in 1 g of anhydrous magnesium sulfate ($MgSO_4$)?

$$\text{Molecular weight of } MgSO_4 = 120$$
$$\text{Equivalent weight of } MgSO_4 = 60$$
$$1 \text{ mEq of } MgSO_4 = \tfrac{1}{1000} \times 60 \text{ g} = 0.06 \text{ g} = 60 \text{ mg}$$
$$1.0 \text{ g of } MgSO_4 = 1000 \text{ mg}$$
$$\frac{60 \text{ (mg)}}{1000 \text{ (mg)}} = \frac{1 \text{ (mEq)}}{x \text{ (mEq)}}$$
$$x = 16.7 \text{ mEq, } \textit{answer.}$$

Milliequivalents

To convert milligrams (mg) to milliequivalents (mEq):

$$mEq = \frac{mg \times Valence}{\text{Atomic, formular, or molecular weight}}$$

To convert milliequivalents (mEq) to milligrams (mg):

$$mg = \frac{mEq \times \text{Atomic, formula, or molecular weight}}{Valence}$$

To convert milliequivalents per milliliter (mEq/mL) to milligrams per milliliter (mg/mL):

$$mg/mL = \frac{mEq/mL \times \text{Atomic, formula, or molecular weight}}{Valence}$$

Milliequivalents

How many milliequivalents of Na^+ would be contained in a 30-mL dose of the following solution?

Disodium hydrogen phosphate	18 g
Sodium biphosphate	48 g
Purified water ad	100 mL

Milliequivalents

To convert milligrams (mg) to milliequivalents (mEq):

$$mEq = \frac{mg \times Valence}{Atomic,\ formular,\ or\ molecular\ weight}$$

To convert milliequivalents (mEq) to milligrams (mg):

$$mg = \frac{mEq \times Atomic,\ formula,\ or\ molecular\ weight}{Valence}$$

To convert milliequivalents per milliliter (mEq/mL) to milligrams per milliliter (mg/mL):

$$mg/mL = \frac{mEq/mL \times Atomic,\ formula,\ or\ molecular\ weight}{Valence}$$

Each salt is considered separately in solving the problem.

Disodium hydrogen phosphate

$$\text{Formula} = Na_2HPO_4.7H_2O$$

$$\text{Molecular weight} = 268 \text{ and the equivalent weight} = 134$$

$$\frac{18\ (g)}{x\ (g)} = \frac{100\ (mL)}{30\ (mL)}$$

$$x = 5.4 \text{ g of disodium hydrogen phosphate per 30 mL}$$

$$1\ mEq = \frac{1}{1000} \times 134\ g = 0.134\ g = 134\ mg$$

$$\frac{134\ (mg)}{5400\ (mg)} = \frac{1\ (mEq)}{x\ (mEq)}$$

$$x = 40.3 \text{ mEq of disodium hydrogen phosphate}$$

Because the milliequivalent value of Na^+ ion equals the milliequivalent value of disodium hydrogen phosphate, then

$$x = 40.3 \text{ mEq of } Na^+$$

Milliequivalents

To convert milligrams (mg) to milliequivalents (mEq):

$$mEq = \frac{mg \times Valence}{Atomic,\ formular,\ or\ molecular\ weight}$$

To convert milliequivalents (mEq) to milligrams (mg):

$$mg = \frac{mEq \times \text{Atomic, formula, or molecular weight}}{\text{Valence}}$$

To convert milliequivalents per milliliter (mEq/mL) to milligrams per milliliter (mg/mL):

$$mg/mL = \frac{mEq/mL \times \text{Atomic, formula, or molecular weight}}{\text{Valence}}$$

Sodium biphosphate

$$\text{Formula} = NaH_2PO_4.H_2O$$

$$\text{Molecular weight} = 138 \text{ and the equivalent weight} = 138$$

$$\frac{48\ (g)}{x\ (g)} = \frac{100\ (mL)}{30\ (mL)}$$

$$x = 14.4 \text{ g of sodium biphosphate per 30 mL}$$

$$1\ mEq = \tfrac{1}{1000} \times 138\ g = 0.138\ g = 138\ mg$$

$$\frac{138\ (mg)}{14{,}400\ (mg)} = \frac{1\ (mEq)}{x\ (mEq)}$$

$$x = 104.3 \text{ mEq of sodium biphosphate}$$

$$\text{and also,} = 104.3 \text{ mEq of } Na^+$$

Adding the two milliequivalent values for Na^+ = 40.3 mEq + 104.3 mEq = 144.6 mEq, *answer.*

A person is to receive 2 mEq of sodium chloride per kilogram of body weight. If the person weighs 132 lb., how many milliliters of a 0.9% sterile solution of sodium chloride should be administered?

$$\text{Molecular weight of NaCl} = 58.5$$

$$\text{Equivalent weight of NaCl} = 58.5$$

$$1 \text{ mEq of NaCl} = \tfrac{1}{1000} \times 58.5\ g = 0.0585\ g$$

$$2 \text{ mEq of NaCl} = 0.0585\ g \times 2 = 0.117\ g$$

$$1\ kg = 2.2\ lb. \qquad \text{Weight of person in kg} = \frac{132\ lb.}{2.2\ lb.} = 60\ kg$$

Because the person is to receive 2 mEq/kg, then 2 mEq or 0.117 g × 60 = 7.02 g of NaCl needed and because 0.9% sterile solution of sodium chloride contains

9 g of NaCl per liter,

$$\frac{9\ (g)}{7.02\ (g)} = \frac{1000\ (mL)}{x\ (mL)}$$

$$x = 780 \text{ mL, } \textit{answer.}$$

Millimoles and Micromoles

As noted previously, the SI expresses electrolyte concentrations in *millimoles per liter (mmol/L)* in representing the combining power of a chemical species. For monovalent species, the numeric values of the milliequivalent and millimole are identical.

A ***mole*** is the molecular weight of a substance in grams. A ***millimole*** is one thousandth of a mole and a ***micromole*** is one millionth of a mole.

Example Calculations of Millimoles and Micromoles

How many millimoles of monobasic sodium phosphate (m.w. 138) are present in 100 g of the substance?

To calculate millimoles (mmol):

A *millimole* is 1/1000 of the gram molecular weight of a substance.

$$1 \text{ millimole} = \frac{\text{Molecular weight, grams}}{1000}$$

$$\text{m.w.} = 138$$
$$1 \text{ mole} = 138 \text{ g}$$
$$\frac{1 \text{ (mole)}}{x \text{ (mole)}} = \frac{138 \text{ (g)}}{100 \text{ (g)}}$$
$$x = 0.725 \text{ moles} = 725 \text{ mmol, } \textit{answer.}$$

How many milligrams would 1 mmol of monobasic sodium phosphate weigh?

$$1 \text{ mole} = 138 \text{ g}$$
$$1 \text{ mmol} = 0.138 \text{ g} = 138 \text{ mg, } \textit{answer.}$$

What is the weight, in milligrams, of 1 mmol of $HPO_4^{=}$?

$$\text{Atomic weight of } HPO_4^{=} = 95.98$$
$$1 \text{ mole of } HPO_4^{=} = 95.98 \text{ g}$$
$$1 \text{ mmol of } HPO_4^{=} = 95.98 \text{ g} \times \frac{1}{1000} = 0.09598 \text{ g}$$
$$= 95.98 \text{ mg, } \textit{answer.}$$

Osmolarity

As indicated in Chapter 11, osmotic pressure is important to biologic processes that involve the diffusion of solutes or the transfer of fluids through semipermeable membranes. The *United States Pharmacopeia*[2] states that knowledge of the osmolar concentrations of parenteral fluids is important. The labels of pharmacopeial solutions that provide intravenous replenishment of fluid, nutrients, or electrolytes, and the osmotic diuretic mannitol are required to state the osmolar concentration. This information indicates to the practitioner whether the solution is hypo-osmotic, iso-osmotic, or hyperosmotic with regard to biologic fluids and membranes.

Osmotic pressure is proportional to the *total number* of particles in solution. The unit used to measure osmotic concentration is the *milliosmole* (mOsmol). For dextrose, a nonelectrolyte, 1 mmol (1 formula weight in milligrams) represents 1 mOsmol. This relationship is not the same with electrolytes, however, because the total number of particles in solution depends on the degree of dissociation of the substance in question. Assuming complete dissociation, 1 mmol of NaCl represents 2 mOsmol ($Na^+ + Cl^-$) of total particles, 1 mmol of $CaCl_2$ represents 3 mOsmol ($Ca^{++} + 2Cl^-$) of total particles, and 1 mmol of sodium citrate ($Na_3C_6H_5O_7$) represents 4 mOsmol ($3Na^+ + C_6H_5O_7{}^-$) of total particles.

The milliosmolar value of *separate* ions of an electrolyte may be obtained by dividing the concentration, in milligrams per liter, of the ion by its atomic weight. The milliosmolar value of the *whole* electrolyte in solution is equal to the sum of the milliosmolar values of the separate ions. According to the *United States Pharmacopeia*, the ideal osmolar concentration may be calculated according to the equation[2]:

$$\text{mOsmol/L} = \frac{\text{Weight of substance (g/L)}}{\text{Molecular weight (g)}} \times \text{Number of species} \times 1000$$

Example Calculations of Milliosmoles

A solution contains 5% of anhydrous dextrose in water for injection. How many milliosmoles per liter are represented by this concentration?

Formula weight of anhydrous dextrose = 180
1 mmol of anhydrous dextrose (180 mg) = 1 mOsmol
5% solution contains 50 g or 50,000 mg/L
50,000 mg ÷ 180 = 278 mOsmol/L, *answer.*

Or, solving by dimensional analysis:

$$\text{mOsmol/L} = \frac{\text{Weight of substance (g/L)}}{\text{Molecular weight (g)}} \times \text{Number of species} \times 1000$$

$$\frac{50{,}000 \text{ mg}}{1 \text{ L}} \times \frac{1 \text{ mOsmol}}{180 \text{ mg}} = 278 \text{ mOsmol/L, } \textit{answer.}$$

A solution contains 156 mg of K^+ ions per 100 mL. How many milliosmoles are represented in a liter of the solution?

$$\text{mOsmol} = \text{mg of drug} \times \frac{1 \text{ mmol of drug}}{\text{Molecular weight (mg)}}$$

Atomic weight of K^+ = 39
1 mmol of K^+ (39 mg) = 1 mOsmol
156 mg of K^+ per 100 mL = 1560 mg of K^+ per liter
1560 mg ÷ 39 = 40 mOsmol, *answer.*

A solution contains 10 mg% of Ca^{++} ions. How many milliosmoles are represented in 1 liter of the solution?

Atomic weight of Ca^{++} = 40
1 mmol of Ca^{++} (40 mg) = 1 mOsmol
10 mg% of Ca^{++} = 10 mg of Ca^{++} per 100 mL or
100 mg of Ca^{++} per liter
100 mg ÷ 40 = 2.5 mOsmol, *answer.*

How many milliosmoles are represented in a liter of a 0.9% sodium chloride solution?

Osmotic concentration (in terms of milliosmoles) is a function of the total number of particles present. Assuming complete dissociation, 1 mmol of sodium chloride (NaCl) represents 2 mOsmol of total particles ($Na^+ + Cl^-$).

$$\text{Formula weight of NaCl} = 58.5$$
$$\text{1 mmol of NaCl (58.5 mg)} = \text{2 mOsmol}$$
$$1000 \times 0.009 = \text{9 g or 9000 mg of NaCl per liter}$$
$$\frac{58.5\ (\text{mg})}{9000\ (\text{mg})} = \frac{2\ (\text{mOsmol})}{x\ (\text{mOsmol})}$$
$$x = 307.7, \text{ or 308 mOsmol, } \textit{answer.}$$

CALCULATIONS CAPSULE

Millimoles and Milliosmoles

To calculate millimoles (mmol):

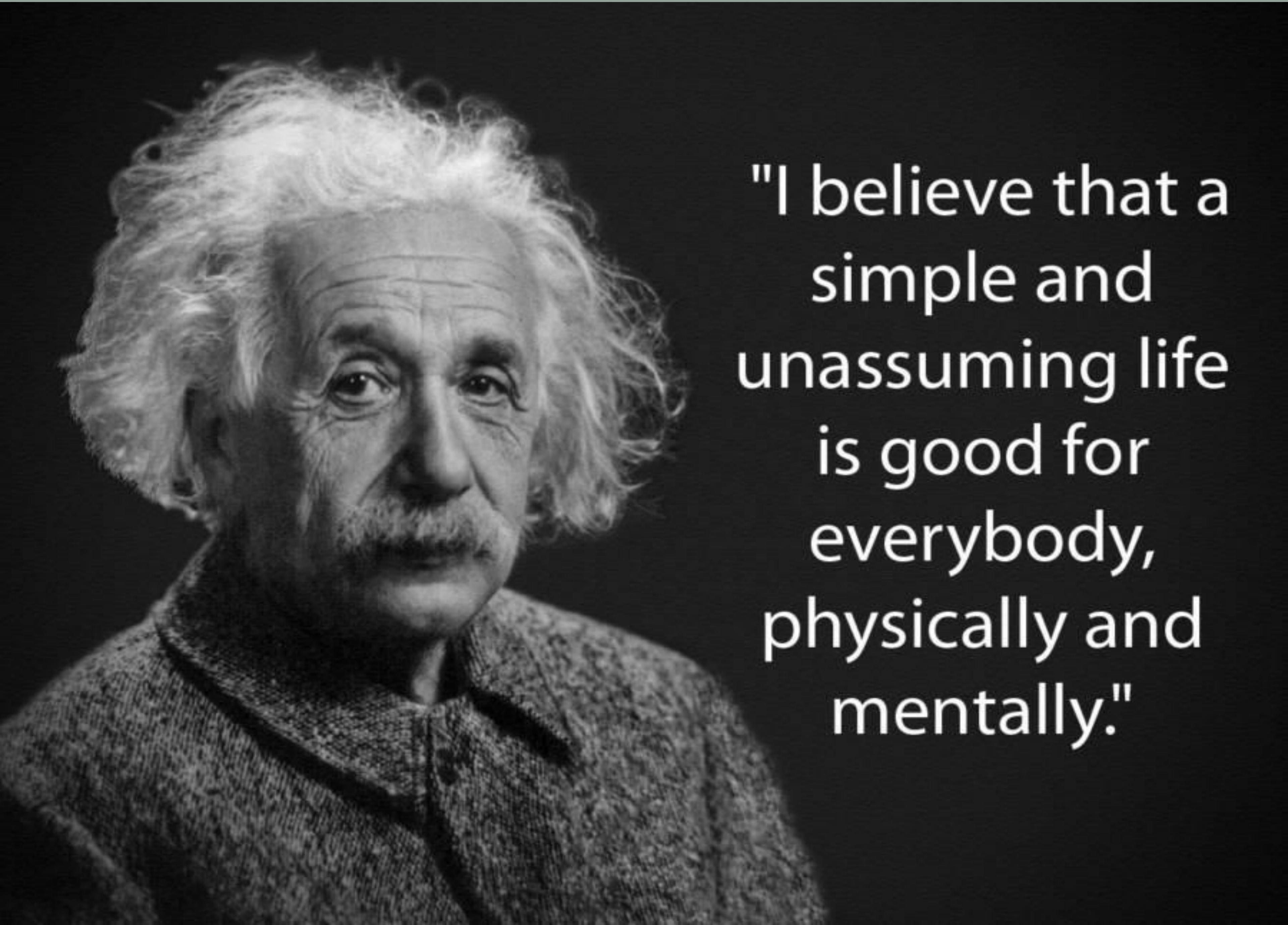
A *millimole* is $^1/_{1000}$ of the gram molecular weight of a substance.

$$\textit{1 millimole} = \frac{\textit{Molecular weight, grams}}{\textit{1000}}$$

To calculate milliosmoles (mOsmol):

A *milliosmole* is $^1/_{1000}$ of an osmol. When substances do not dissociate, the numbers of millimoles and milliosmoles are the same. There are 2 milliosmoles per millimole for substances that dissociate into two particles and 3 milliosmoles per millimole for substances that dissociate into three particles.

$$\textit{mOsmol} = \textit{mg of drug} \times \frac{\textit{1 mmol of drug}}{\textit{Molecular weight (mg)}}$$


"I believe that a
simple and
unassuming life
is good for
everybody,
physically and
mentally."