



*Clinical Disorders of
Hydration and
Acid-Base Equilibrium*

SECOND EDITION

by

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SECOND EDITION

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Preface to the Second Edition

There should always be some reason for the writing of a second edition. In this instance there are several. In the first place, there have been significant advances in some of the fields which are discussed in this monograph. Secondly, a new chapter has been incorporated dealing with the special problems presented by the pediatric age group. This excellent discussion was contributed by Dr. Robert W. Winters. Lastly, the author thinks he has learned how to present some of this material more precisely and more clearly than he did four years ago.

LOUIS G. WELT

*Chapel Hill, N.C.
July, 1959*

Preface to the First Edition

This monograph is an attempt to examine the pathogenesis and treatment of disorders of fluid and electrolyte metabolism with reference to what is known and what may reasonably be inferred concerning the mechanisms that are responsible for the maintenance of normal volume, tonicity, composition, and pH of body fluids. It would seem logical to assume that pathologic alterations in these functions represent dislocations from a normal equilibrium resulting from modifying influences impinging on basic physiologic processes. The alternative and more traditional approach, that the pathologic alterations represent mechanisms peculiar to each individual disease, leads inevitably to a consideration of these abnormalities in terms that may be unrelated to the interplay of basic physiologic mechanisms. This, in turn, encourages a therapeutic approach which may be unrealistic, as it is preoccupied with a particular "abnormality" without consideration of the possibility that this "abnormality" may have some value for the total economy of the patient under the particular circumstances, and that unless the conditioning circumstances are favorably modified, the correction of an "abnormality" to "normal" may be prejudicial to the health of the patient.

In contrast, there is the danger that an attitude may develop characterized by a reluctance to correct a specific abnormality in a particular patient because such therapy was unsuccessful in another. Generalizations have limited utility, for each patient presents a new challenge; each problem must be individualized and therapy adjusted to suit the needs of the particular patient.

In this discussion the description of the physiologic processes is incomplete, and will need modification or radical alteration as

more is learned about the metabolism and excretion of electrolytes and water. Many processes are still undescribed. New knowledge may invalidate some of the concepts that are presented. However, a consideration of these abnormal states with constant reference to physiologic homeostatic mechanisms will lead to new insights and a rational therapeutic regimen.

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L.G.W.

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PART ONE

*Physiologic
Considerations*

Definitions

A. UNITS OF MEASUREMENT

A discussion of the composition of body fluid has much more meaning if the concentrations of the specific components of this fluid are expressed in such a way that the concentrations of the several solutes may be readily compared and interrelated with one another. Since the interrelationships of the various compounds and ions are on a molecular and ionic basis, it is desirable to express their concentrations in those terms.

The units of measurement that are employed for this purpose are:

Millimol	(mM)
Milliequivalent	(mEq.)
Milliosmol	(mOsm)

1. Millimol

A mol of a substance is the molecular weight of that substance in grams. For example: the chemical formula for the glucose molecule is $C_6H_{12}O_6$. The molecular weight is: $6(12) + 12(1) +$

6(16) = 180. One mol of glucose equals 180 Gm. One millimol of glucose is $\frac{1}{1000}$ of 180 Gm., or 180 mg.

Other examples are as follows:

Molecular weight of NaCl	= 23 + 35.5 = 58.5
1 mol	= 58.5 Gm.
1 mM	= 58.5 mg.

Molecular weight of KCl	= 39.1 + 35.5 = 74.6
1 mol	= 74.6 Gm.
1 mM	= 74.6 mg.

Molecular weight of NaHCO ₃	= 23 + 1 + 12 + 3(16) = 84
1 mol	= 84 Gm.
1 mM	= 84 mg.

Molecular weight of CaCl ₂	= 40 + 2(35.5) = 111
1 mol	= 111 Gm.
1 mM	= 111 mg.

The conversion from the weight in milligrams to millimols is a simple calculation:

Millimols in 1 Gm. NaCl	= 1000 ÷ 58.5 = 17.1 mM
Millimols in 1 Gm. KCl	= 1000 ÷ 74.6 = 13.4 mM
Millimols in 1 Gm. NaHCO ₃	= 1000 ÷ 84 = 11.9 mM
Millimols in 1 Gm. CaCl ₂	= 1000 ÷ 111 = 9 mM

The unit mol or millimol may also be applied to ions such as Na⁺, K⁺, Ca⁺⁺, Cl⁻, HCO₃⁻, SO₄⁻⁻, etc. A mol of any of these ions is the sum of their atomic weights expressed in grams. For example:

1 mol Na ⁺	(atomic weight = 23)	= 23 Gm.
1 mol K ⁺	(atomic weight = 39.1)	= 39.1 Gm.
1 mol Ca ⁺⁺	(atomic weight = 40)	= 40 Gm.
1 mol Cl ⁻	(atomic weight = 35.5)	= 35.5 Gm.
1 mol HCO ₃ ⁻	(sum of atomic weights = 61)	= 61 Gm.
1 mol SO ₄ ⁻⁻	(sum of atomic weights = 96)	= 96 Gm.

One millimol of each of these ions is $\frac{1}{1000}$ of a mol.

The concentration of gases can also be expressed in terms of molecular equivalents. One mol of an ideal gas at standard temperature and pressure (0° C., 760 mm. Hg) occupies 22.4 L.; therefore, 1 mM occupies 22.4 cc. One mol of carbon dioxide occupies a slightly smaller volume at standard temperature and pressure, 22.26 L. Hence, 1 mM of CO₂ occupies 22.26 cc. The concentration of a gas in fluid is usually measured in terms of volume per cent, i.e., cubic centimeters of gas per 100 cc. of fluid. To correct volume per cent of CO₂ to millimols per liter:

$$\frac{\text{Vol. \% CO}_2 (0^\circ \text{ C., 760 mm. Hg}) \times 10}{22.26} = \text{mM CO}_2/\text{L.}$$

2. Milliequivalent

In many circumstances these ions are considered from the standpoint of an electrochemical reaction between them. In this context it is desirable to use a unit of measurement that refers to combining equivalents. An *equivalent* of an ion is the sum of its atomic weights divided by the valence. Thus, in the case of univalent ions a milliequivalent is the same as a millimol. However, in the case of divalent ions such as Ca⁺⁺ or SO₄⁻⁻, 1 mM equals 2 mEq. One millimol of Ca⁺⁺ (2 mEq. of Ca⁺⁺) will react completely with 2 mM (2 mEq.) of Cl⁻.

B. OSMOTIC PRESSURE

As will be noted in Chapter 2, the composition of the intracellular and extracellular fluids differs markedly. Nevertheless, it is believed that the total solute concentration in each of these is approximately equal. This is presumably the consequence of the fact that the cell membrane which separates these fluids is completely permeable to water (363).

When two aqueous solutions are separated by such a membrane, water molecules will move from one solution to the other. An

equilibrium with respect to this movement of water will be achieved when the same number of molecules of water pass in each direction in a unit of time and there is no net alteration in the volume of either of these solutions. This tendency for the water molecules to pass from one solution to the other is spoken of as "escaping tendency" by Clark (96); it is related to the average energy of the molecules of water per mol and is referred to as the *chemical potential* of the water (86, 87). When the chemical potentials of the water of two contiguous fluids differ, there will be a net movement of water from the solution with the higher chemical potential to that of the lower until equilibrium is again reached.

The chemical potential of water molecules can be influenced by the addition of solutes to water, or by changes in hydrostatic pressure and temperature. The addition of solutes reduces the chemical potential of the water, and the reduction is proportional to the concentration of solutes in the aqueous solution. In con-

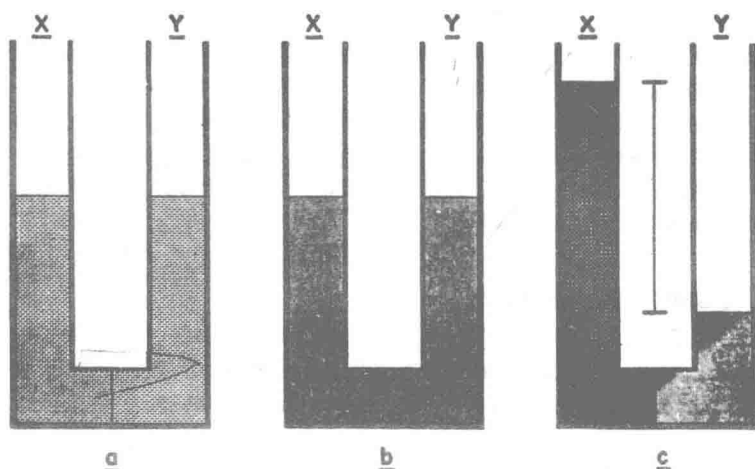


FIGURE 1

An illustration of osmotic pressure. a. Uniform distribution of water. b. Uniform distribution of water and urea. c. Addition of glucose to side X where it exerts an effective osmolality since the membrane is impermeable to this solute.