

[PREFACE TO THE SECOND EDITION]

Practical and Theoretical Acid-Base Physiology

John A Kellum and Paul WG Elbers

When we first considered creating a second edition of Stewart's classic "How to Understand Acid-Base" our motivation was solely to improve its accessibility to a growing number of readers. However, as we began to plan for this edition we became increasingly interested in what made the original text so popular and at the same time why it produced such negative reactions from some quarters of the academic world. We suspected that these two opposite reactions might be closely related to the same root causes.

One of the features that attracted us to the Stewart model was its simplicity and simultaneously its comprehensiveness. Classical acid-base teaching employs the Henderson-Hasselbalch equation for classification of acid-base disorders into respiratory (carbon dioxide is abnormal) and metabolic (bicarbonate is abnormal) and defines a framework for compensatory changes in the variable deemed non-primary. Next, classical teaching employs either a set of ad hoc rules or, more simply, base-excess methodology to puzzle out complex disorders and to quantify the magnitude of the abnormality. Finally, classical teaching employs a limited charge equilibrium method (anion gap) to help narrow the differential diagnosis. Compared to the unified theory of the Stewart model, the classical approach certainly seems inelegant. Moreover, there was a need to plug various leaks in the classical model with more ad hoc corrections. For example, anion gap assumes a near normal concentration of albumin and phosphate. When these concentrations are not normal, the anion gap has to be "corrected".

In contrast, the Stewart model requires, to use a term of our internet age, no "plug-ins". In addition the Stewart model works in all conditions not just those commonly found in medicine. This feature that the model holds even outside of the clinical range did little to impress its detractors. They argued that a model that has utility even when we don't need it is not a better model and suggested that the vary act of showing that the model provides accurate predictions in highly non-physiological states is evidence that it is not needed. We respectfully disagree and point out that if model does not hold under extreme conditions it might not hold at other times as well. A law is not a law when it holds true only sometimes.

However, a much bigger challenge to the Stewart model has come from the empirical

sid - or more precisely from epistemology. If the Stewart model predicts that changes in the proportion of anions and cations will result in changes in pH, then we will have to change our definitions of acids and bases. The problem is that the Stewart model leads to conclusions that are completely at odds with the status quo - although not so different from how acid-base was understood as recently as the 1960s. For example, the acidosis that results from dilution of plasma with saline (discussed in Chapter 20) was described in Cushing's time but the explanation for the phenomenon has never been entirely established. In the "now traditional" model, saline resuscitation results in a dilution of plasma bicarbonate and when PCO_2 is held constant by respiration, an acidosis results. However, it seems illogical for dilution of bicarbonate to result in acidosis when reducing carbon dioxide results in alkalosis. After all, they are both just forms of carbonic acid and it seems improbable that the law of mass action would stand still in the case of saline resuscitation.

According to the Stewart model, the addition of saline results in a reduction in the strong ion difference (SID) because one is combining a solution with a [SID] of roughly 40 mEq/L (plasma) with one that has a [SID] of 0 (saline). The model predicts that changes in [SID] will result in changes in pH. The problem is that changes in $[\text{Na}^+]$ and $[\text{Cl}^-]$ are not supposed to result in changes in pH. $[\text{Na}^+]$ and $[\text{Cl}^-]$ are not acids or bases and thus adding them to a solution should have no effect on the pH. Yet, as we have all observed, the pH changes.

This apparent paradox has problems for epistemology but we should not be too troubled by them. As scientists and clinicians we don't have to understand why something is in order to determine that it is. The Stewart model predicts that as [SID] changes so too will pH and our experience confirms this. It is therefore not logical to conclude that because we do not understand the mechanism whereby [SID] changes pH, it cannot be so.

Stewart hypothesized that water dissociates into H^+ and OH^- to a greater or a lesser extent when [SID], $[\text{A}_{\text{TOT}}]$ or PCO_2 change. To date there are no empirical observations that confirm water dissociation as the mechanism whereby [SID], $[\text{A}_{\text{TOT}}]$ or PCO_2 effects pH and studies of water lattice under conditions of varying [SID], in fact, suggest no such relationship. Thus, the Stewart hypothesis has no empiric support. This does not in any way invalidate the model or call into question the output of the model however. Although experience is the only judge of scientific theories, scientific knowledge does not exclusively arise from experience. Scientific theories are genuine hypotheses that go beyond the limits of finite human experience. In theoretical physics, for example, models of the universe require extra dimensions - yet, there are no observations that have been made that require extra dimensions. The model's soundness is based on its ability to make predictions in the observable world as well as the world we cannot observe. For acid-base physiology we are far more concerned with explaining the observable world. Our observation that changes in [SID] result in changes in pH may not be explainable by water dissociation but nevertheless the observation and model which describes it cannot be discarded.

Throughout this book, we refer to the Stewart hypothesis as a ready explanation for the observed association between the variables [SID], $[\text{A}_{\text{TOT}}]$ and PCO_2 and the variable pH. We

recognize that this theoretic construct is only one of a number of possible explanations. In our experience though, the human mind requires an explanation for the phenomenon we observe. We find it easier to remember things when we can attribute a causal link. While empirical evidence has not been found to support the Stewart hypothesis, no clear disproof yet exists either. Thus, we offer the hypothesis as a potential explanation but more importantly direct our attention to the model and its use - the practical application of the model as well as the theoretical. Although we cannot yet determine the cause, we are nevertheless able to use the model to make predictions and the accuracy of these predictions is the only true test of the model. Thus far, the predictions have been spot on.

