Letters

Reaction to Why Do We Teach Equilibrium Calculations?

A recently published correspondence by Stephen J. Hawkes on teaching equilibrium calculations troubles me *(1)*. Hawkes dismisses equilibrium calculations as mere algorithms, best deferred until the student "can use computer programs". I find it difficult to believe that a computer program enhances understanding. From a chemist's point of view, the equilibrium condition is a limit, a limit that (because of stochastic considerations) does not exist. It might be better to make the reaction quotient statement using < or > but the use of those relations is delayed until quantum mechanics.

Hawkes says, "Equilibrium is a rare phenomena except in the activities of chemists in their laboratories" *(1)*. "Thou know'st 'tis common" *(2)*. Even business and economics students learn about a Nash equilibrium. This *Journal* has published a number of exercises purporting to introduce the abstract notion—concept—of equilibrium. However, such activities do involve some arithmetic.

The Editorial in the issue immediately following the published correspondence is equally disturbing *(3)*. John Moore seems to share Hawkes' antipathy toward arithmetic.

This reader will persist in his "concept" of chemistry as an experimental science. I believe chemistry is an experimental science involving questions of how much, how many, to what extent, in what sequence: questions answered with numbers. Chemistry should be taught as such.

Literature Cited

1. Hawkes, Stephen J. *J. Chem. Educ.* **2003**, *80*, 1381.
2. Shakespeare, W. *The Tragedy of Hamlet, Prince of Denmark* 1.2.72.
3. Moore, J. W. *J. Chem. Educ.* **2004**, *81*, 7.

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The author replies:

Computer programs assist in understanding equilibrium because they can deal with the simultaneous solution of multiple equilibria. Solubility of barium sulfate in 0.1 M sodium sulfate is affected by solubility of the ion pair and by the activity coefficient so that the usual answer of solubility product/concentration is in error by a factor of 32. Among all the solubilities in 0.1 M negative ion like this, about a third are in error by more than 100. In pure water, a third are in error by more than 10 *(1)*. Calculation of the pH of buffers is often in error by up to 0.3 unit *(2)*. It is not pointed out to beginners that pH = {–log[H+]} – (0.2 ± 0.2). Multiple equilibria and the effect of ionic strength are neglected in beginning chemistry to simplify the math, deceiving students into believing that they have mastered a skill when they only produce wrong answers that match a test key. This is illustrated by three texts *(3)* that calculate the solubility of calcium carbonate as an example, neglecting the hydrolysis of the carbonate ion.

Don Lewis does not accept that equilibrium is a rare phenomenon other than in chemists' laboratories. The entire ecosystem is in disequilibrium as is the earth's crust, the oceans, the atmosphere, the sun, and the stars. Ruins of ancient monuments illustrate their disequilibrium with the environment.

It is naive to take issue with John Moore's statement *(4)* that one major cause of ineffective teaching is the assumption that "Students who can answer numeric questions on exams actually understand the principles of chemistry." I had to learn this error the hard way. Lambeth and Robinson *(5)* showed that the concept of equilibrium is often not understood by students who can plug numbers successfully into mass action expressions.

It is true that chemistry involves questions that are answered with numbers. That does not mean, however, that each and every aspect of chemistry must be taught quantitatively or with quantitative rigor. The chapters of equilibrium calculations that encumber our texts are out of all proportion to their usefulness. Most students will never use them, and their emphasis obscures the understanding of the nature and cause of equilibrium.

"Rigor" in introductory chemistry is often equated with quantitation. Consequently the understanding of chemical reactions and properties is obscured. This was illustrated by Stumpo *(6)* who asked students to calculate ΔE of a reaction, and then on another question on the same test asked a question aimed at its meaning. 77% of the students calculated correctly, but only 24% showed understanding of its meaning.

The ability to calculate a number does not measure understanding of the number.

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1. Hawkes, S. J. *CHEM13 News* **1996**, 1
2. Hawkes, S. J. *Chem. Educator* **1997**, *1* (6): S1430-4171.
3. Hawkes, S. J. *J. Chem. Educ.* **2000**, *77*, 321–326.
4. Moore, J. W. *J. Chem. Educ.* **2004**, *81*, 7.
5. Lambeth, J. M.; Robinson, W. R. Presented at the 210th ACS Conference, Division of Chemical Education Session, Chicago, Aug 1995; CHED Newslett. 1995, Fall; Abstract 336.
6. Stumpo, V. M. *J. Chem. Educ.* **1992**, *69*, 459–462.

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