PROBLEMS WITH CHEMICAL FORMULAE: XX CENTURY SCHOOL PUPILS AND XIX CENTURY SCIENTISTS

by

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Abstract

A recent survey of secondary school pupils' attitudes to chemical formulae show interesting similarities with the attitudes of XIX century scientists to the formulae system developed by Berzelius (the basis of the present system). Dalton's opposition to this system, Children's alterations of a Berzelius original when translating it to English, a fact praised by contemporaries, and other objections of the time are compared with today's secondary school pupils comments collected in a recent study. These comparisons make it easier to understand the difficulties in teaching formulae at school.

Key words: formulae; chemical symbols; chemical education

Introduction

Symbols and formulae for chemical substances have been used since the Greek civilization [1], but the pre-

sent system [2] derives fundamentally from the works of Jacob Berzelius (1779 - 1848), though with contributions from many other scientists of the XIX century. However, the establishment of Berzelius system met with many difficulties and criticisms from his contemporaries.

Teaching chemical formulae to school pupils has been a difficult task [3], and a recent study [4] on the topic has shown possible reasons which lead pupils to make mistakes when writing and interpreting formulae.

It is interesting to note that many of the pupils attitudes to formulae bear striking similarities with those of the XIX century scientists that opposed Berzelius system. We will present both and attempt showing the similarities.

Historical difficulties in establishing chemical formulae

After Lavoisier's (1743-1794) reformulation of the names of chemical compounds in the last part of the 18th century, Thomson [5] used formulae for minerals based on Bergman's [6] system. But it was Berzelius in 1813 who proposed the system which led to what has now been adopted by IUPAC [2].

The history of symbols in chemistry is well known and easily accessible in a number of works [1, 7]. What is perhaps not so well known and accessible is J.J. Berzelius

own justification for the system published in 1814 [8]. Berzelius stated:

> "When we endeavour to express chemical proportions, we find the necessity of chemical signs. Chemistry has always possessed them, though hitherto they have been of very little utility. They owed their origin, no doubt, to the mysterious relation supposed by the alchymists to exist between the metals and the planets, and to the desire which they had of expressing themselves in a manner incomprehensible to the public. The fellow-labourers in the antiphlogistic revolution published new signs founded on a reasonable principle, the object of which was, that the signs, like the new names, should be definitions of the composition of the substances, and that they should be more easily written than the names of the substances themselves. But, though we must aknowledge that these signs were very well contrived, and very ingenious, they were of no use; because it is easier to write an abbreviated word than to draw a figure, which has but little analogy with letters, and which, to be legible, must be made of a larger size than our ordinary writing. In proposing new chemical signs, I shall endeavour

to avoid the inconveniences which rendered the old ones of little utility. I must observe here that the object of the new signs is not that, like the old ones, they should be employed to label vessels in the laboratory: they are destined solely to facilitate the expression of chemical proportions, and to enable us to indicate, without long periphrases, the relative number of volumes of the different constituents contained in each compound body. By determining the weight of the elementary volumes, these figures will enable us to express the numeric result of an analysis as simply, and in a manner as easily remembered, as the algebraic formulas in mechanical philosophy".

Berzelius then proceeded to justify his use of letters from the Latin names and lay out criteria for the use of the second letter, when necessary.

Dalton was strongly opposed to Berzelius formulae system. In his book "The Life and Scientific Researches of John Dalton", published in 1854, William C. Henry [9] says:

> "He (Dalton) steadily persisted in denying the superior precision and expressiveness of the admirable system of chemical formulae, proposed by Berzelius in 1815, and now employed by all European chemists.

In a letter addressed to Prof. Graham, April 1837, ... he thus strongly condemns the Berzelian notation:

"Berzelius's symbols are horrifying; a young student in chemistry might as soon learn Hebrew as make himself acquainted with them. They appear like a caos of atoms. Why not put them together in some sort of order ? Is not the allocation a subject of investigation as well as the weight ? If one order is found more consistent than another, why not adopt it till a better is found ? Nothing has surprised me more than that such a system of symbols should ever have obtained a footing anywhere." Again in another document, he says "I do not, however, approve of his addopting and defending the chemical symbols of Berzelius, which appear to me equally to perplex the adepts of science, to discourage the learner, as well as to cloud the beauty and simplicity of the atomic theory.""

Not only Dalton was opposed to Berzelius system. Even one of his translators, J.G. Children, altered Berzelius original when translating "The Use of the Blowpipe in Chemical Analysis and in the Examination of Minerals" [10] in 1822. He justified the change as follows:

"These formulae I have omitted in toto; ... I have taken this liberty because I do not think the introduction of these, or any other symbols, at all necessary: it requires some time and patience to make oneself thoroughly master of them; and as it strikes me, to little purpose. Why are the symbols of the old chemists abolished, but from experience having proved them to be unnecessary ? ... I will candidly own too, that thinking them rather calculated to perplex than facilitate our progress, I do not wish to see them used in this country, ..."

J.G. Children's attitude was praised in a review of the above translation [11] published in the journal of the prestigious Royal Institution as follows:

"Now we beg to dissent in toto from the assertion that these or any other signs are at all necessary, and we contend that they are calculated rather to mislead and mystify, than facilitate our progress, or elucidate our results. If we gain any thing in brevity, (and very little do we even in that respect) it is at the expense of great risk of confusion, ..."

In the same journal, J.G. Children [12] said:

"A short account of his (Berzelius) doctrine will, therefore, probably not be uninteresting to our readers, though, perhaps, they may

think with us, that the simpler theory usually adopted in our own country answers every purpose equally well, and with greater facility, than the more complicated system of our continental neighbours."

Another contemporary, Whewell [13] said:

"The greater part of English chemists appear to have been hitherto averse from the practice of using a technical and mathematical notation to express the chemical composition of bodies; while in France, Germany and Sweden, such a notation is and has been for some time commonly employed. The disinclination of our countrymen to adopt this invention seems to arise from a belief that such an instrument is unnecessary, and from a perception of several anomalies and inconveniences in the system followed by foreigners."

However, John Prideaux [14] of the Plymouth Institution, defended the system:

"They (the formulae) constitute a prompt, impressive and peculiarly legible shorthand".

This lack of interest (if not aversion) to formulae is also evident in text books of the time.

William Henry's four volume textbook [15] intitled "The Elements of Experimental Chemistry" did not use the new formulae. A number of editions of this work were published, which seems to show it was a main source of information for chemistry English speaking students in those days. Thomas Thomson's "A System of Chemistry" in five volumes [16] did not use formulae either.

Pupils difficulties with formulae

A recent study [4] of secondary school pupil's attitudes to chemical formulae shows interesting similarities with the previous comments of XIX century scientists. For example, whereas Dalton said "Berzelius symbols are horrifying", pupils have express their dislike saying

"it's hard"
"it's difficult"
"it's complicated"
"it's confusing"
"boring"
"hard to understand"

Concerning the use of subscripts in formulae, 23 pupils in 90, 25%, said there are 6 atoms of hydrogen and

2 of oxygen in $6H_2O$. Though with different words, the expressed idea of their justification is basically the following:

"The 6 cames before the H so it means 6 atoms of hydrogen and 2 before the O means 2 atoms of oxygen".

Also, 16% of pupils answered 12 hydrogen and 1 of oxygen justifying:

"There is a 6 in front of the H_2 so it means 12 atoms of hydrogen. There is only one oxygen as there are no numbers by it."

Concerning the use of brackets with subscripts, such as in $Ca(NO_3)_2$, 21% of the pupils said that 2 means 2 calcium atoms, justifying as follows:

"The 2 is outside the brackets as well as the Ca and so the 2 affects the Ca."

Also, 14.5% said the 2 means two of $Ca(NO_3)_2$ assuming that the figure 2 is a coefficient; 12% said that the 3 means 3NO. 13% of pupils said that both formulae and names are alternatives for the same thing.

Conclusions

Teaching formulae to secondary school pupils has met with a number of difficulties which bear a striking similarity with the objections presented by scientists contemporary with Berzelius' presentation of his system of formulae, basically the same as we presently use. The diffi-

culties in today's pupils seem to be partially due to lack of clear ideas about the concepts of atoms and molecules. One would think that this was also a problem with XIX century scientists, though this is questionable. In any case, XIX century scientists antecipate XX century pupils problems in understanding Berzelius system of formulae. Though a highly convenient system for modern purposes, it is reasonable to expect difficulties in teaching formulae to school pupils.

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