LABORATORY JARGON IN CHEMISTRY – INVESTIGATION OF SCIENTIFIC LITERATURE AND SURVEY OF LECTURERS

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ABSTRACT

"Sodium chloride consists of sodium and chlorine". This sentence shows a common laboratory jargon statement that experts understand because they know that sodium and chloride ions are *meant*. Young learners, who learned about sodium and chlorine as dangerous or poisonous substances in their initial lessons, look in vain for gray sodium metal and yellow chlorine gas in common salt: They cannot know *what is meant*. If we establish on the substance level that sodium and chlorine can be obtained from sodium chloride by melt electrolysis, the statement would be correct. Once ions are known, the correct answer would be on the particle level: "Sodium chloride crystals consist of sodium and chloride ions arranged in an ionic lattice". The article will show more examples of jargon regarding acid-base reactions, will ask professors about using the jargon in their lectures, gives advice for improving Chemistry education. *[African Journal of Chemical Education—AJCE 11(1), January 2021]*

INTRODUCTION

By a multiple-choice test [1] well-known laboratory jargon statements on acid-base reactions were offered to students of Muenster University in Germany. Different studies [1, 2] show that many participants adhere to jargon statements such as "NaOH molecules dissociate in water to form Na^+ and OH^- ions" instead of ticking off the answer: “Solid sodium hydroxide consists of ions and water molecules separate them from each other in solution”. In a new study [3], JOLINE BUECHTER examines statements in scientific literature and interviews professors and lecturers of our Department of Chemistry who are involved in teaching Chemistry teacher students.

LABORATORY JARGON IN SCIENTIFIC LITERATURE

If one starts out from the hypothesis that incorrect statements can already be found in usual scientific literature, then one cannot reproach students and later young learners at schools for formulating imprecisely. For this purpose, the topic "acid-base reactions" is chosen and investigated as an example. In particular, one has to pay attention to whether, in the sense of Johnstone’s Triangle [1], macro, submicro and symbolic level are described separately and not mixed up arbitrarily, whether theories of Arrhenius and Broensted are presented in a professional scientific manner.

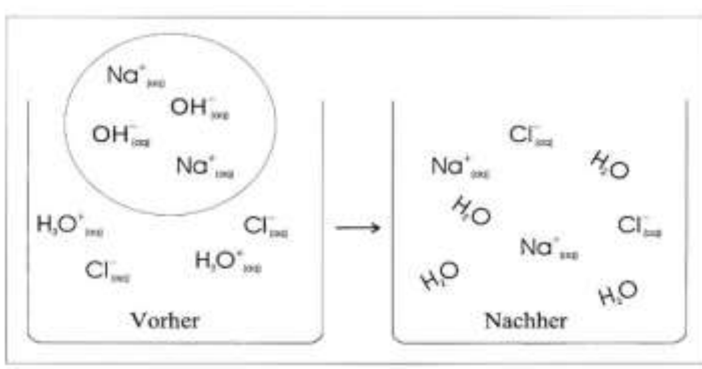


Fig. 1: Submicro-level: Beaker model before and after neutralization [1]

An example: The neutralization of hydrochloric acid by sodium hydroxide solution is often described as „$HCl(aq) + NaOH(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O$" – and it is omitted that both initial solutions also consist of ions. Either all involved particles are named at the submicro level: "$H^+(aq) + Cl^-(aq) + Na^+(aq) + OH^-(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O$" – and, if necessary, beaker models are additionally provided (Fig. 1). Or, at the symbolic level, one formulates only the usual chemical symbols without specifying particle types. At the macro level, the equation by substance names should be formulated: "Hydrochloric acid + sodium hydroxide solution → sodium chloride solution + water" – so the three levels are not mixed.

Textbook by MORTIMER and MUELLER [4]. In chapter 15.4 "Arrhenius acids and bases" the acid is described as a "substance which dissociates to form H_3O^+ ions when dissolved in water", the usual HCl-H_2O example has been provided (Fig. 2). But the offered equation represents the proton transfer according to the Broensted theory – dissociation should be described by the equation „$HCl \rightarrow H^+ + Cl^-$", $H_3O^+(aq)$ ions are not part of Arrhenius' theory.

If it is important that students learn both theories in a factually correct way, dissociation and corresponding equations should be argued in the sense of Arrhenius' theory, protolysis and proton transfer in the sense of Broensted's theory. On the other hand, according to Broensted, molecules or ions react as acid *particles* or base *particles*: HCl molecules give off a proton to H_2O molecules – reacting *particles* must always be specified. Arrhenius acids may be described as *substances* that contain H^+-ions.

Therefore, in Chapter 18 of the textbook the following sentences are also problematic: "Acid is a compound that gives off protons", "Acid is a substance that can give off protons". If the learner interprets "compound" as a substance, he or she will arrive at familiar laboratory jargon, at statements such as "hydrochloric acid gives off one proton, sulfuric acid gives off two protons".

In diluted hydrochloric or sulfuric acid there are H_3O^+ ions giving off protons, in pure sulfuric acid there are mainly H_2SO_4 molecules which are proton donors – in any case there are acid *particles* and not substances.

Chapter 18.2 states that "acetic acid (CH_3CO_2H) plays the role of an acid" – here too, acetic acid *molecules* should be named for the proton transfer. This statement applies only to pure acetic acid, but not to acetic acid solutions: Because of the equilibrium between molecules and ions, there are two types of acid particles, the H_3O^+ ion and the HAc molecule – both species can transfer protons to base particles, such as OH^- ions or NH_3 molecules.

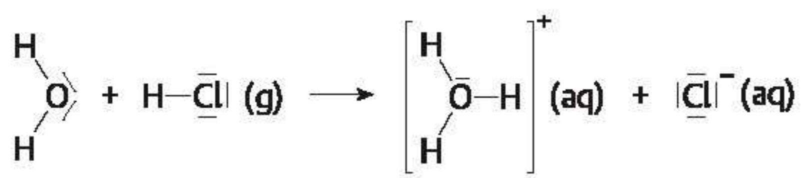


Fig. 2: "Arrhenius acids and bases" according to MORTIMER and MUELLER [4]

In the following statement, one finds again a direct change from the submicroscopic level to the substance level: "There are many molecules and ions that can occur both as acids and as bases; in the reaction with acetic acid, water occurs as a base". On the one hand acetic acid *molecules* and water *molecules* should be named, on the other hand the learner is confused by the laboratory jargon "water as a base": Water as a pure substance with a pH value of 7 cannot suddenly be a base with a pH of 9 or 12! If the authors would describe H_2O *molecules* as amphoteric that can react both as an acidic and as a basic particle, depending on the reaction partner, the learner would be able to understand the statement and will not develop misconceptions. The further statement "Ammonia is a base compared to water" represents a laboratory jargon of the same category: "The NH_3 *molecule* react as a base with an H_2O *molecule* as an acid ", would be a scientifically correct statement.

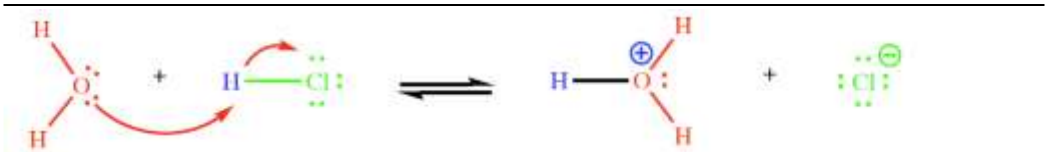
Chapter 19 begins with the statement: "Water dissociates to a small extent to H^+(aq) and OH^-(aq) ions, the equilibrium constant is the ionic product of water". Already on the next page the "dissociation of water" is formulated with the Broensted equation $H_2O + H_2O \leftrightarrows H_3O^+ + OH^-$. Why don't the authors stick on Broensted's theory and write about the "protolysis among H_2O-molecules"? How should young learners imagine the "dissociation of water as a substance "? – a classic laboratory jargon!

Textbook of RIEDEL [5]. In chapter 3, the author first describes the Arrhenius theory with applicable equations, although he emphasizes the "dissociation of hydrogen chloride" – instead of HCl *molecules*. He introduces Broensted's theory with the laboratory jargon: "Acids are substances that can split off H^+ ions (protons), bases are substances that can take up H^+ ions". Why it's not accepted worldwide that this theory only works with acid and base *particles*? – with molecules or ions and not with substances!

An example continues like this: "The compound HCl is an acid because it can split off protons". Does the "compound HCl" refer to the substance hydrogen chloride or the solution hydrochloric acid? In the first case HCl-*molecules* would be acids, in the second case H_3O^+ *ions* in acidic solutions would be acid *particles*.

In a second sentence one can read: "The Cl^- ion created in this process is a base, because it can take up protons. Cl^- is the conjugated base of the acid HCl". In this case, the author correctly identifies the chloride *ion* as a base, why not the HCl *molecule* as the conjugated acid?

Textbook by VOLLHARDT and SHORE [6]. In Chapter 2.2 the authors choose the usual model (Fig. 3) and note for explanation: "The red oxygen atom of water is protonated by the blue hydrogen atom of the acid to form the blue hydronium ion and the green chloride ion". In addition to non-existent "colored particles", the formulation "oxygen atom of water" highlights problems of mixing macro and submicro level: Meant is the oxygen atom of one water *molecule*. With regard to the names of species, the authors cannot avoid in Figure 3 the correct terms "hydronium ion and chloride ion" – why do they not properly call the first two models in their visualization "H_2O *molecule* and HCl *molecule*"?



water hydrogen chloride hydronium ion chloride ion

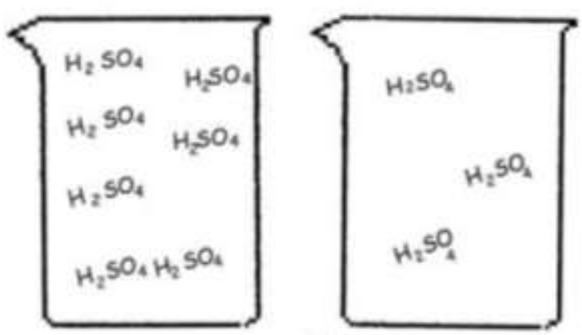
Fig. 3: Proton transfer example according to VOLLHARDT and SHORE [6]

Later, conjugated acids and bases are mentioned according to Broensted's theory, but then authors are switching to Arrhenius' theory: "HCl is a strong acid because the equilibrium is very favorable for its dissociation into H^+ and Cl^- ". If one would have referred to the HCl *molecule* as a strong acid and postulated full *protolysis*, learners would immediately correctly associate the transfer of protons and recognize H_3O^+ ions as a protolysis product.

As can be seen from the above-mentioned examples of the acid-base topic, the authors make no effort to consistently separate Arrhenius and Broensted theory, nor do they make any effort to name acid and base *particles* when describing proton transfers in sense of Broensted's theory. Students would have to be very well instructed to recognize relevant jargon statements and correct them independently. We will be happy to send a copy of this paper to the publishers of all authors, so that the laboratory jargon in their books can be corrected.

INTERVIEWS WITH LECTURERS

After textbook analysis the next step should be to ask Chemistry professors and lecturers of our University who are involved in the training of teacher students, about their attitude towards the laboratory jargon problem. For this purpose, lecturers of our Chemistry-education institute are familiar with most of our publications [7, 8] which explain the students' language problems and the distinction between Johnstone's three levels of reflection. Especially possible misconceptions of students are well known and problematized.



pure acid diluted acid

Fig. 4: Misconception of "molecules" in diluted sulfuric acid [8]

An example: Students in upper grades of various high schools were asked which particle types occur in pure and diluted sulfuric acid. In addition to the misconception cited (Fig. 4), verbal answers include the term "dissociation" – but diluted sulfuric acid was correctly stated with involved ions. However, many participants were not aware of ions that are separated from each other, but rather assumed "acid molecules" in diluted sulfuric acid (Fig. 4).

On the background of those misconceptions the interviews of lecturers should give an answer to the question to what extent laboratory jargon can produce such errors in teaching, to what extent professors are aware of mistakes by the jargon. The essay "Laboratory jargon among lecturers and misconceptions of students" [1] was distributed to eight lecturers who were willing to be interviewed. Interviews were realized about three weeks after the essay was distributed and took 20 - 30 minutes.

The topic-centered interview according to MISOCH [9] was chosen as a suitable method and this catalog of **eight questions** was designed:

1. Have you ever heard of "laboratory jargon" before reading the article?
2. Did you discuss the article or topic of laboratory jargon with your colleagues?
3. Before the article, have you ever consciously dealt with your language as a teacher? If so, how?
4. Can you confirm that you have used or are using laboratory jargon among colleagues, no matter how frequented?
5. Do you believe that you use laboratory jargon in your teaching, even if unconsciously and without meaning to?
6. Do you think that students imitate the teaching of lecturers, their scientific language and methods?
7. After the research in my bachelor thesis I discovered that about 50 % of students have problems to correct given laboratory jargon statements, although they could choose and mark the offered right answer between four alternatives. What should be changed in future teaching, whether at university or at school, so that chemistry teachers do not create students' misconceptions?
8. In your opinion, what are the biggest problems that students have with chemistry?

Results. Regarding teaching at university level, it was expected that lecturers knew the existing laboratory jargon before the article was published, but did not discuss jargon problems in more detail with their colleagues. In this case, it was suggested that there should be a difference between pure chemists and chemistry educators – those in particular are consciously dealing with their language in teaching prior to reading the distributed essay.

The first question, whether lecturers have already heard of "laboratory jargon", was answered by about 90 % of participants with "yes", only one teacher said "probably rather not". The majority of lecturers have heard concrete examples of laboratory jargon from Prof. BARKE, and the topic of jargon also came up again and again during the correction of scientific articles or doctoral theses'. One person even stated that she had dealt with it in her own doctoral project. Overall, laboratory jargon is therefore well known.

Many lecturers did not directly address this issue but pointed out that there are deliberate language shortcuts in their own teaching. About 40 % of faculty indicated no direct exchange with colleagues on this issue but did consciously examine their own scientific language.

Participants admit to using laboratory jargon among their colleagues. Some of them are rather less aware of this, while others very consciously defend the opinion that laboratory jargon is necessary in order to present complex content in an abbreviated manner – after all, the counterpart knows *what is meant*. Some do use the jargon, but they always reflect on it critically. Only one participant claimed not to use laboratory jargon.

Furthermore, it was important to find out whether lecturers use the jargon in their teaching, even if this may happen unconsciously, especially since lecturers use the lab jargon among colleagues. All instructors, except two, reported using the jargon in their teaching, even if unconsciously. The majority of respondents make an effort to address the problem of imprecise language in order to prevent misunderstandings regarding chemical terminology.

It could not be answered whether students adopt the way of speaking or presenting content from their instructors. However, there was often the opinion that a lecturer acts as a role model and that students accept the content conveyed as correct – but incorrect ways of expression could be unconsciously adopted and later transferred to students at school.

What could be changed in teaching in order to create fewer misconceptions of learners in the future was answered very differently. The reflection on one's own language according to differentiate levels of substances, particles and chemical symbols should be addressed. However, one person doubted whether anything concrete has to be changed at all, whether misconceptions can actually be created. Some flexibility should be maintained, since jargon is everywhere, at least in the laboratory. In addition, it is important that lecturers are aware of the audience they have in mind: One may adapt the language accordingly.

Regarding the question about the biggest problems students have with chemistry, it was found that many lecturers see difficulties in the level of abstraction regarding chemical theories. The bad reputation of chemistry according to environment problems was also mentioned. Furthermore, it seemed to be problematic that different models are used to illustrate certain theories and students may be overwhelmed here. It is also a problem that theories are no longer sufficient to explain phenomena at a certain time and then have to be discarded or expanded.

In addition to their expertise regarding Johnstone's levels of communication, Chemistry educators showed a very high level of interest in these problems. However, pure scientists were also mostly open-minded, at least acknowledging the problem of laboratory jargon. Only one participant has not yet strongly addressed the issue, and another was generally reluctant towards our investigation.

In further studies, it would be possible to specifically examine the language of professors in their lectures and seminars. Subsequently, the language of participating students could be questioned, for example in their seminar papers or exams. Here, however, interviews would have to be conducted before and after to find out why certain jargon statements are adopted from lecturers.

CONCLUSIONS

Examples from textbooks have been used in this article only for the acid-base topic – of course, the laboratory jargon can also be found for redox reactions, mole terms and other topics [3]. Since it is usually difficult for teachers and learners to argue consistently at the submicro level of smallest particles, it seems beneficial to introduce a "Didactical periodic table of atoms and ions" (Fig. 5) into teaching and learning. In particular, the existence of ions – and "ionized molecules" – is vividly conveyed without introducing the entire nucleus-shell structure of atoms or ions and matching numbers of protons, neutrons and electrons [7].

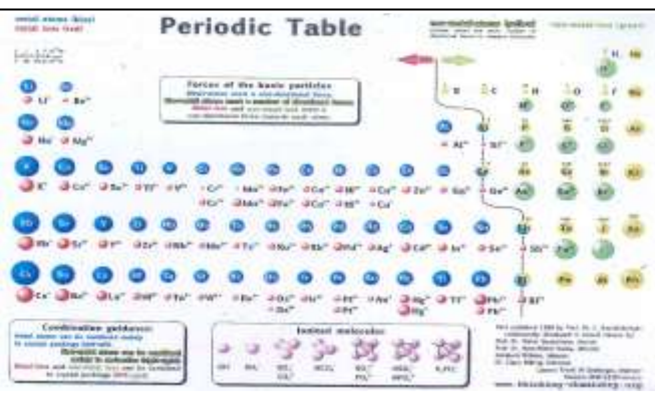


Fig. 5: PTE – Didactical periodic table of elements like atoms and ions [10]

First, learners can formally understand metals and alloys from the combination of metal atoms (left in PTE) into metal lattices, and the combination of nonmetal atoms (right in PTE) into molecules [11]. On the other hand, the ion concept comes more successfully into the awareness of learners by combining ions (left and right in PTE) into ion lattices and finding ionic symbols such as $Ca^{2+}(Cl^{-})_2$ or $(Al^{3+})_2(O^{2-})_3$ independently according to the electro neutrality rule [12]. Most observed misconceptions exist about the concept of ions [8] and could be eliminated by working with this Didactical periodic table [12].

With a solid knowledge of ions, it would be easier for learners at universities and schools to argue consistently with ions in addition to usually familiar atoms and molecules, and to avoid mixing substances with particles, also terms of Arrhenius and Broensted theories. A laboratory jargon would not develop at all – understanding of Chemistry could be optimized.

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