CHEMISTRY-TEACHER EDUCATION IN TANZANIA

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ABSTRACT

In science history formulae and first chemical equations have been developed during the 19th century. In 1865 Kekulé proposed even the difficult benzene structure, afterwards other molecular structures came up with Van't Hoff in 1874. Sometimes one can see today in different countries Chemistry education on this level of the 19th century: only formulae and equations are taught and memorized by students. Arrhenius in 1884 developed first ideas to describe ions in acidic, basic and salt solutions, Laue and Bragg in 1912 and 1914 could finally solve the problem according to structures of salt crystals: Ions in ionic lattices and ionic bonding through electric forces have been described. After more than 100 years we should come up with differentiation between atoms, ions and molecules, and discuss besides atoms and molecules also the ions as smallest particles in our well-known substances at school. In Tanzania I could offer teacher training courses by **Probono Schoolpartnerships for One World (Frankfurt, Germany, www.probono-oneworld.de)** for 25 Chemistry teachers during eight years by one month in every year. So, I got the opportunity to do empirical research with the help of those teachers. Some results of empirical research in Tanzania and also in Indonesia show that Chemistry education doesn't work well: There is nearly no knowledge about ions in solid salts, or about particles which can transfer protons or electrons by acid-base and redox reactions. Therefore, after instruction of important properties of matter in first lessons at schools, the article proposes how to introduce atoms, ions and molecules simultaneous during the first year of Chemistry lessons. These are the requisites to teach and to learn Chemistry on basis of smallest particles of matter and to interpret acid-base and redox reactions by transfer of protons and electrons. This way is well accepted by teachers and students, and Chemistry understanding will highly improve. *[African Journal of Chemical Education—AJCE 15(1), January 2025]*

INTRODUCTION

In Frankfurt/Germany one can find a charitable place where the collaboration with African states is realized: an office of organization "**Probono – Schoolpartnerships One World**" which offers teacher training for teachers in Chemistry, Physics, Biology, Math and English language in Tanzania. By the invitation of **Senior Expert Service SES Bonn/ Germany**, five German lecturers traveled in the years 2022, 2023 and 2024 for one month to Moshi/Tanzania to run five one-week seminars, and to visit during three weeks 12 involved secondary-high schools in the area of Moshi and Asusha, to look to about 25 teachers for every subject. The main goal of all is to improve the scientific knowledge of those teachers, and to encourage teachers to stop with teacher-centered education and switch to student-centered education. After lecturing in 2022 - 2024 contents of Form I, II and III there will be one more year 2025 for teaching Form-IV contents.

The Author taught Chemistry for contents in Form I, II and III, every year same Chemistry teachers were attending the workshops at Uhuru hotel in Moshi. In **Form-I course,** main properties of substances on the **Macro level** are discussed and shown by experiments. One other big topic is the introduction of atoms as smallest particles by metals and noble gases. To enlarge the knowledge about particles a Periodic table of atoms and ions as basic building blocks of matter was offered (Fig. 1). With the help of this table one can combine mentally "metal atoms left and left" to pure metal crystals or to alloys. With "non-metal atoms right and right" one obtains most of our molecules like H_2O, CO_2 or CH_4. Finally, the "ions left and right" should be combined to ionic lattices, demonstrated by sphere-packing or lattice models, and symbolized by ionic formulae: Na^+Cl^-, $Ca^{2+}(Cl^-)_2$ or $(Al^{3+})_2(O^{2-})_3$. This way [1] to the **Sub-micro level** and writing ionic formulae was very new for my participants.

This part of the seminar seems most important for knowing ions just in the beginning of Chemistry education to avoid formulas for salts like NaCl or $CaCl_2$ which are mostly interpreted by students as molecules, causing severe misconceptions [1].

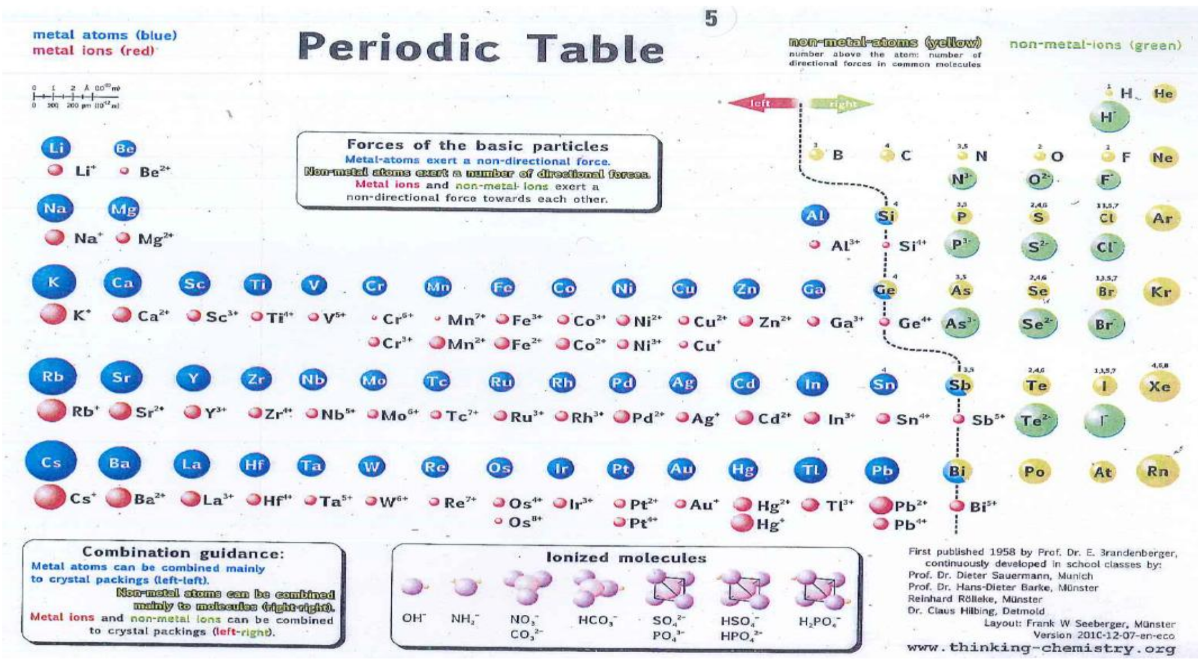

Fig. 1: Periodic table of atoms and ions for combining models of all matter [2]

Name of salt crystal	**involved ions**	**ratio of ions**	**empirical formula**
Calcium fluoride	Ca^{2+}, F^-	$Ca^{2+}(F^-)_2$	CaF_2
Sodium hydroxide	…………….	……………	……………..

Fig. 2: Worksheet for exercising ionic formulae (12 chlorides, nitrates, sulfates and oxides)

Therefore, we did exercises with a special worksheet (Fig. 2), and it seems now easy for participants to fill it out without big mistakes, for nitrates, sulfates or carbonates they could see those ion symbols with their charge from the bottom of the Periodic table (Fig. 1). They have been really happy to gain such new knowledge which they didn't get in their teacher training college or university. Also, some molecular structures have been shown by model sets, for example models of different alkane, alcohol or isomer structures.

In **Form II** the energy by chemical reactions was the central topic. Several qualitative and quantitative experiments were performed in group work and presented by five groups. This should show how student-centered education can be realized. The course was finished by a questionnaire by given chemical equations of acid-base and redox reactions with the task to interpret those equations by smallest particles and to decide which reactions are acid-base and which are redox reactions. Proton transfers or electron transfers should be shown. Later the results of participant's answers will be presented and discussed.

In **Form III** acid-base and redox reactions were shown by experiments and interpreted by reactions of involved atoms or ions or molecules. One example: Neutralization reactions are mostly shown by the well-known equation "HCl(aq) + NaOH(aq) → NaCl(aq) + H_2O. If you look to the particles, H^+(aq) ions + OH^-(aq) ions are reacting to H_2O molecules (Fig. 3). The other ions remain as sodium chloride solution, no "solid salt" is produced – another misconception about neutralization. Using the Broensted theory and the proton transfer it is proposed to take instead of H^+(aq) ions better H_3O^+(aq) ions: you can see the transfer of one proton from this particle to the basic particle: H_3O^+(aq) + OH^-(aq) → H_2O + H_2O (Fig. 3).

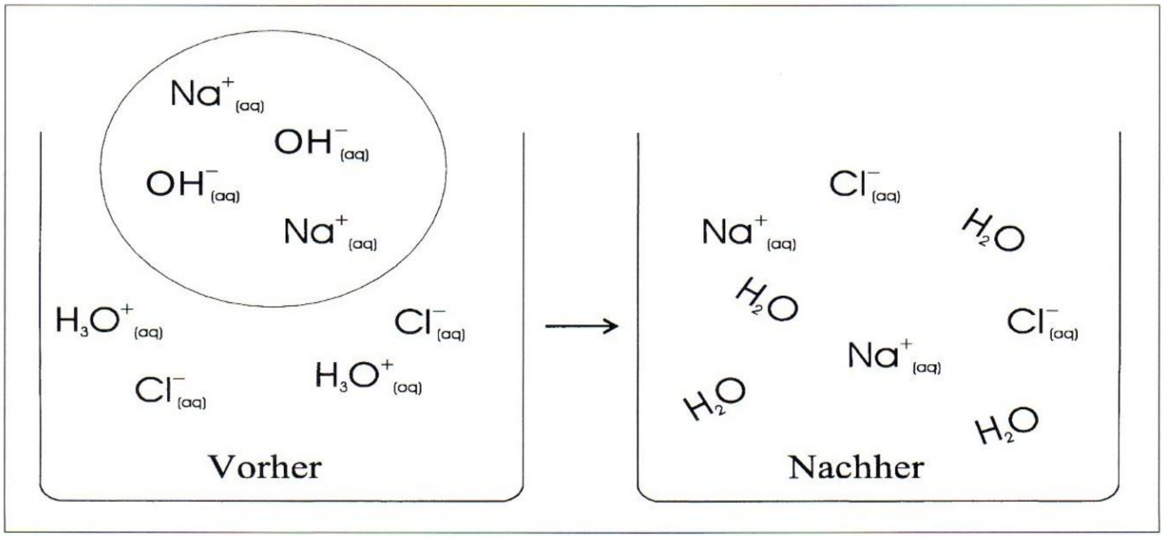

Fig. 3: Beaker model of the neutralization of hydrochloric acid by sodium hydroxide [3]

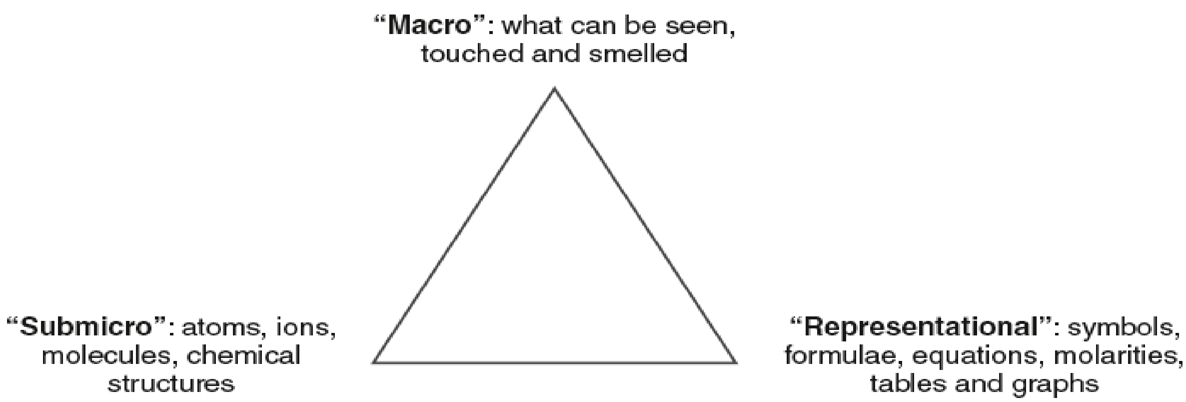

Fig. 4: Johnstone's Chemical Triangle for Chemistry education [4]

Johnston's Chemical Triangle (Fig. 4) shows the concept behind all concrete and mental models and their shortening by formulae. Mostly chemical lessons are going from an experiment (Macro level) direct to the chemical equation (Symbolic level) and equations are to be memorized by students. By this way they cannot understand Chemistry and the best student is the one who is able to memorize all those equations. If first smallest particles are taught and the structure of involved substances (Submicro level), students will gain the real understanding and can see all formulae and equations as shortenings of those discussed structural models. They even will develop mental models in their mind and keep them for interpreting new formulae and reaction equations [3].

EMPIRICAL RESEARCH DURING THE PROBONO PROJECT

In the **Form-I course**, I was curious if Chemistry teachers are ready to tell me the smallest particles of different substances. So, I gave them a one-paper questionnaire with the title “Smallest particles of substances” and the question: “Which particles (atoms, ions or molecules) are present in following substances?”. Participants took very often the answer “atoms” regarding particles in solid salts like chlorides, sulfates or carbonates, while they offer “ions” if asked particles in salt solutions. So, the ion idea is well-known – but not applied by crystals of salts. The answer “molecules” was taken for water, carbon dioxide or sulfur oxide, but not for pure sulfur or phosphorous oxide. All in all, the concepts of atoms, ions or molecules in substances were not clear and may be taught by the Periodic table.

At the end of the **Form-II course** participants should solve a questionnaire created by my former doctorate Mrs. Dr. Asih Wisudawati [5]. She did first research with students of her UIN university in Yogyakarta/Indonesia and could see that even students at universities have difficulties to interpret acid-base and redox reactions by proton and electron transfers. Because in Form-III courses acid-base and redox reactions are big topics I want to know how my teachers are solving the questions before this course takes place. I gave them the questionnaire with eight tasks (see appendix at the end). There are two other questions Nr. 9 and 10 regarding wishes to become acquainted with

Broensted's theory and explanations by proton and electron transfer. All teachers answered "yes, we will get to know all this"!

The example in the questionnaire deals with the **redox reaction** between magnesium and hydrochloric acid and informed that Mg atoms give two electrons and become Mg^{2+} ions, that 2 $H^+(aq)$ ions take those two electrons and change to H_2 molecules (see appendix). Because of this example most redox reactions (Nr. 2, 5 and 6) are recognized and described by electron transfers. Also, textbooks in Tanzania [6, 7] are describing those reactions well.

Regarding **acid-base reactions** one can read in textbook "Chemistry for Secondary Schools" [6] that "acids are considered to be proton donors". But no proton transfers are described by following reaction equations – the authors took Arrhenius' theory and wrote about "dissociation of acids in water". Those descriptions base on substances and not on particles – but they are obligatory for Broensted's proton transfers by acid-base reactions. One example: H_2SO_4 molecules of pure sulfuric acid are reacting with H_2O molecules by proton transfer: $H_2SO_4 + H_2O \rightarrow H_3O^+(aq) + HSO_4^-(aq)$. In diluted sulfuric acid the $H_3O^+(aq)$ ions are the acidic particles and react with $OH^-(aq)$ ions to H_2O molecules [1, 3].

Because participants could not study these ideas by textbooks or in their teacher colleges the problems of tasks 1, 3, 4, 7 and 8 are not solved. They tried mostly without success to find small particles for their equations but called them "redox reactions" and not acid-base reactions. They could not declare a proton transfer from a proton donor to a proton acceptor particle. But like in the test before participants took often "acid or salt molecules" instead of reacting ions and produced "salt molecules" by neutralization reactions. In task 3 weak acetic acid is asked and CH_3COOH molecules are wanted – but no one took those molecules for explanation. Of course, it was hard to find "spectator ions" which are not reacting – one has never seen those questions or heard about spectator ions. From these results I decided to introduce Broensted's theory very carefully during the course in April 2024 [1].

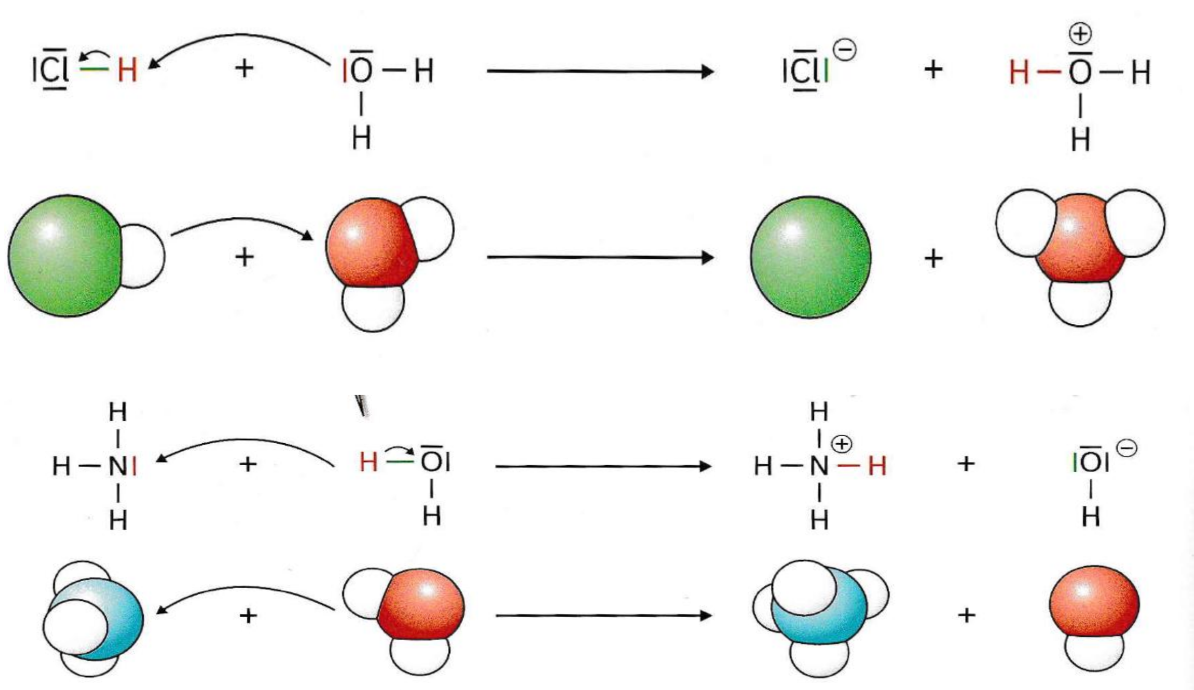

Fig. 5: Models of proton transfer between molecules, H_2O molecules as ampholytes [8]

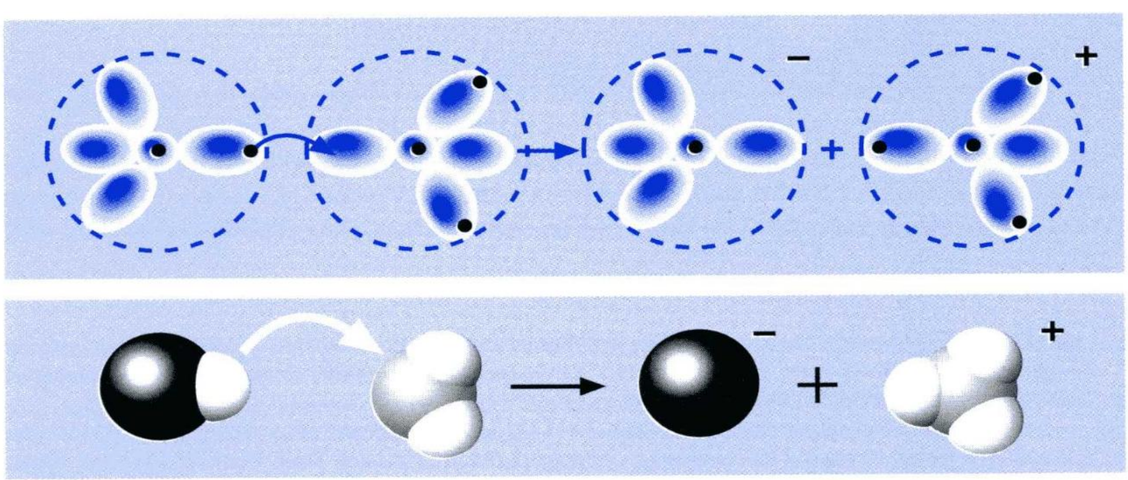

Fig. 6: Model of proton transfer between electron clouds of HCl and H_2O molecules [9]

The main topics for the **Form-III course** are acids, bases and neutralization, also electrolysis and redox reactions by electron transfer. To introduce successfully acid-base reactions I discussed some models. Figure 5 shows the reaction between HCl and H_2O molecules to form Cl^-(aq) ions and H_3O^+(aq) ions, Figure 6 goes in details to look to the proton in one electron cloud of the HCl molecule to switch by transfer into one electron cloud of the H_2O molecule to form the related ions. Figure 5 shows also the H_2O molecule as an ampholyte. It means that an H_2O molecule can take a proton (first picture) and can give also a proton (second picture): the NH_3 molecule has a free electron pair and takes the proton. Such ampholyte particles must contain a hydrogen atom and a free electron pair: besides H_2O molecules also HSO_4^-(aq) ions or $H_2PO_4^-$(aq) ions are ampholyte particles. They are proton donors or proton acceptors – it depends on the reaction partner [1].

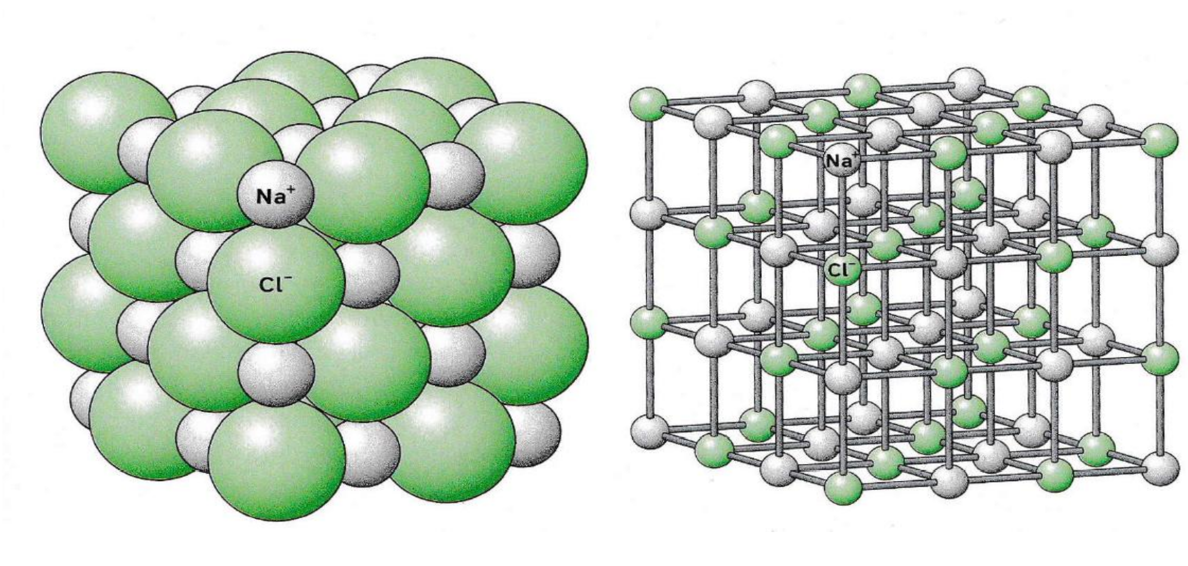

Fig. 7: Sphere packing and lattice model of sodium chloride crystals [8]

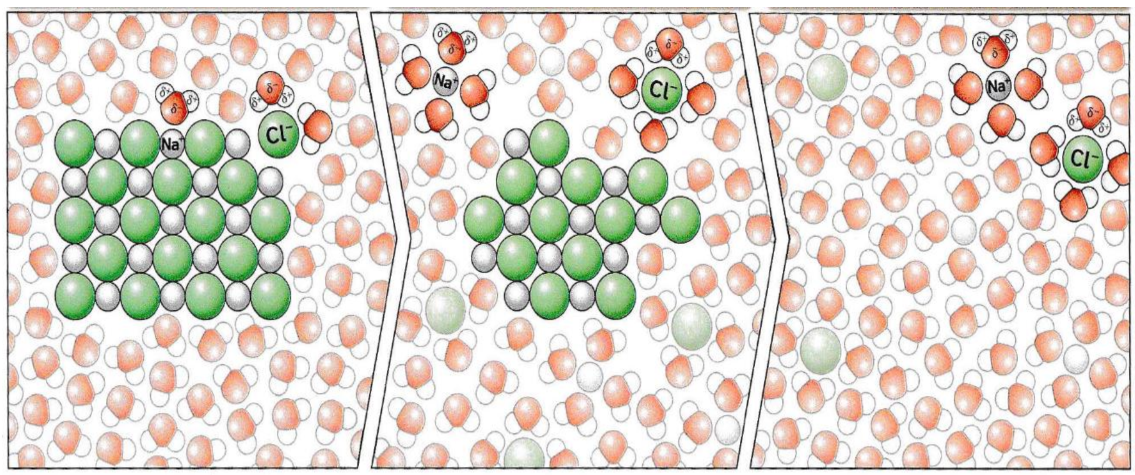

Fig. 8: Model for dissolving processes of sodium chloride crystals in water [8]

For visualizing the structure of sodium chloride crystals, I offered a nice picture of one of the German textbooks (Fig. 7), also models of dissolving sodium chloride in water (Fig. 8). If possible, one should try to build those models with big and small balls to show the number of neighbor particles or the coordination number 6 for one sodium ion, and also 6 for one chloride ion in the packing. The second lattice model should be compared to the sphere packing model and should be discussed: the sticks between spheres have no original in the ionic lattice, electric forces hold the ions together and not electron pairs.

The second picture (Fig. 8) shows how H_2O molecules are surrounding every ion and producing hydrated ions: Na^+(aq) and Cl^-(aq) ions. By the dipole of H_2O molecules, they arrange with the negative pole to positive charged cations and the positive pole to the negative charged anions. If all H_2O molecules are used to produce hydrated ions the sodium chloride solution is saturated: maximum of 36 g sodium chloride can be dissolved in 100 g of water.

Finally, the problem of the **Laboratory jargon** was discussed in all courses. One example: A teacher in the workshop explained his molecular model of butane and said: "Butane contains of carbons and hydrogens: you see four carbons and there 10 hydrogens". After some discussion my answer was: “A butane molecule contains of four C atoms and 10 H atoms”. Even scientists use the Laboratory jargon – knowing that colleagues suppose what is meant. But young students at school don’t know the meaning of “four carbons and ten hydrogens” – they may think of “black carbon pieces” and “colorless hydrogen bubbles”. So, we tried in our courses to avoid such expressions by the laboratory jargon [10].

After this introduction in the Form-III course teachers solved another time the eight tasks in our questionnaire (see appendix) – now nearly all tasks are done correctly! And they answered question 10 “Do you like to go so deep into the Submicro level” hundred percent with “Yes, I like this way in Chemistry education, finally I am understanding Chemistry”. **They said thanks to our Probono organization in Frankfurt/Germany to realize those four courses for a much better understanding in sciences, mathematics and English.**

CONCLUSION

For modern Chemistry instruction the Ministry of education in Tanzania should change guidelines in the direction of interpreting formulae and chemical reactions by atoms, ions or molecules. Especially acid-base and redox reactions should be taught in sense of Broensted’s theory by proton and electron transfers, and therefore no substances but smallest particles are to be taken for argumentation: after 100 years of discovering, this way should finally be introduced in Chemistry education for teachers at colleges and students at schools.

By those new guidelines new textbooks for Chemistry education should be written. Normally teachers have no scientific books at home, they mostly look into textbooks and prepare their lectures on this basis: besides students also Chemistry teachers need them. Finally, the schedule of teacher colleges and universities has to be adapted in this direction because my teachers in the Probono teacher training project are writing only formulae and equations, they have never interpreted chemical reactions by atoms, ions and molecules. With this new way they will understand Chemistry much better and may improve lessons at school. Also, the student-centered education can be realized by discussing with students most experiments or phenomena by the question: "Which particles are reacting?". Those discussions are more fruitful than writing chemical equations at the board and memorizing them.

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APPENDIX [10]

Asih Wisudawati

Questionnaire "Redox or Acid-base reaction?"

For understanding Chemistry we need three levels of reflection:

1. **Macro level** of observations according to substances and chemical reactions,
2. **Submicro level** with interpretation of all observations with mental models by particles of matter like atoms, ions, molecules and by chemical structures,
3. **Symbolic level** with shortenings of mental models by chemical symbols like atomic, ionic, molecular symbols, and chemical equations. In following problems the macro and symbolic level is presented in this questionnaire, the submicro level is asked by participants.

One example for the wanted answers in the following eight problems:

Macro level: Magnesium reacts with hydrochloric acid; gaseous hydrogen is observed.

Symbolic level: $Mg(s) + 2 HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

Submicro level: **a) Which particles (atoms or ions or molecules) are involved?**

Answer: Mg atoms / H^+ ions, Cl^- ions / Mg^{2+} ions Cl^- ions (1:2) / H_2 molecules

b) Write down equation of those atoms, ions or molecules which react!

Mg atom + 2 H^+ ions $\rightarrow$ Mg^{2+} ion + H_2 molecule

c) Which atoms, ions or molecules are NOT involved in the reaction?

Cl^- ions are „spectator ions“

d) Redox or acid-base reaction? Explain transfer of electrons or protons.

Redox: Mg atom gives two electrons: Mg atom $\rightarrow$ Mg^{2+} ion + 2 e- (oxidation)

2 H^+ ions take two electrons: 2 H^+ ions + 2 e- $\rightarrow$ H_2 molecule (reduction)

Try to solve the next eight problems in this way!

Take a blank white paper and write down your answers according to (a) – (d).

1. Solid sodium carbonate reacts with hydrochloric acid, gaseous carbon dioxide is observed: $Na_2CO_3(s) + 2 HCl(aq) \rightarrow 2 NaCl(aq) + H_2CO_3(aq)$ ($H_2CO_3 \rightarrow H_2O + CO_2$)
2. Zinc reacts with diluted sulfuric acid, gaseous hydrogen is observed: $Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g)$
3. Acetic acid solution reacts with sodium hydroxide solution, small heat is observed: $HAc(aq) + NaOH(aq) \rightarrow NaAc(aq) + H_2O$ (**H**Ac = **H**$OOCCH_3$)
4. Hydrochloric acid reacts with sodium hydroxide solution, big heat is observed: HCl(aq) + NaOH)aq) $\rightarrow$ $NaCl(aq) + H_2O$
5. Iron reacts with blue copper chloride solution, brown copper develops on iron: $Fe(s) + CuCl_2(aq) \rightarrow FeCl_2(aq) + Cu$
6. Copper reacts with silver nitrate solution, silver crystals are growing on copper: $Cu(s) + 2 AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2 Ag$
7. Solid calcium carbonate reacts with acetic acid, gaseous carbon dioxide is observed: $CaCO_3(s) + 2 HAc(aq) \rightarrow CaAc_2(aq) + H_2CO_3(aq)$ ($H_2CO_3(aq) \rightarrow H_2O + CO_2$)
8. Solid magnesium oxide reacts with hydrochloric acid, magnesium oxide dissolves: $MgO(s) + 2 HCl(aq) \rightarrow MgCl_2(aq) + H_2O$
9. **Let us know which of alternatives (a) – (d) was the most difficult for you. Explain.**
10. **Do you like to go with (a) – (d) so deep into the Submicro level? Explain.**