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WESTFÄLISCHE WILHELMS-UNIVERSITÄT MÜNSTER

Structure of Matter –
Diagnosis of Misconceptions and Challenge


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Verschiedene Molekülmodelle
Unterricht Chemie
Unterricht Physik
CHEMIE & Schule
LEHREN
Bitte keine Selbstbedienung
CHEMIE

AUFGABEN
LEHREN
Unterricht Chemie
Unterricht
CHEMIE & schule
Bitte keine Selbstbedienung.
Molekülmodelle
PePe · Portfolio

Hans-Dieter Barke · Günther Harsch · Siegbert Schmid
Essentials of Chemical Education

For everybody teaching chemistry or becoming a chemistry teacher, the authors provide a practice-oriented overview with numerous examples from current chemical education, including experiments, models and exercises as well as relevant results from research on learning and teaching. With their proven concept, the authors cover classical topics of chemical education as well as modern topics such as every-day-life chemistry, student's misconceptions, the use of media or the challenges of motivation. This is the completely revised and updated English edition of a highly successful German title.

Chemistry

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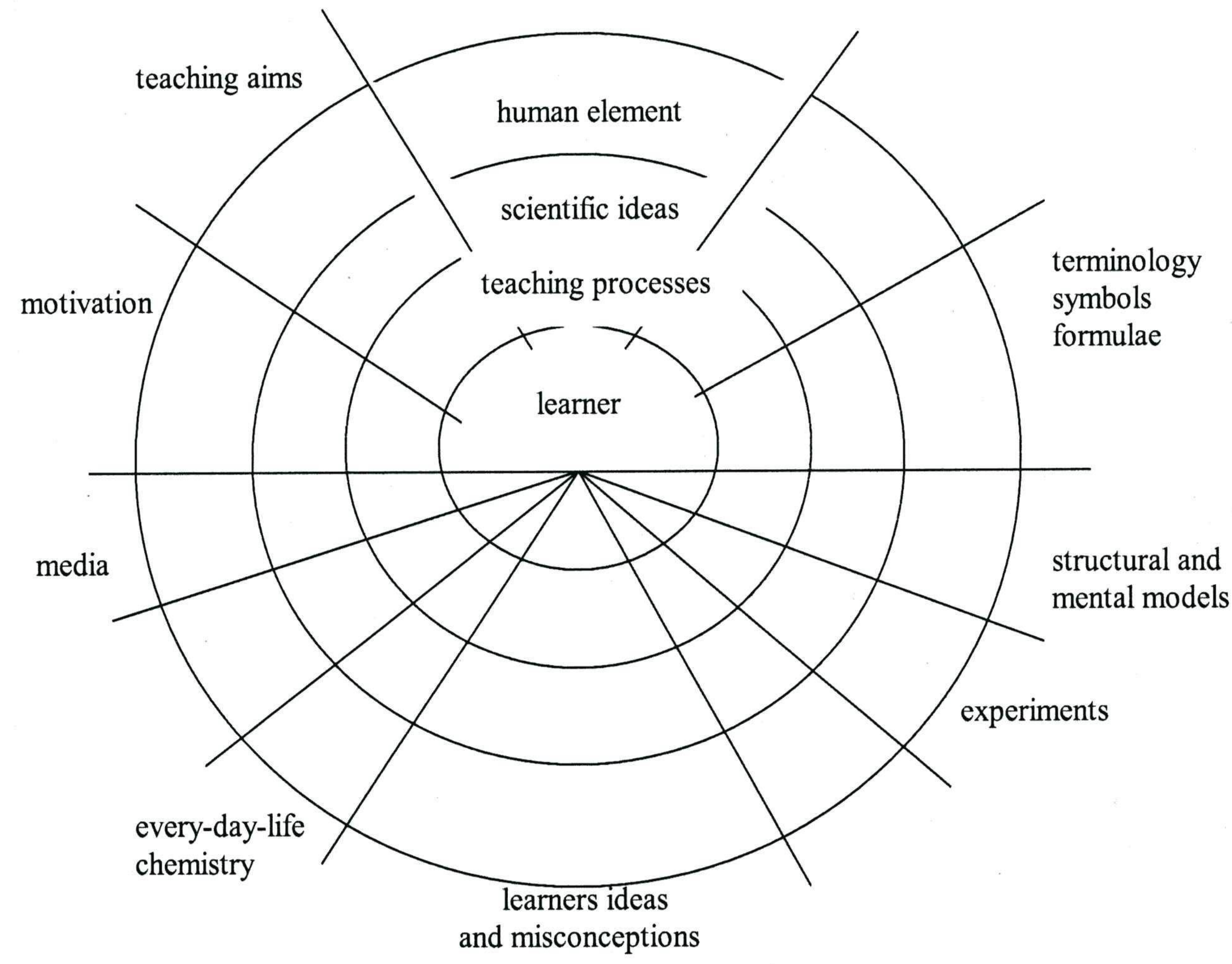
Essentials of Chemical Education

Hans-Dieter Barke
Günther Harsch
Siegbert Schmid

Essentials of Chemical Education

Springer


teaching aims
human element
scientific ideas
teaching processes
terminology
symbols
formulae
motivation
learner
media
structural and
mental models
experiments
every-day-life
chemistry
learners ideas
and misconceptions

Barke‘s 3-level concept (1986):
phenomena – structural models – chemical symbols

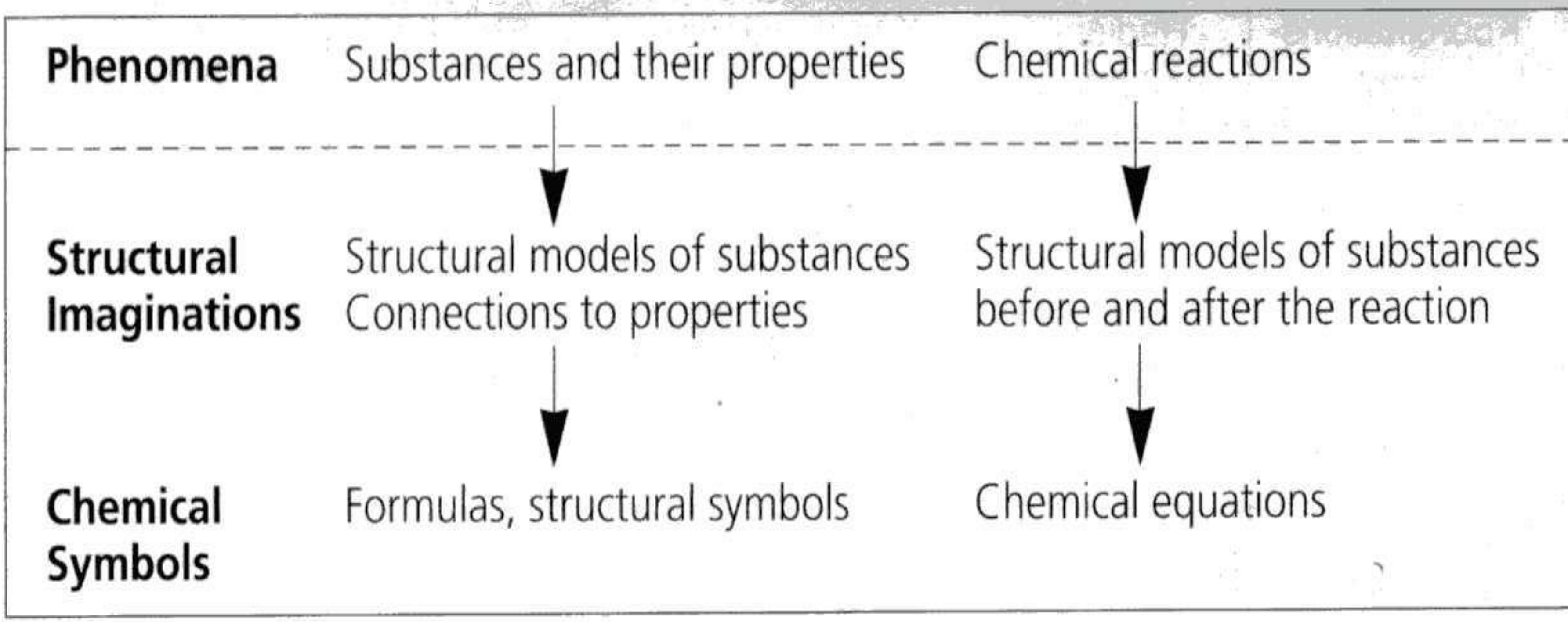
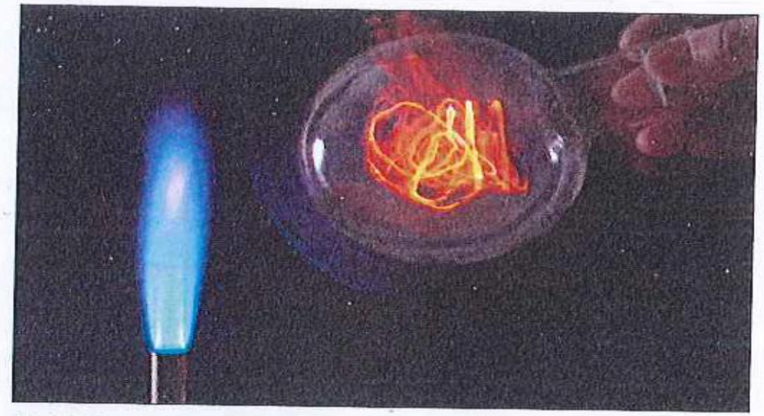
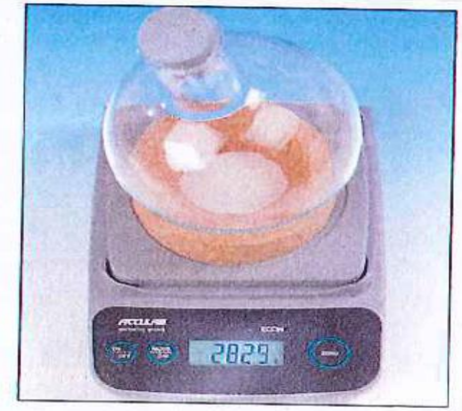


Figure 2. Structural imaginations: mediator between phenomena and chemical symbols [2]

Masse vor der Reaktion

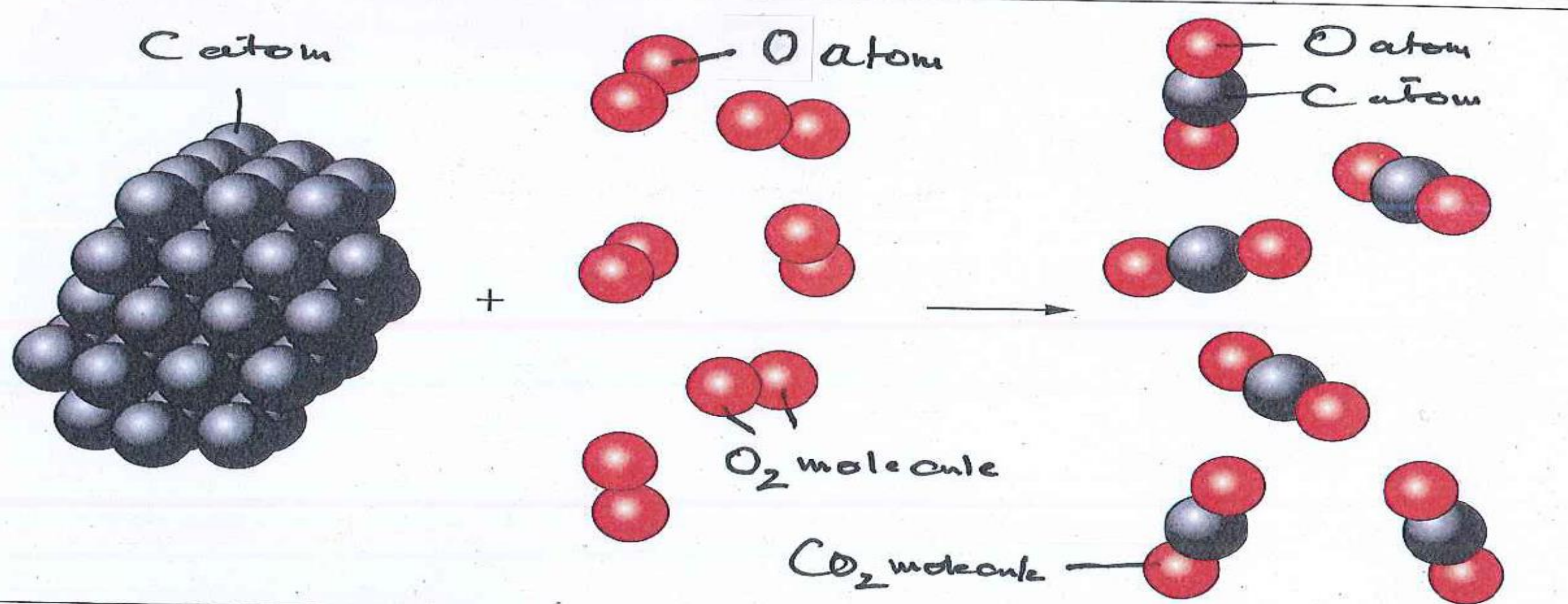


Kohlekörner verbrennen vollständig



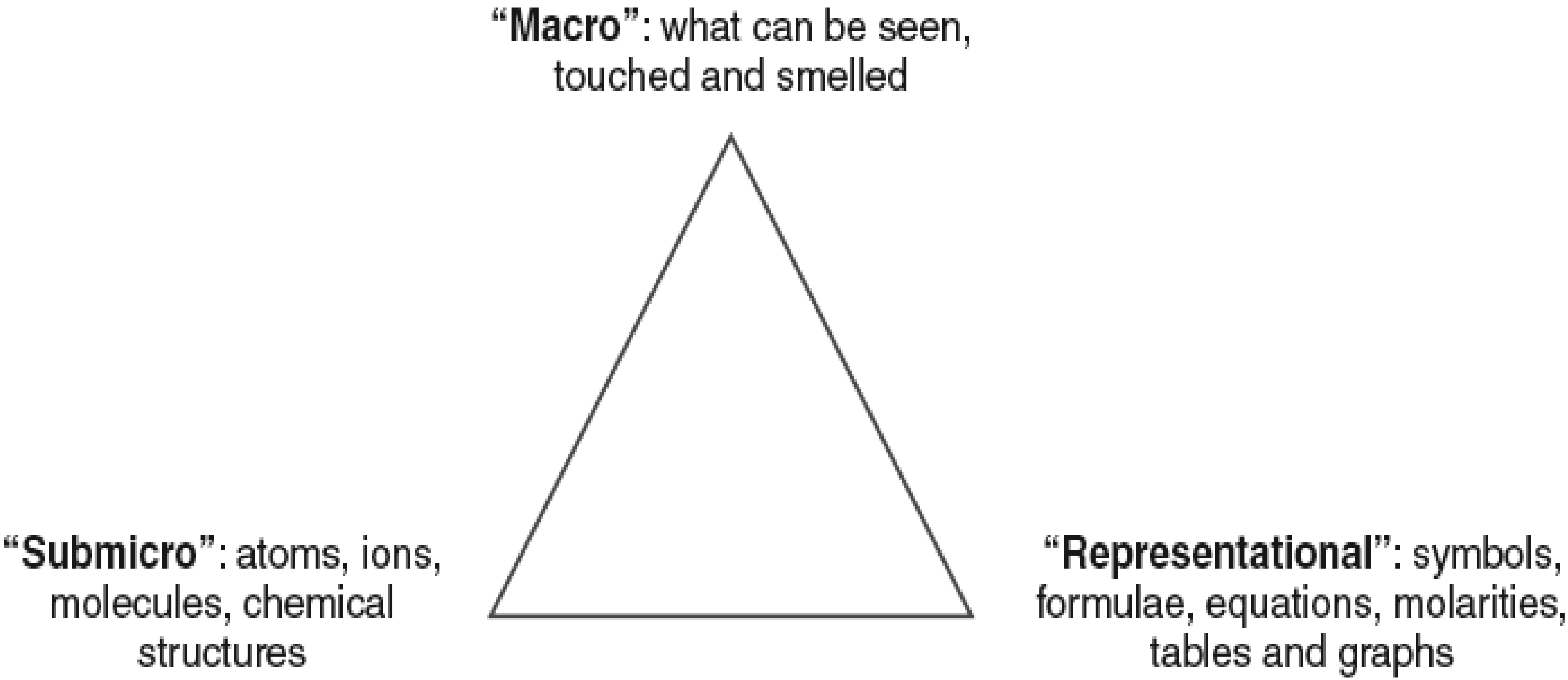
Masse nach der Reaktion

reaction of carbon and oxyen

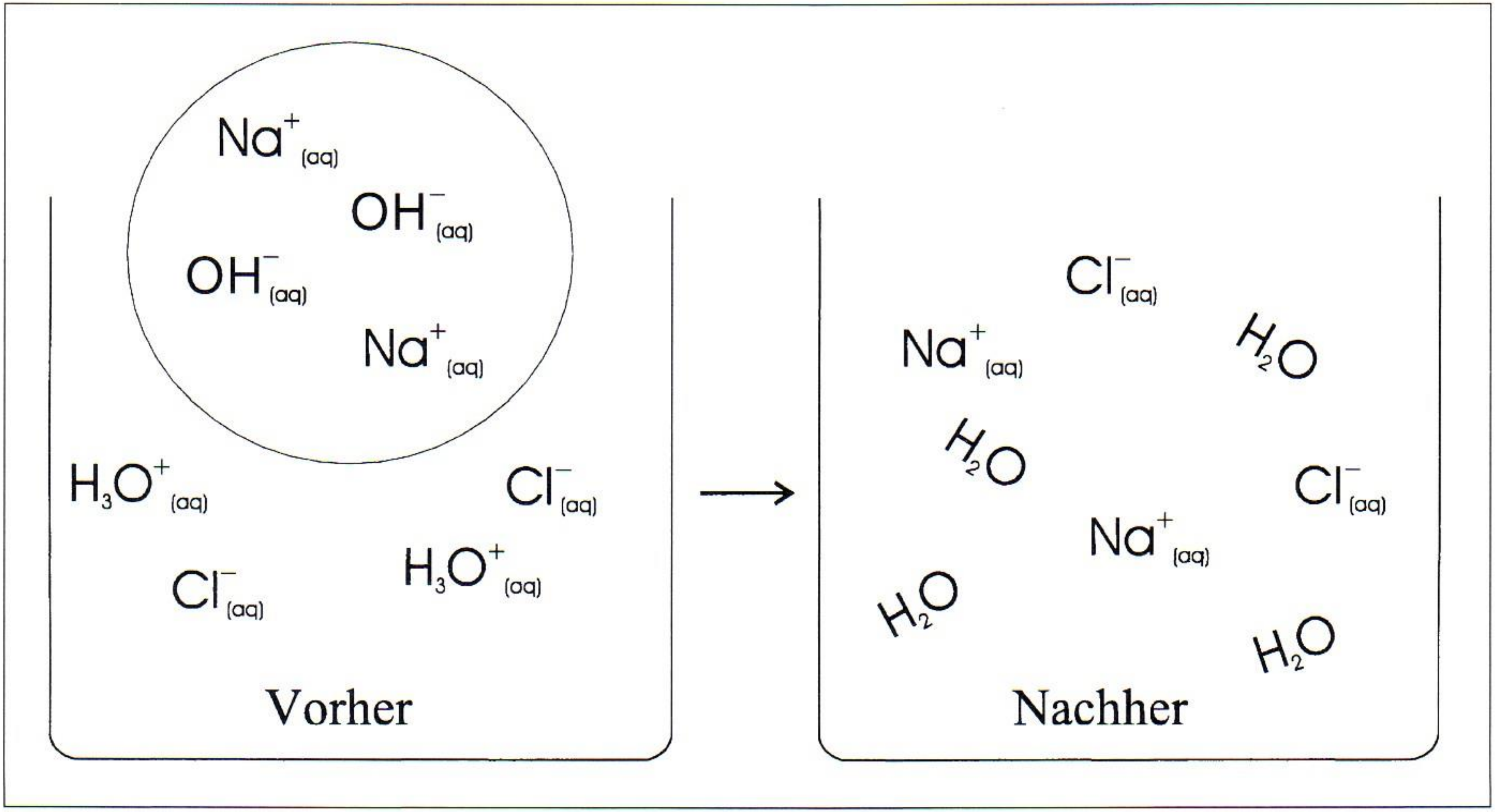


Model of regrouping C- and O atoms by the reaction

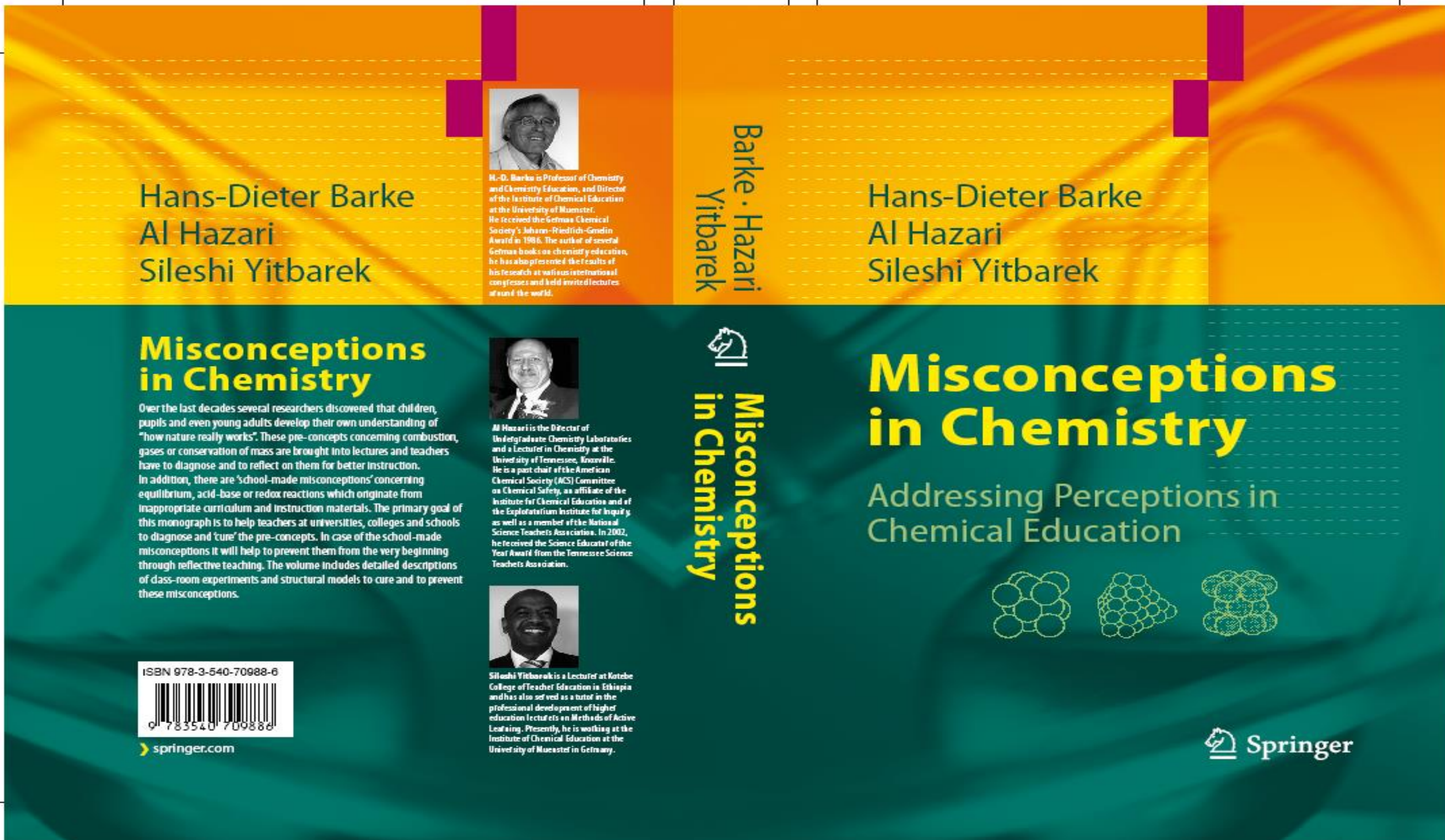
Johnstone´s triangular concept (2000)



Example for Submicro level: „beaker model" of particle arrangements for neutralization



Barke, H.-D. et al: Misconceptions in Chemistry. Berlin, Heidelberg 2009 (Springer)

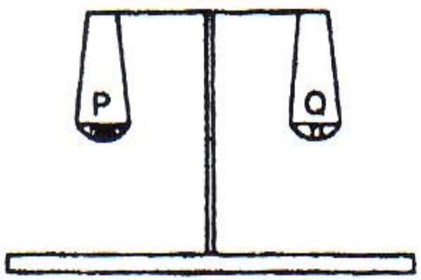


Preconcepts and school-made misconceptions

- **Preconcepts:** brought by children through careful observation in their every-day life:
  - combustion („something is going away"),
  - transmutation of substances („copper changes from red to green, iron from grey to black"), - gases are substances? („they have no mass"), etc.

- **School-made misconceptions:** developed by inappropriate teaching on the representational level:
  - chemical equilibrium („reactants and products show same concentration, same amount of substance"),
  - weak acids („they have a pH of 3 or above"),
  - redox reactions („oxygen is always involved"), etc.

Preconcepts of children:
Children's ideas in science (Driver 1985)



A small amount of iron wool was placed on pan P, and weights were added to pan Q to balance the scales.

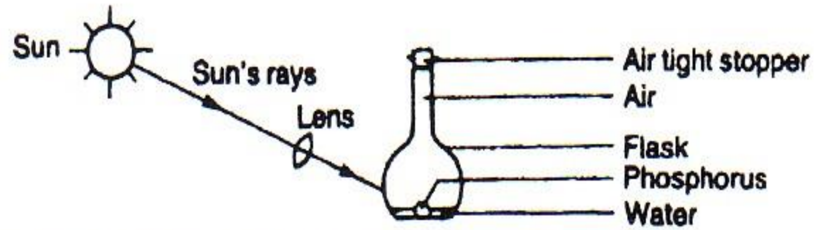
The iron wool was then removed and heated in air.

It formed a black powder which was carefully collected and returned to pan P.

What do you expect to happen to pan P?

Explain the reason for you answer.

I expect pan p was lighter because by heating it certain things were being burnt away and so making it lighter



A piece of phosphorus was held in a flask as shown in the diagram. The mass of the flask and contents equalled 205 g. The sun's rays were focussed on the phosphorus, which then caught fire. The white smoke produced slowly dissolved in the water.
After cooling, the flask and its contents were weighed again.

(a) Would you expect the weight to be:

- ☐ A More than 205 g
- ☐ B 205 g
- ☑ C Less than 205 g
- ☐ D Not enough information to answer

Tick in the box next to the answer you choose.

(b) Give the reason for your answer:

Nothing in the container could escape but the smoke has dissolved and the phosphorus destroyed making it weigh less

Preconcepts of children:

Formulas – but no scientific mental model (Barke, 1980)

Questionaire

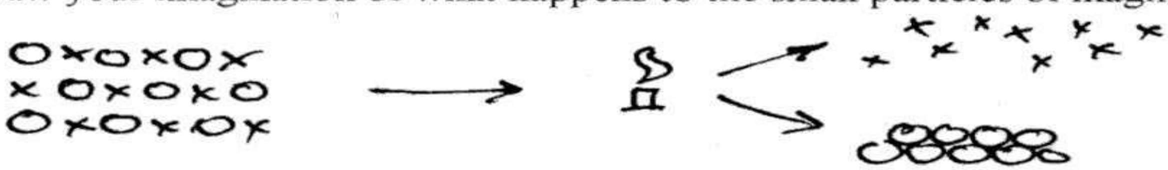
1. Write the chemical equation for the combustion of magnesium:

$$2\,Mg + O_2 \longrightarrow 2\,MgO$$

2. Describe what happens to the small particles of magnesium during the combustion:

magnesium contains two kinds of particles: one evaporates by combustion, the other one remains as magnesium oxide.

3. Draw your imagination of what happens to the small particles of magnesium:



Ox = magnesium   O = magnesium oxide   x = gas

Figure 1. Questionnaire about the combustion of magnesium (teacher questions in block letters, student responses hand-written)

Preconcepts of children:
Concept Cartoons for diagnosis and challenge (Temechegn, Sileshi 2004)

- Performing key experiments, asking for explanation and discussing explanation, showing concept cartoon for diagnosis
- Teaching the scientific concept after reflection of alternative concepts of childs, asking for new explanation
- Comparing the answers of the concept cartoon , finding the right answer
- Defending inappropriate statements of the cartoon with the new scientific concept.

A sample of pure water is intensely heated in a closed container. What is the composition of the vapor?

What do you think?

School-made misconceptions (Sopandi 2003): molecules and ions in „Bonaqua“ mineral water

3. **Mineralwasser**

Auf dem Etikett eines Mineralwassers (siehe unten) liest man „mit Kohlensäure“ und die Namen mehrerer Salze: Im Mineralwasser sind Salze und Kohlenstoffdioxid gelöst.

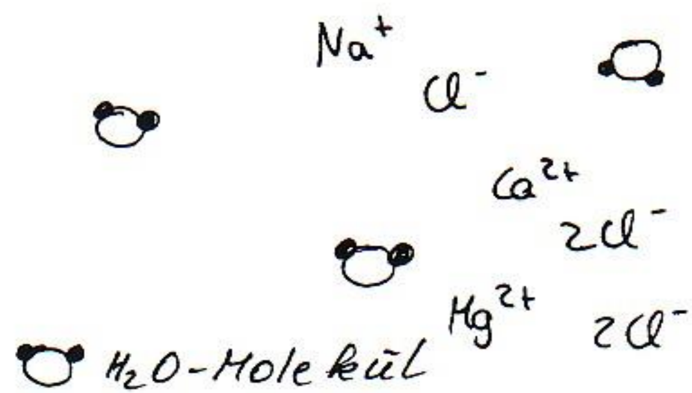
O.. stimmt **O.. stimmt nicht** **O.. Ich weiß es nicht**

Mögliche Gründe für Deine Antwort :

O.. Mineralwasser enthält CO_2-Moleküle
O.. Mineralwasser enthält kleine Salzkristalle
O.. Mineralwasser enthält Moleküle mehrerer Salze
O.. Mineralwasser enthält Ionen mehrerer Salze
O.. deine eigene Begründung: ……………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

*Zeichne Deine Vorstellung von **allen Teilchen** auf, die mit H_2O-Molekülen gemischt vorliegen. Lies dazu das Etikett genau.*

Etikett eines Mineralwassers

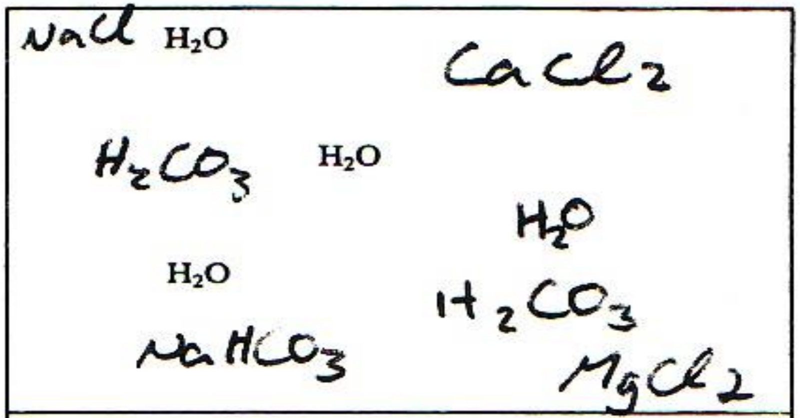


Teilchenvorstellung des Mineralwassers

School-made misconceptions (Sopandi 2003): molecules and ions in mineral water

Gründe für deine Antwort :

O.. Mineralwasser enthält Kohlendioxid-Moleküle
O.. Mineralwasser enthält kleine Salzkristalle
O.. Mineralwasser enthält Moleküle mehrerer Salze
O.. Mineralwasser enthält Ionen mehrerer Salze
O.. deine eigene Begründung: ...Enthält...
gelöstes ... Kohlendioxid
und ... Ionen ... der ... Salze ....



Teilchenvorstellung des Mineralwassers

Mögliche Gründe für Deine Antwort :

☒.. Mineralwasser enthält CO_2-Moleküle
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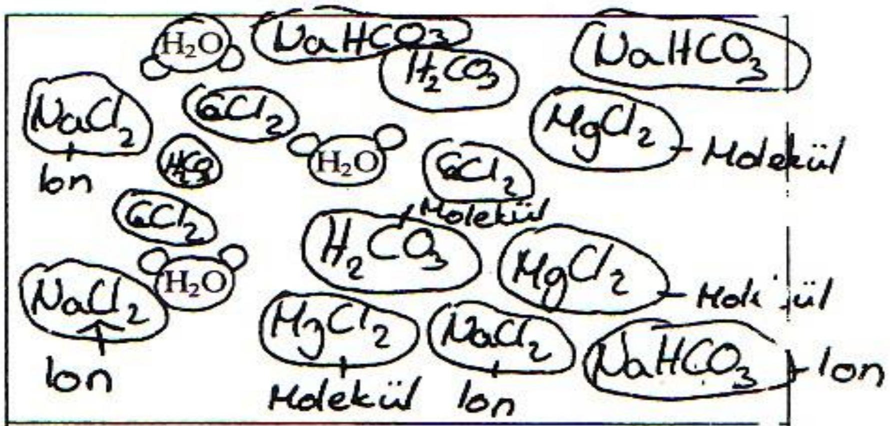
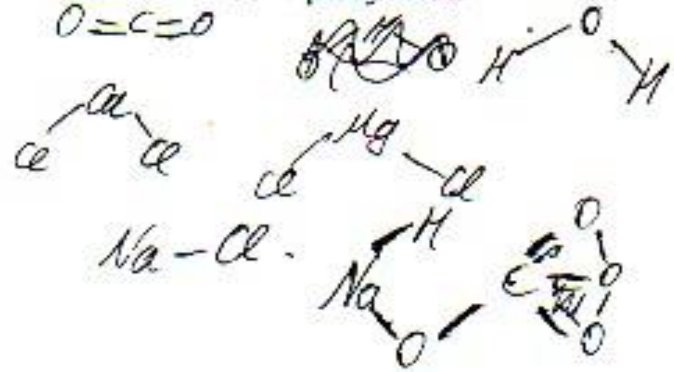
☒.. Mineralwasser enthält Ionen mehrerer Salze
O.. deine eigene Begründung: ....
....
....



Teilchenvorstellung des Mineralwassers

Место для рисунков



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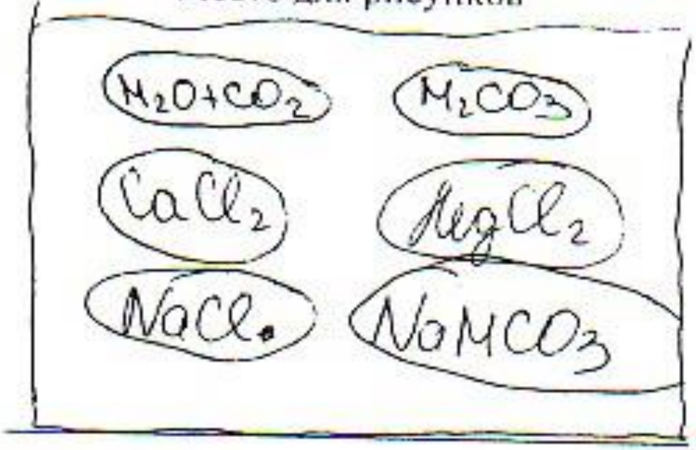

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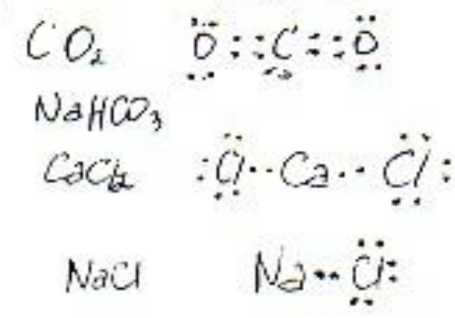

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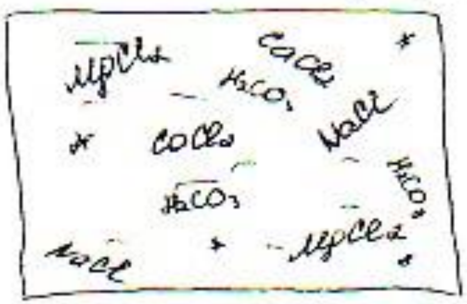

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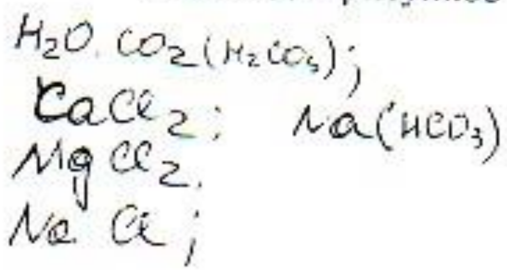

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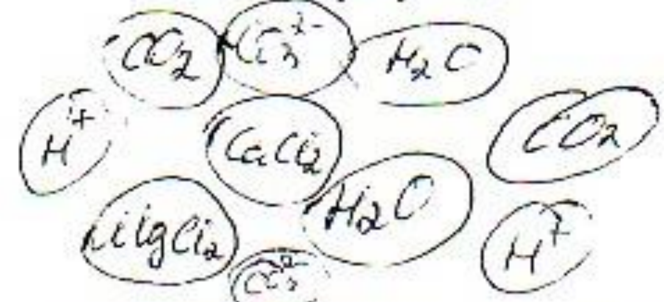

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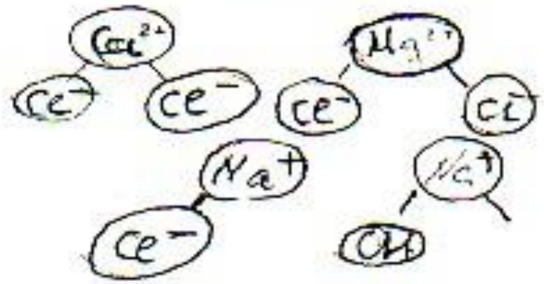

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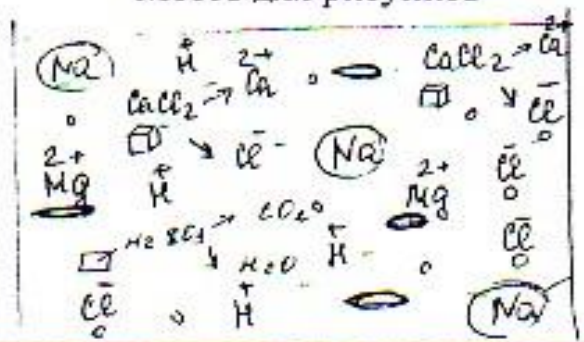

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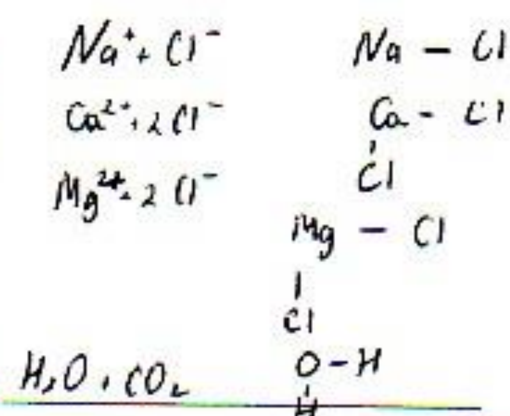
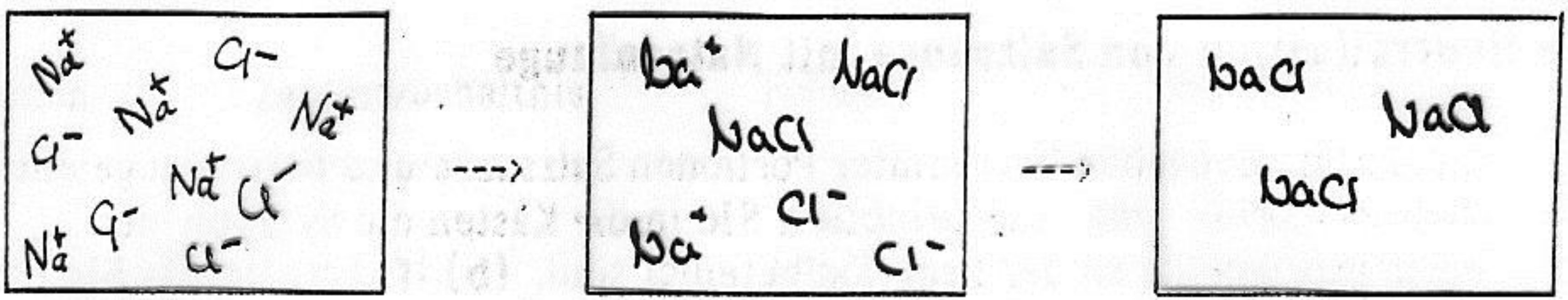


School-made misconceptions:
Mental models of salt crystals and salt solutions

Kristallisation von Kochsalz aus der Lösung 2

4. Eine Natriumchloridlösung enthält Na^+-Ionen und Cl^--Ionen. Verdampft das Wasser, so bilden sich weiße Natriumchloridkristalle.
a) Zeichnen Sie Ihre Teilchenvorstellung auf, **b) kreuzen Sie an**.

a)



vor d. Verdampfen — während — nach d. Verdampfen

b) Die Lösung ist "neutral": ☒ ja, ☐ nein **Begründen Sie:** Na+ und Cl−
Der Kristall ist "neutral": ☒ ja, ☐ nein gleichen sich aus

School-made misconceptions:
Mental model of ionic bonding (Taber, 2002)

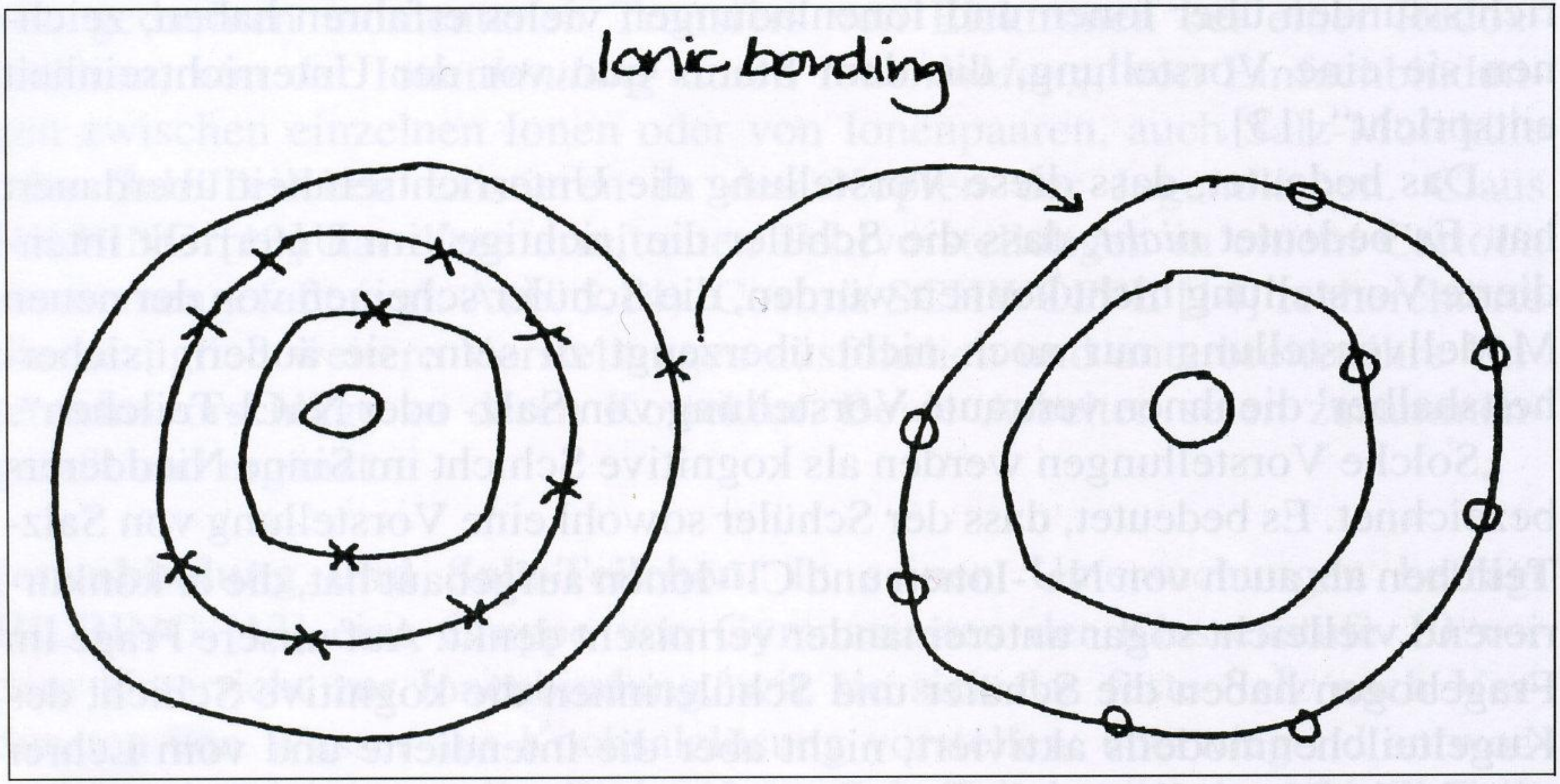
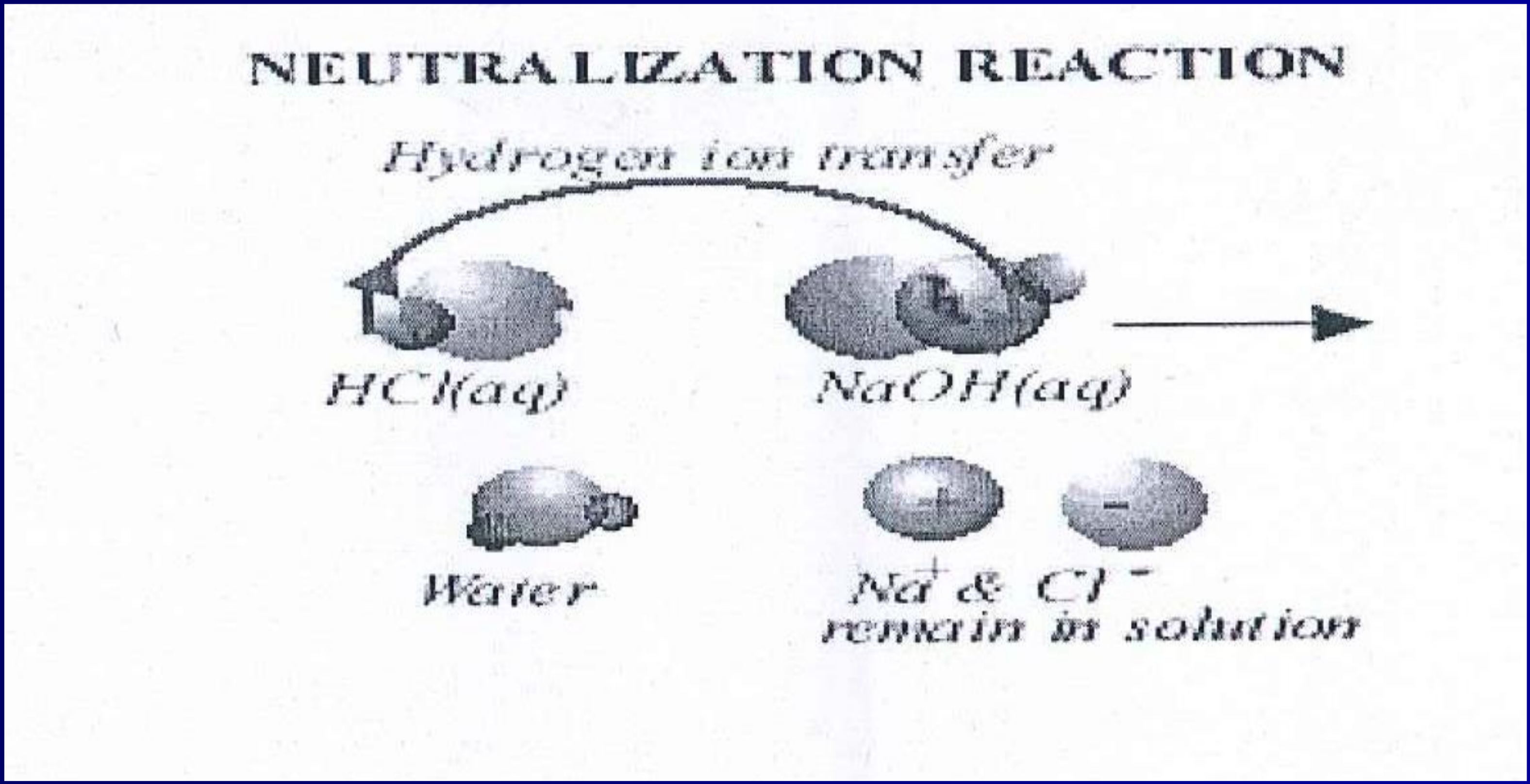
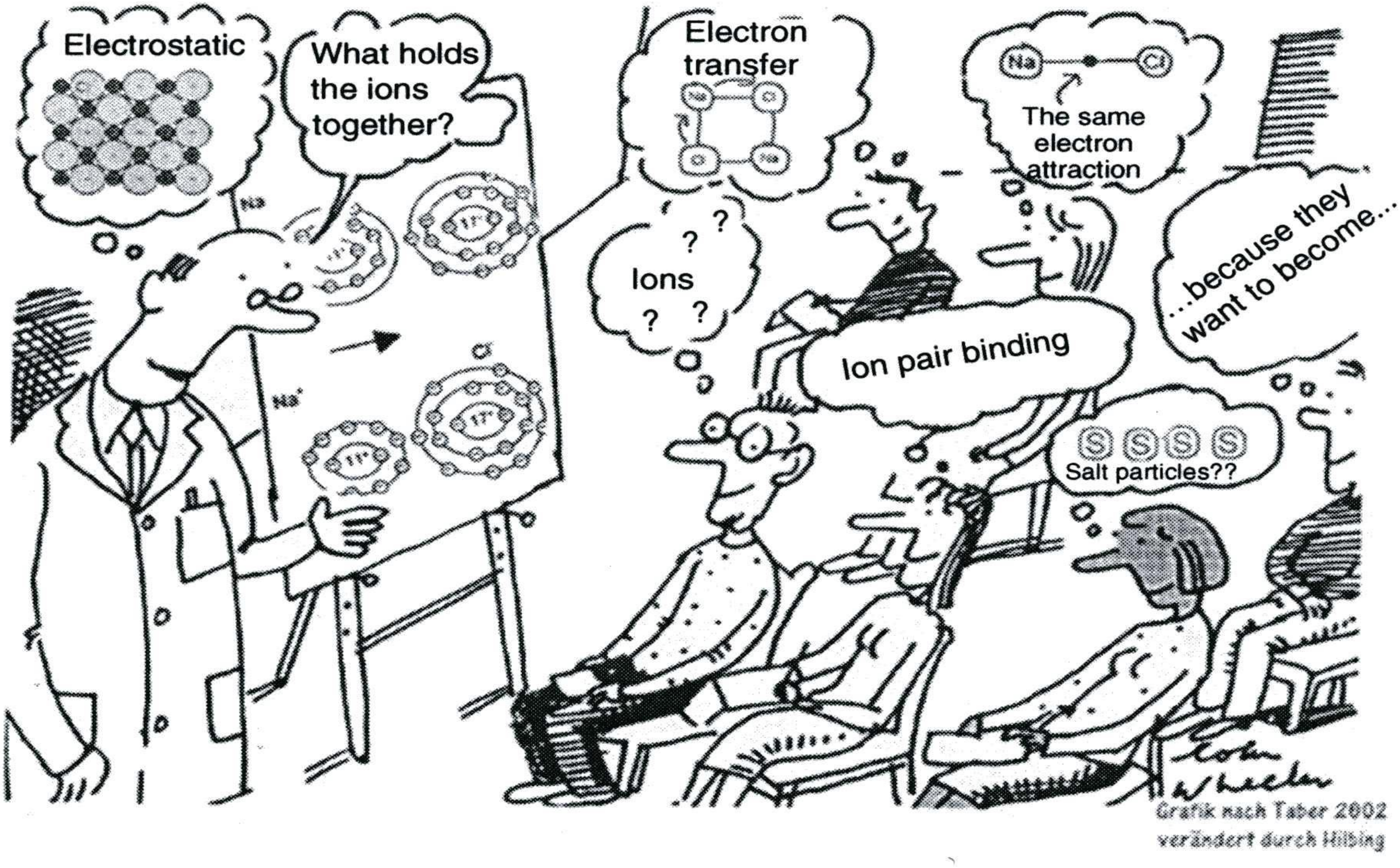


Abb. 5.15. Modellvorstellung eines Schülers zur Ionenbindung [16]

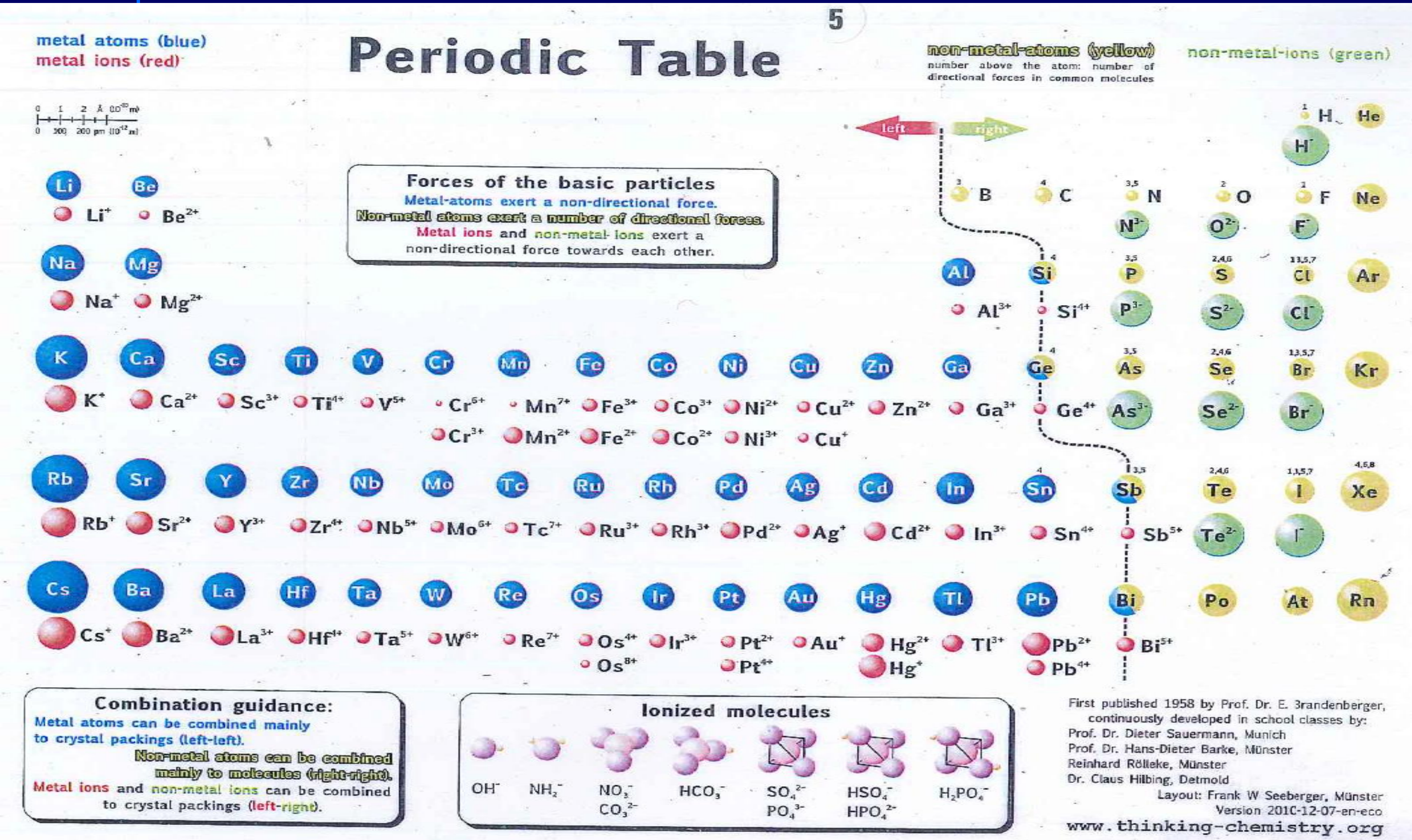
Textbook-made misconceptions: a picture from a Tanzanian chemistry book for Secondary schools



School-made misconceptions:
NaCl structure and ionic bonding (Hilbing 2003)



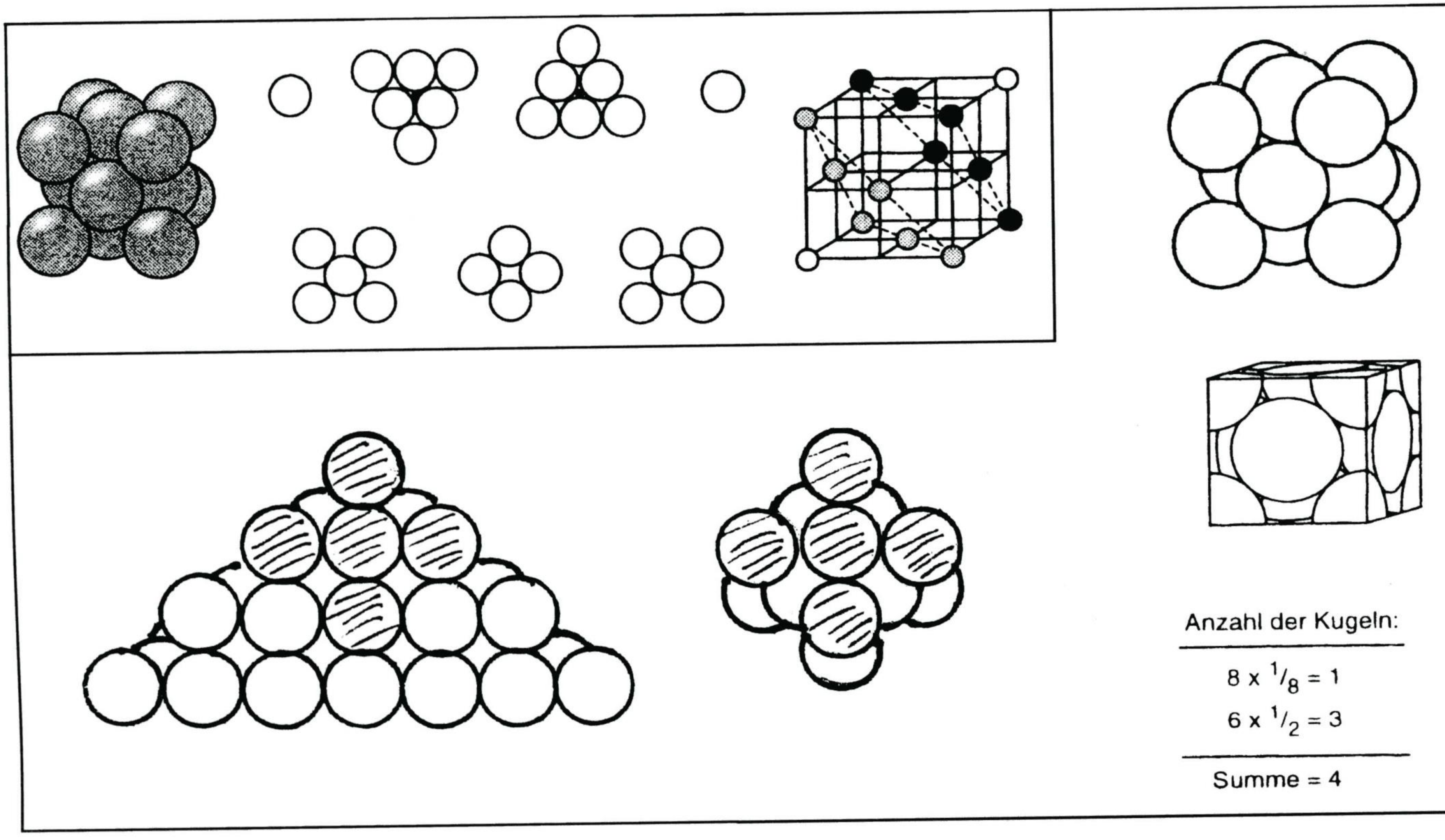
Periodic table of basic particles of matter - atoms and ions: (see also www.chemischdenken.de)



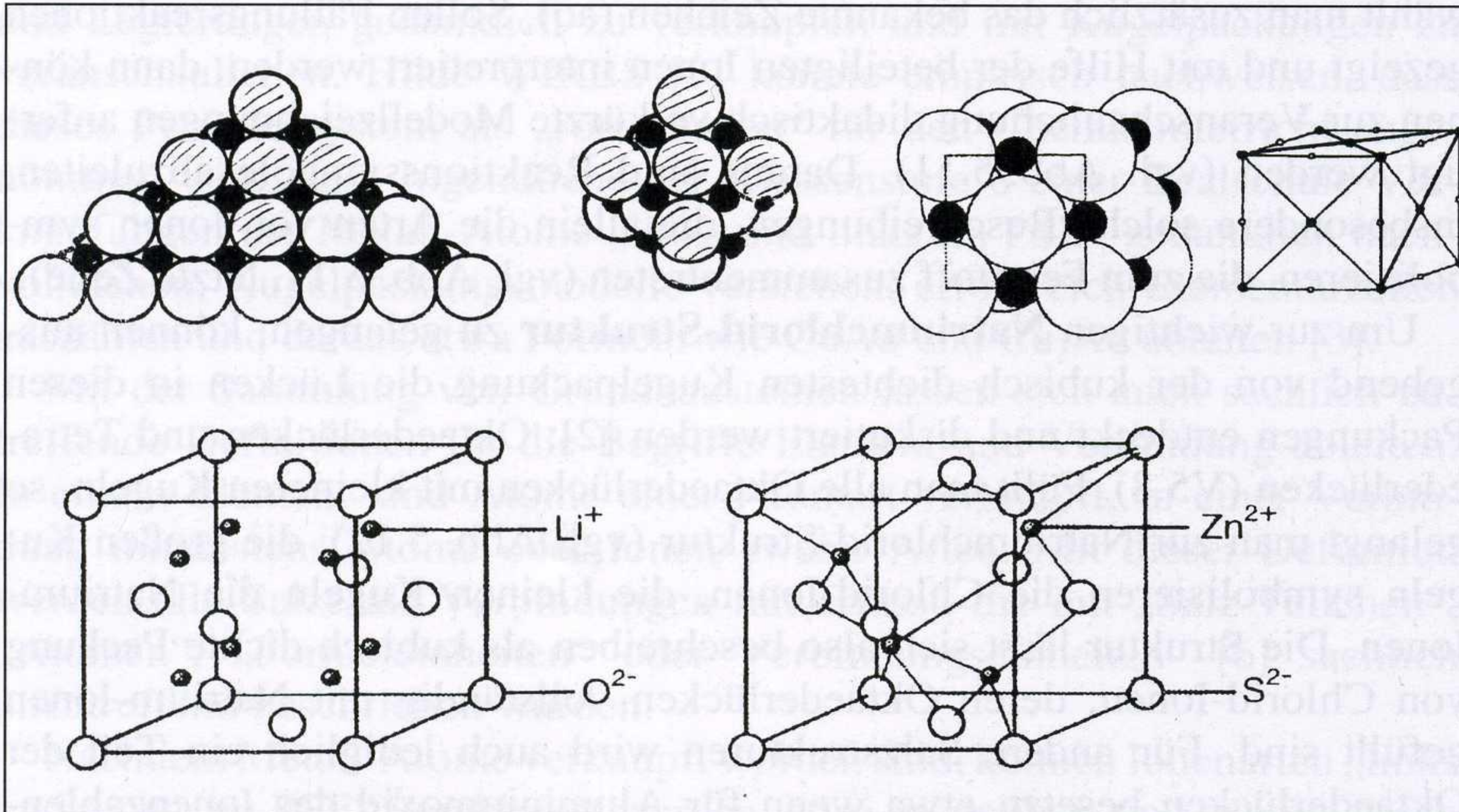
Prevention of misconceptions:
Combination of basic particles – without altering them (Sauermann, Barke 1997)

- **1. Metal atoms „left and left in PSE":**
-
- x Ag → Ag_x (metal structure, closest sphere packing)
-
- **2. Nonmetal atoms „right and right in PSE":**
-
- 1 C atom + 4 H atoms → 1 CH_4 molecule (tetrahedral)
- **3. Ions „left and right in PSE":**
-
- n Na^+ + n Cl^- → $(Na^+)_n(Cl^-)_n$ (ionic lattice, ionic bonding)
-

Prevention of misconceptions:
building sphere packings to visualize metal structures



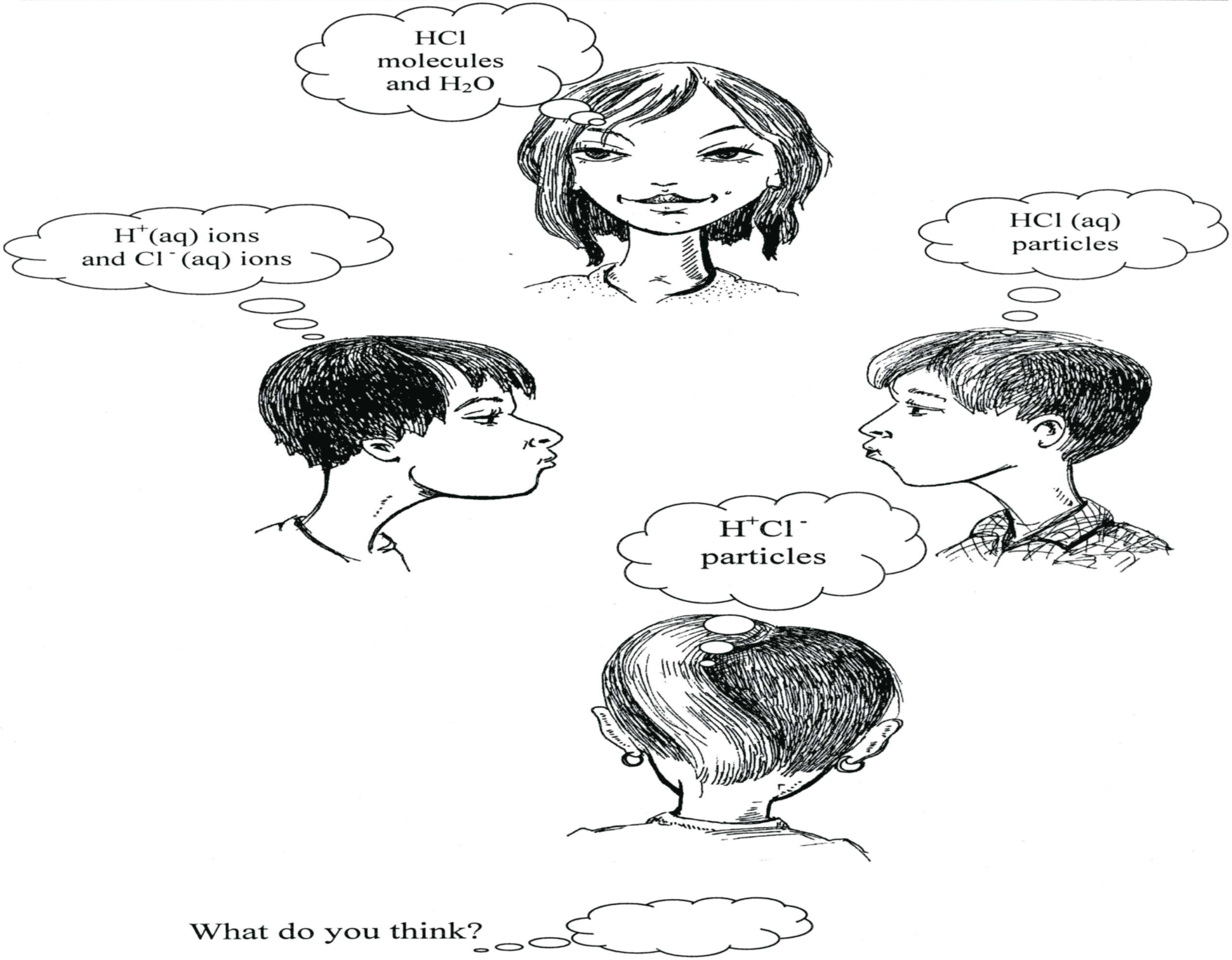
Prevention of misconceptions: building sphere packings or ball-stick models to visualize salt structures



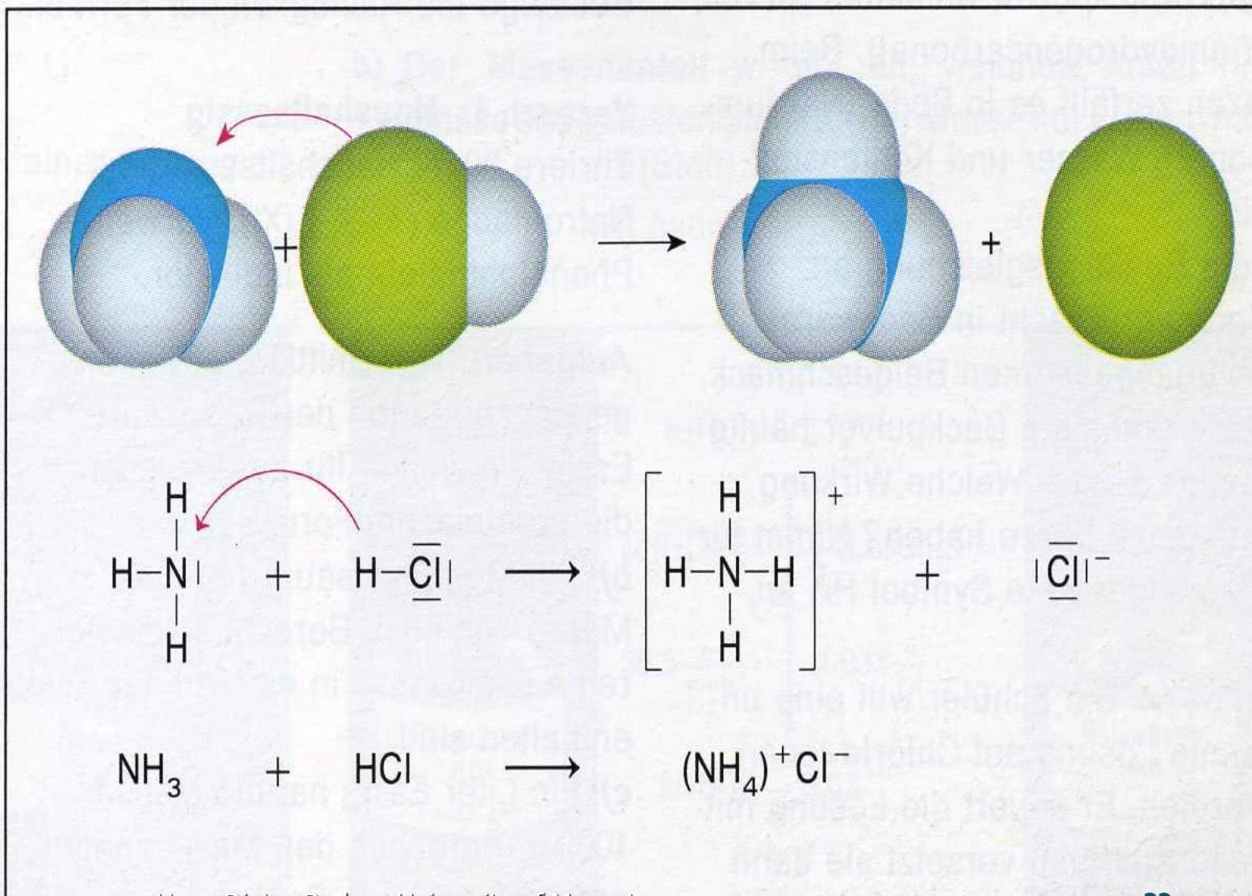
Discussing Concept Cartoons to avoid most misconceptions: (Temechegn, Sileshi 2008)

- Performing key experiments and taking concept cartoons for first explanations, also for diagnosis of misconceptions.
- Teaching the scientific concept after reflec-ting misconceptions and finding the right scientific statement in the concept cartoon.
- Discussing the statements of the cartoon and applying the new scientific concept to find out why some statements are wrong.

What species are present in hydrochloric acid ?

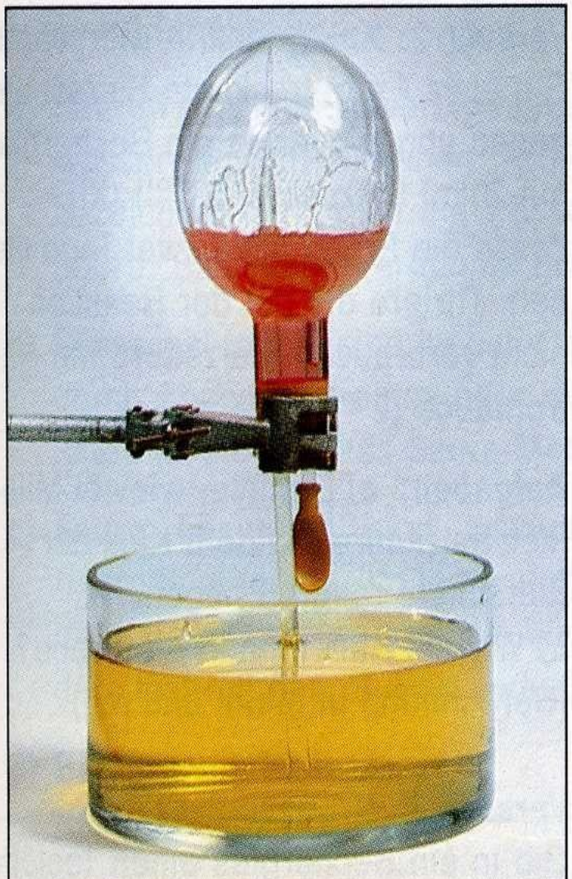


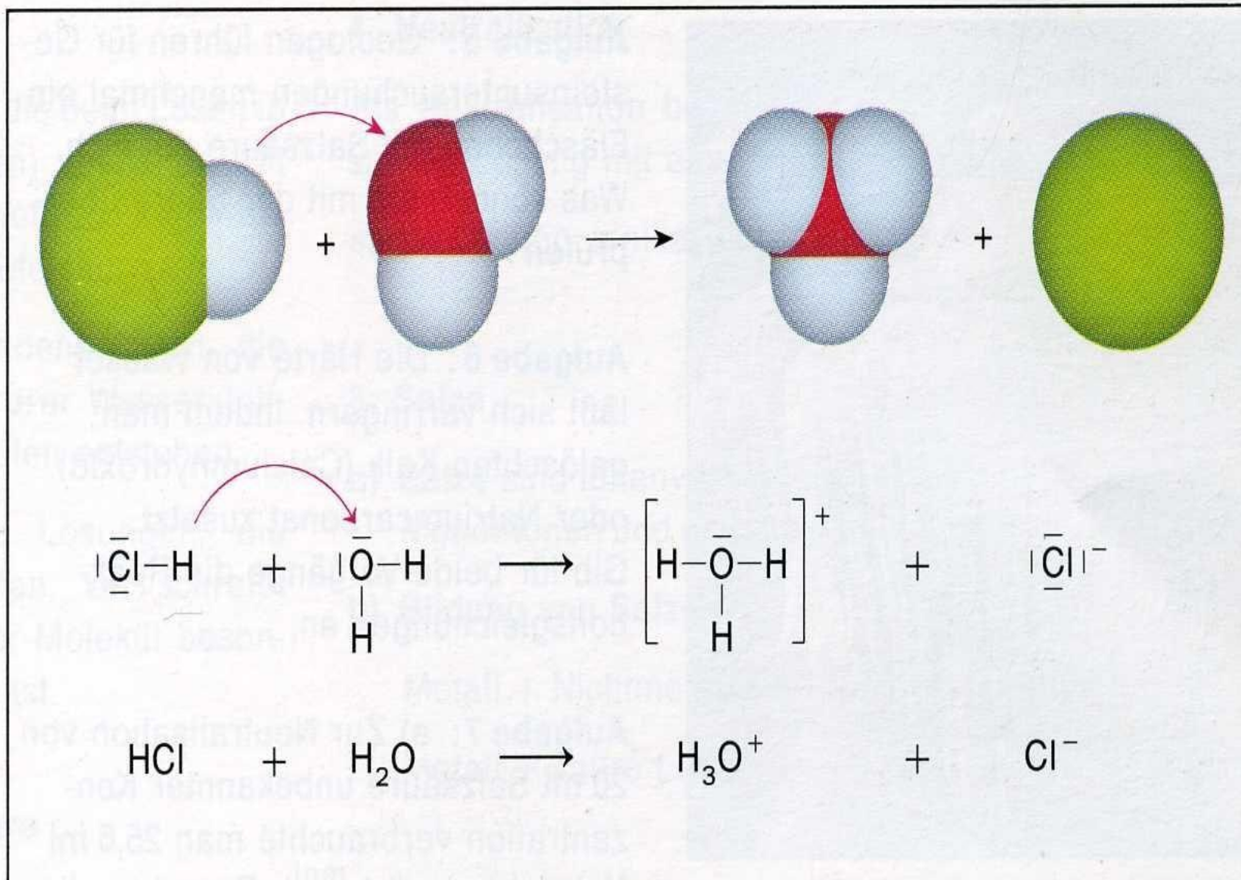
Prevention of misconceptions: molecules and ions as acid or base PARTICLES



Ammoniak reagiert mit Chlorwasserstoff. Es entsteht Ammoniumchlorid, eine Ionenverbindung.

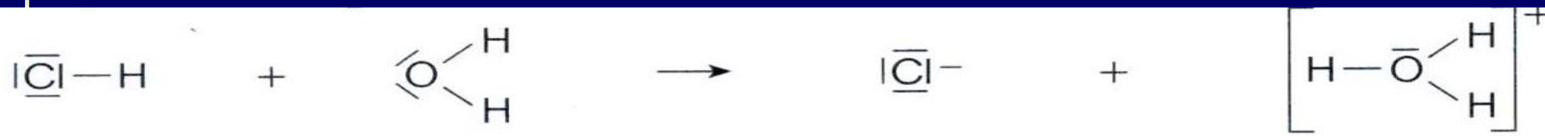
Prevention of misconceptions: molecules and ions as acid or base PARTICLES



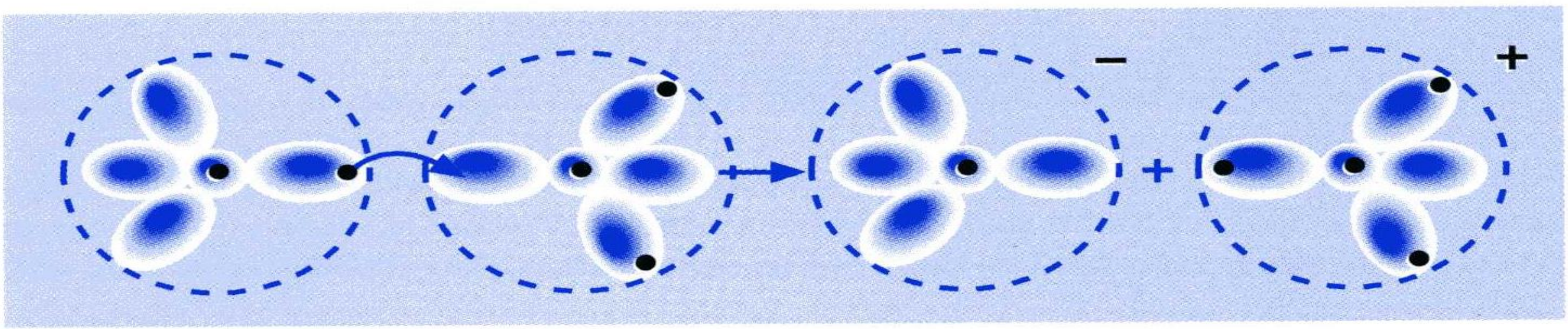


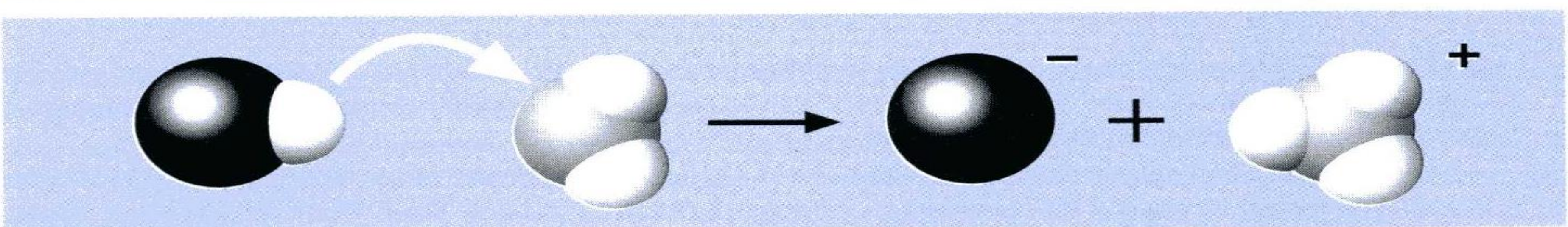
Chlorwasserstoff reagiert mit Wasser. Es entsteht eine saure Lösung.

Proton is switching from one electron cloud to another: (Christen, H. R., Baars, G.: Chemie. Frankfurt 1997)

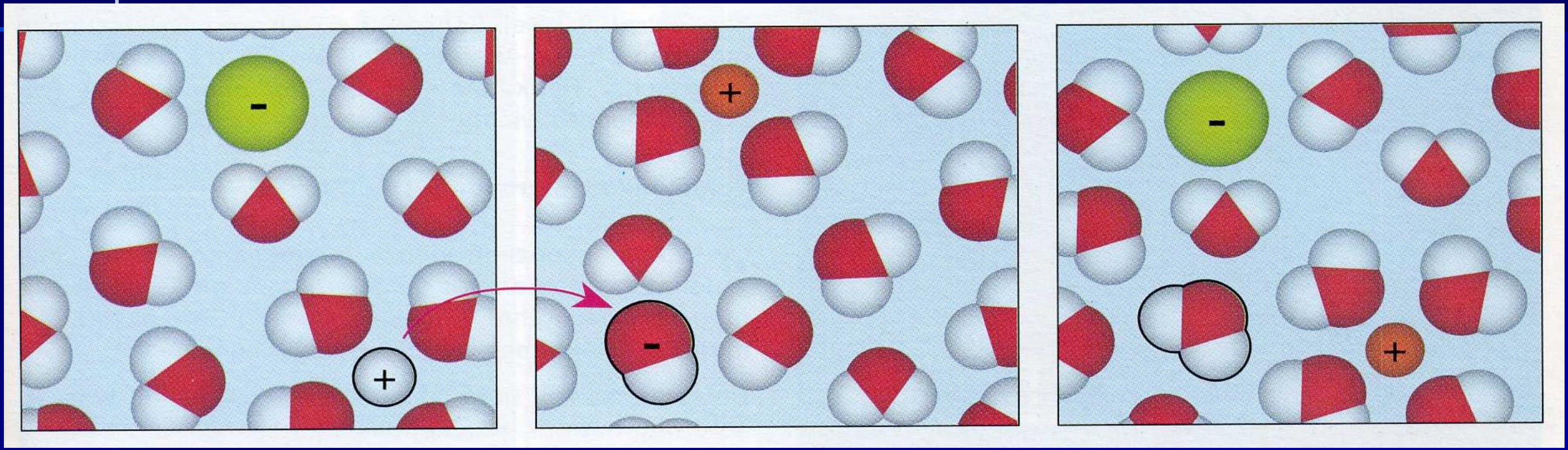


Es treten also keine freien, selbständig existierenden H^+-Ionen auf (wie es 1883 von Arrhenius postuliert worden war); das anfänglich durch ein Elektronenpaar an das Chloratom gebundene Proton löst sich von der anziehenden Wirkung der Elektronen, «schlüpft» dann in eine der mit zwei Elektronen besetzten Wolken des Sauerstoffatoms und wird durch diese Elektronen gebunden:





Prevention of misconceptions: ions as acids or bases by neutralization of strong acids



hydrochloric acid + sodium hydroxide solution → sodium chloride solution

$H_3O^+(aq)$ + $Cl^-(aq)$ + $Na^+(aq)$ + $OH^-(aq)$ → $Na^+(aq) + Cl^-(aq) + 2\ H_2O$

$H_3O^+(aq)$ + $OH^-(aq)$ → $2\ H_2O$

Questionnaire „Which atoms, ions or molecules react?“ (Asih Wisudawati, AJCE 2019)

Explain the following reactions in four ways:

a) Which atoms, ions or molecules are involved in the reaction?
b) Write down the equation of those atoms, ions or molecules which react.
c) Which atoms, ions or molecules are NOT involved in the reaction?
d) Redox or acid-base reaction? Explain transfer of electrons or protons.

One example:

Zinc reacts with diluted sulfuric acid, gaseous hydrogen is observed:
$Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g)$

a) $Zn + 2\,H^+ + SO_4^{2-} \rightarrow Zn^{2+} + SO_4^{2-} + H_2$
b) $Zn + 2\,H^+ \rightarrow Zn^{2+} + H_2$
c) SO_4^{2-}
d) Redox: Zn atom gives two electrons to 2 H^+ ions

Questionnaire „Which atoms, ions or molecules react?" (Asih Wisudawati, AJCE 2019)

At the end of the questionnaire it was asked:

9. Which of the alternatives (a) – (d) is the most difficult for you?

„Most difficult answer" is „(d) Explain transfer of electrons or protons". Comments are: „proton or electron transfer confuses me, because I need basic concepts of chemistry, because we need to understand (a) – (c), because one has to understand function of particles".

10. Do you like to go with (a) – (d) so deep into the Submicro level?

Comments: „Yes – to differentiate redox and acid-base reactions, it can help to understand chemistry better, yes - because it can support to be a better teacher, yes – because I can improve my understanding of chemistry".

Challenge of misconceptions by Submicro level: Which atoms, ions or molecules are reacting? Acid-base or redox reaction?

$Mg + 2\ HCl(aq) \rightarrow MgCl_2(aq) + H_2$

Mg atom + 2 H^+(aq) ions → Mg^{2+}(aq) ion + H_2 molecule

Electron transfer – Redox reaction:

Donor: Mg atom → Mg^{2+}(aq) ion + 2 e^- (Ox.)

Acceptor: 2 H^+(aq) ions + 2 e^- → H_2 molecule (Red.)

Challenge of misconceptions by Submicro level: Which atoms, ions or molecules are reacting? Acid-base or redox reaction?

$MgO + 2\ HCl(aq) \rightarrow MgCl_2(aq) + H_2O$

O^{2-} ion + 2 $H_3O^+(aq)$ ions → 3 H_2O molecules

Proton transfer – Acid-base reaction:

Donors: 2 $H_3O^+(aq)$ ions → 2 H_2O molecules + 2 H^+

Acceptor: O^{2-} ion + 2 H^+ → H_2O molecule

Challenge of misconceptions by Submicro level: Which atoms, ions or molecules are reacting? Acid-base or redox reaction?

$Mg(OH)_2$ + 2 HCl(aq) → $MgCl_2$(aq) + 2 H_2O

2 OH^- ions + 2 H_3O^+(aq) ions → 4 H_2O molecules

Proton transfer – Acid-base reaction:

Donors: 2 H_3O^+(aq) ions → 2 H_2O molecules + 2 H^+

Acceptors: 2 OH^- ions + 2 H^+ → 2 H_2O molecules

Donor-Acceptor reactions: Good bye to the Laboratory Jargon (Published in African Journal of Chemistry Education AJCE 6 (2016), 17)

Laboratory jargon (misconceptions)	Appropriate terminology (Broensted)
1. Acid-base definitions (also historically) Acids contain hydrogen, by neutralization it can be replaced by a metal: from CH_3COOH the composition CH_3COONa can be derived (Liebig 1824)	Acid molecules or ions are proton donors. HAc molecules contain H atoms which can be donated as H^+ ions to H_2O molecules to form H_3O^+ ions. By neutralization an HAc molecule or an H_3O^+ ion gives a proton to an OH^- ion: $HAc + OH^-(aq) \rightarrow H_2O + Ac^-(aq)$ $H_3O^+(aq) + OH^-(aq) \rightarrow 2\ H_2O$, $Na^+(aq)$ ions remain
Hydrogen chloride dissociates into ions to form hydrochloric acid: $HCl \rightarrow H^+ + Cl^-$ (Arrhenius 1887)	HCl molecules are protolyzing: they are giving protons to H_2O molecules, H_3O^+ (aq) ions and Cl^-(aq) ions are formed and are the main particles of hydrochloric acid (see Fig. 1). H_3O^+ (aq) ions are the proton donors

The self-dissociation of water incorporates the equilibrium by ions: $H_2O \leftrightharpoons H^+ + OH^-$	The autoprotolysis of H_2O molecules provides an equilibrium with ions: $H_2O + H_2O \leftrightharpoons H_3O^+ + OH^-$
Water is an ampholyte: it can be an acid or a base	H_2O molecules are ampholytes: the molecule can either give a proton (as an acid) or may take a proton (as a base) – depending on the partner
The concentration of water is calculated: c = 55.5 mol / Liter	The concentration of H_2O molecules in water is: c = 55.5 mol H_2O molecules / Liter
Strong acid means low pH, weak acid means relatively high pH	Strong acids are completely protolyzed, weak acids are partly protolyzed, an equilibrium between molecules and ions exists: $HAc + H_2O \leftrightharpoons H_3O^+(aq) + Ac^-(aq)$
Acetic acid is a weak acid with low concentration	The HAc molecule is a weak acid, HAc molecules exist in equilibrium with corresponding ions
Neutralization makes HAc and NaOH a conjugated acid-base pair	Conjugated acid base pairs differ by one proton and are HAc / Ac^- and H_2O / OH^-

Empirical studies by Yuli Rahmawati in Indonesia (UNJ University of Jakarta, Indonesia)

She worked with **„Laboratory Jargon“.** One example of her questionnaire:
Task 2: „Lab. Jargon: Hydrochloric acid gives off a proton. Which is the scientific right sentence?“

a) Hydrochloric acid can be depronoted.
b) Hyd. acid can also absorb protons
c) H_3O^+(aq) ions are present in hyd. acid, they can emit protons.
d) HCl molecules are present in hyd. acid, they release protons.

Questions	German	Indonesia	
1	68	92	84
2	40	15	19
3	90	54	50
4	77	63	59
5	55	48	45
6	22	25	33
7	50	15	22
8	82	83	65
9	64	79	87
10	55	23	31
	Year 3	Year 3	Year 1-4

Only 15 % of Indonesian students chose the right answer c – they mostly wanted answer d and are thinking of „HCl molecules“ in hydro-chloric acid.

Lecturers of chemistry-teacher students should avoid the Laboratory jargon – and can avoid „school-made misconceptions“ of future pupils in schools.

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DONOR-ACCEPTOR REACTIONS: GOOD BYE TO THE LABORATORY JARGON

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ABSTRACT

For chemistry education we are discussing mainly two concepts of acids and bases: theories of Arrhenius and Broensted. The first theory discusses the **dissociation** of molecules into ions: hydrochloric acid solution contains H^+ (aq) ions and Cl^-(aq) ions, sodium hydroxide solution contains Na^+(aq) ions and OH^-(aq) ions. This theory therefore deals with substances, which are acids or bases – it would be even better to take the logical names "acidic and alkaline solutions". If both solutions are mixed in equivalent quantities, the H^+ (aq) ions react with OH^-(aq) ions to form H_2O molecules, while the other ions remain in solution. The Broensted theory defines **protolysis** and proton transfers: a molecule or an ion transfers a proton (H^+ ion) to another molecule or ion; two conjugated acid-base pairs are involved. Thus, Broensted acids and bases are no more substances, but individual types of particles. Due to the autoprotolysis of H_2O molecules (not "autoionization of water"), the following equilibrium exists:

$$H_2O \quad + \quad H_2O \quad \leftrightarrows \quad H_3O^+(aq) \quad + \quad OH^-(aq)$$

Through this protolysis it is more advantageous to argue rather with H_3O^+(aq) ions than with H^+(aq) ions. In this theory there are still ampholyte particles which react as acid or as base particles – depending on the reaction partner: H_2O molecules, NH_3 molecules, HSO_4^- ions. Water, ammonia or sodium hydrogen sulfate cannot be regarded as ampholytes – pure water cannot be one time an acid and another time a base: with the pH of 7 it is always a neutral substance. The article will show misconceptions of students and point out the better terminology: reflecting this terminology, students should develop a better understanding of Chemistry! *[African Journal of Chemical Education—AJCE 6(1), January 2016]*

Questions for Prof. Barke and Testimony for the Seminar

http://bit.ly/seminar31102019