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*Educational paper*

## MISCONCEPTIONS IN THE CHEMISTRY TEACHING IN THE REPUBLIC OF MACEDONIA REGARDING THE OXIDATION REACTIONS OF MONOSACCHARIDES

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The easy oxidation of the substances containing aldehyde groups using a mild oxidizing agents, such as solutions containing copper(II) or silver(I) ions, can provide a mean to detect the presence of carbohydrates known as *reducing sugars*. However, using such tests, it is not possible to distinguish between aldoses and ketoses because the alkaline conditions in the reaction system lead to tautomerization of the  $\alpha$ -hydroxyketone and immediate oxidation of the product so that both glucose and fructose will react with the oxidizing agents (the Tollens' and Fehling's reagents). In fact, the reaction of fructose is even faster than that of glucose. A misinterpretation or simple neglect of these experimental facts is present in some textbooks in the Republic of Macedonia and this influences the chemistry teaching by creating misconceptions among students and teachers.

**Key words:** misconceptions; monosaccharides; Tollens' and Fehling's reagents; reducing sugars; chemistry teaching

### INTRODUCTION

There are many terms that refer to students' erroneous notions, although the prevalent one is *misconceptions*. The term "misconception" could be defined as "an idea which is wrong because it has been based on a failure to understand a situation" [1]. The erroneous notions can be formed previously, outside school (preconcepts) but can also stem from the elements of the teaching process itself (school-made misconceptions) [2].

There are numerous studies of misconceptions in chemistry [2–6 and the references therein]. Deeming that the above topic is interesting, important and more than relevant for the contemporary chemical education research, we devoted some of our studies to chemistry misconceptions [7]. While investigating misconceptions among students we came across one school-made misconception and the present contribution is devoted to it – the oxidation reactions of monosaccharides. Namely, we found that

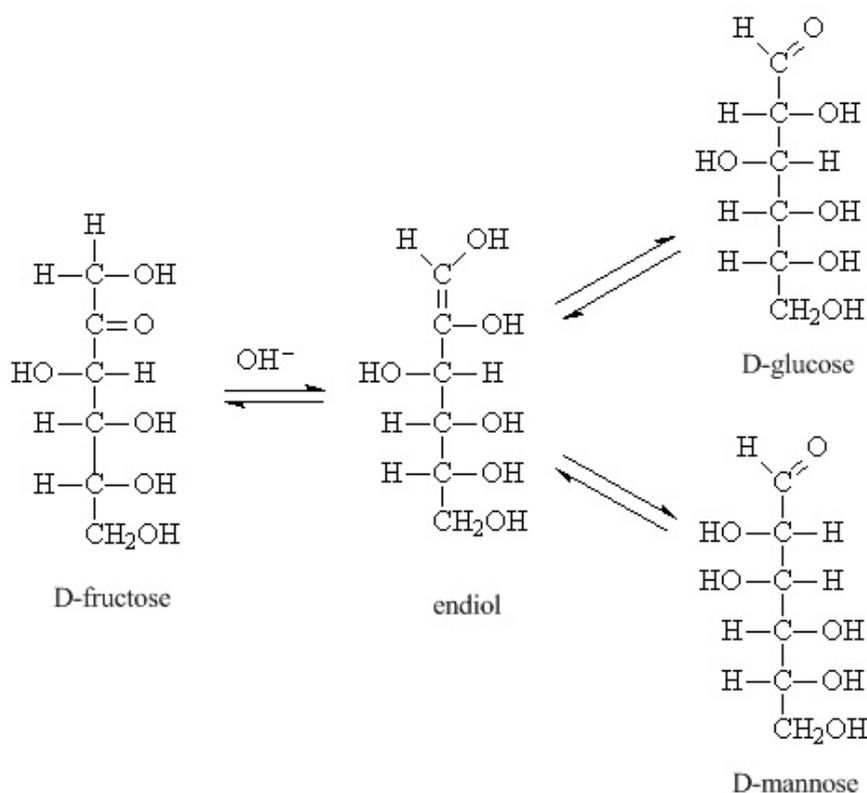
several textbooks used in the Republic of Macedonia include information on glucose and fructose and their characteristic reactions including those with the Tollens' or Fehling's reagents. Some authors [8, 9] mention only the reaction of the Tollens' or Fehling's reagent with glucose but not that with fructose while others [10] state that the reaction with the Fehling's reagent is possible *only* with glucose, but not with fructose, this being, allegedly, a direct evidence that glucose contains aldehyde groups in its molecules and fructose does not. However, if the teacher carries out the corresponding reactions in front of his/her students, he/she will be faced with the unexpected result that can be personally very unpleasant: both glucose and fructose *will react*. Obviously, the statements found in the textbook [10] can lead to development of misconceptions among students and teachers.

The reason why fructose indeed reacts with the mentioned reagents is the molecular rearrangement called tautomerization of the  $\alpha$ -hydroxyketones under

alkaline conditions [11]. The tautomers are rapidly interconverted into constitutional isomers, often distinguished by a different bonding location for the labile hydrogen atoms and differently located double bonds [12]. Under normal conditions the equilibrium between tautomers is not only rapidly reached, but it often strongly favors one of the isomers. Even in such "one-sided" equilibria, evidence for the presence of the minor tautomer comes from the chemical behavior of the compounds in question. The tautomeric equilibria are usually catalyzed by traces of acids or bases that are generally present in most chemical samples. The tautomer of a ketone is endiol, which can form  $\alpha$ -hydroxyaldehyde [13]. The aldehyde and the keto

forms in alkaline solution are in equilibrium, which shifts according to the Le Chatelier–Braun principle: the more of the aldose reacts, the more ketose transforms into aldose.

Fructose is an  $\alpha$ -hydroxyketone which under alkaline conditions is converted to glucose and mannose [14]. The conversion can be explained by the keto-enol tautomerism (Figure 1). Similar explanations can be found in an older Macedonian chemistry textbook [15] (in which this process is called *enolization*) where it is stated that "glucose, fructose and mannose, by the alkalis in the solution, can be transformed into each other via common enol forms".

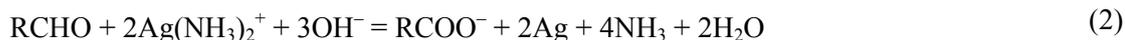


**Figure 1:** Keto-enol tautomerism

If one deals with equally concentrated glucose and fructose solutions it could be noticed that the reaction of fructose is even faster. This phenomenon was claimed to be due to the rupture of the carbon chain (breaking of bonds) in the molecules of fructose resulting with the formation of more molecules that contain aldehyde group [14]. In this way, fructose decomposition gives, overall, products with a more pronounced reducing capability.

It can be concluded that because of the base-catalyzed isomerizations of this kind, the Tollens'

and the Fehling's reagents are not useful for distinguishing aldoses from ketoses or for the specific oxidation of aldoses to the corresponding aldonic acids (the oxidation by  $\text{HOBr}$  is preferred for the latter conversion [12]). Thus, the formation of the orange-red precipitate of copper(I) oxide when working with the Fehling's reagent and elementary silver (in the form of silver mirror or black powder) in a case of the Tollens' reagent (see eq. 1–4) is an explicit evidence that the sample contains *some* reducing sugar – not just glucose [16].



As a part of our continuous interest in the misconception in our educational system [17–23] and having in mind the facts underlined above, we decided to pay attention to the way the oxidation reactions of monosaccharides are treated in our educational system. The idea for the research devoted to the inspection of the conceptions regarding the oxidation reactions of glucose and fructose among high-school students in the Republic of Macedonia originated from the pre-service teachers' lab work which is a part of their engagement during the course. During these classes, namely, the outcome of the demonstrations of the above-mentioned reactions came as a surprise to students although they have previously done similar experiments during the biochemistry lab practice activities [24].

## EXPERIMENTAL SECTION

The sample group was composed of fourth-year students from three high-schools in Skopje. The participants were divided into two groups: a control group, which worked in the usual, traditional, way and an experimental one, which was subjected to an intervention program devised by us. The research was carried out in the academic year 2011/12 from September to November.

A pre-test – post-test design was used as a data collection tool in this research. The first step was to distribute a simple test to the participants with the idea to inspect their opinion about the oxidation reactions of glucose and fructose. In the post-tests, the students were asked to provide argumentation for their answers.

Between the two testings, an intervention program that included experiments and deepened explanations was implemented. In one of the classes, namely, experiments were carried out in front of the students, but the proper interpretation of the reactions was given latter (after approximately two weeks), so students had enough time to think over the experiment outcomes and to try to find the answers for themselves. The idea was to check the role of the experiment in the chemistry teaching – its effect on establishing new knowledge through visualization and creating appropriate requirements for emerging of cognitive disequilibrium

among students holding misconceptions [25]. Additionally, students were given learning materials, some of which were worked on in the class.

## RESULTS AND DISCUSSION

Due to the small sample size (approximately 30 students per group) the results are presented descriptively. Using tables and graphs, all combinations of students' answers in the pre- and post-test are recorded. Although no general conclusions can be drawn, estimations on students' current achievements and progress due to the intervention program could still be made.

The results from the pre- and post-testing, both for the control (in the figure below marked as "c-pre" and "c-post" respectively) and for the experimental group (marked as "e-pre" and "e-post" respectively), are summarized in Table 1 and Figure 2. In Tables 2 and 3 interpretations of students are marked as codes, as well as the number of students having the common opinion. The meaning of the codes is given right below Table 3.

From the analysis of the answers of the students from the experimental group, it was evident (judging from the high percentage of correct answers in the post-test) that the experimentation they witnessed had considerable effect on them. Obviously, the visualization (through experimenting) played a very important part in the chemistry teaching of this topic and contributed to higher motivation and increased interest.

Unfortunately, very few of the students were able to give (almost) correct explanations of the process. Obviously, in addition to the experimenting, strong argumentations during the overall teaching process are needed for better understanding (not only memorizing) certain phenomena and, of course, continuity and consistency in work for both students and teachers.

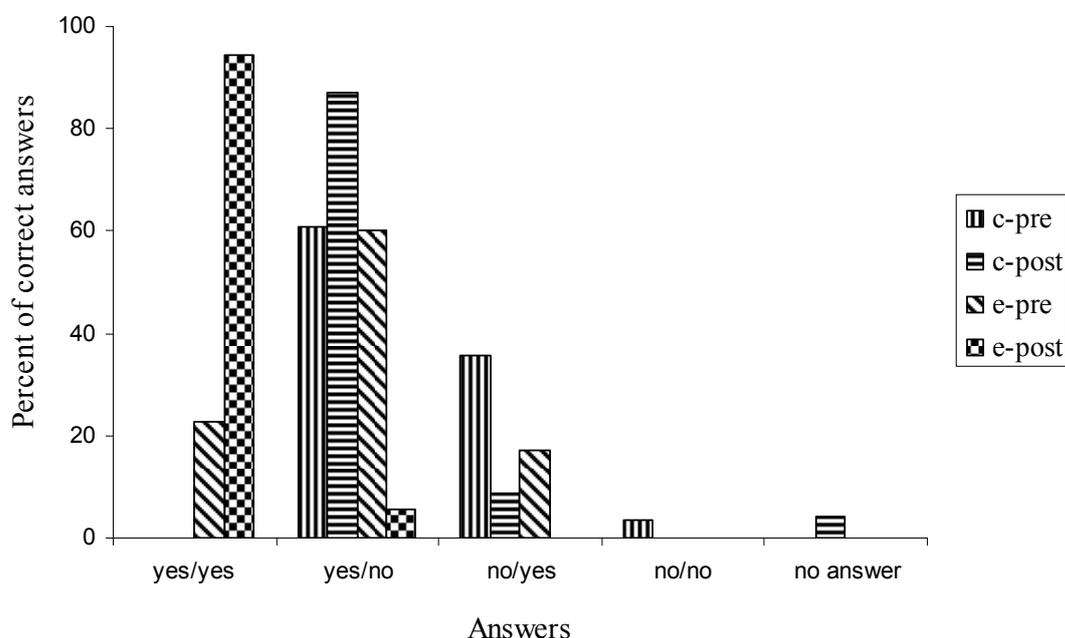
Other authors [26] have also found that the experiment has huge influence in improving the students' knowledge, but that the experiment itself does not produce deep conceptual understanding. It is certainly a good basis for the development of critical thinking, but this will not be developed if

additional activities that stimulate students' abilities for analysis, synthesis, evaluation and creativity are not involved in the teaching process. Sometime,

students are more focused on the technical performance of the experiment than on the analysis of its outcomes [27].

**Table 1:** Pre- and post-test results

Does it reacts with Fehling's reagent	Number of students			
	Control group		Experimental group	
	Pre-test	Post-test	Pre-test	Post-test
Glucose / Fructose				
Yes / Yes	0	0	8	33
Yes / No	17	20	21	2
No / Yes	10	2	6	0
No / No	1	0	0	0
No answer	0	1	0	0



**Figure 2:** Percentage distribution of students' answers in the pre- and post-test

**Table 2:** Occurrence of the interpretations of students who gave false answers in the post-test

Group	Code	FF	T	AG	OHF	OHGF	HC	AKG	N
Control		2	2	19	–	–	–	–	–
Experimental		–	–	–	1	–	–	–	1

Many misconceptions arise among students during chemistry teaching, some being present even among teachers, textbook authors and researchers. The findings from this research showed that such was the case with our student sample regarding the identification reactions of glucose and fructose. Namely, incorrect/incomplete explanations are pre-

sent in some Macedonian textbooks that clearly lead to an occurrence of faulty ideas among readers. In this respect, the experiment (or a demonstration) can be a precious tool for correction and elimination of such erroneous notions, especially when accompanied by other activities that stimulate students' higher mental processes.

In fact, during the overall educational process caution should be exercised to eliminate erroneous notions, to build the correct ideas and "store" them into the permanent knowledge of students. Only then these ideas could become useful *information*. On the contrary, if the new concepts serve only as a way to obtain a reward (such as a good grade) they

will not last long because they have no meaning to the students. The newly acquired knowledge must be very carefully related to the already established concepts (and, in general, to the previous learning) in order to be stable and students would not revert to their pre-concepts.

**Table 3:** Occurrence of the interpretations of students who gave correct answers in the post-test

Group	Code	FF	T	AG	OHF	OHGF	HC	AKG	N
Control		–	–	–	–	–	–	–	–
Experimental		–	–	–	6	12	2	9	4

Meaning of the codes:

**FF:** Glucose reacts with the Tollens' reagent, but fructose reacts only with the Fehling's reagent. **T:** We have not heard about the Fehling's reagent, we have mentioned only the Tollens' reagent. **AG:** Because of the presence of aldehyde group; because of the glucose structure; the aldehyde group is more reactive than the keto one; keto group is less reactive than the aldehyde one; keto group does not react. **OHF:** Because of the presence of OH-groups in the molecules of fructose (sometimes students added that "the glucose will react in every case" or "the glucose reacts due to the presence of aldehyde group"). **OHGF:** Because of the presence of OH-groups in the molecules of glucose and fructose. **HC:** Because of the chiral C-atoms. **AKG:** Both the aldehyde and the keto group react. **N:** I do not know; the answer is vague and unclear; no answer.

Finally, it needs to be pointed out that no one is "immune" to making errors or to misinterpreting some statements. The important things are: 1) to address and pay special attention to such statements, and 2) to organize all participants in the teaching process (students, teachers, textbook authors and researchers) to work together in eliminating misconceptions and embed scientifically correct concepts in students' minds. It is essential that these concepts be precisely formed in the first years of chemistry studying, so as to reduce to a minimum the possibility of emerging of misconceptions in the latter phases of chemistry education.

#### REFERENCES

- [1] *Cambridge Dictionaries Online*, 2012, retrieved from <http://dictionary.cambridge.org/dictionary/british/misconception> (26 July 2013).
- [2] H. D. Barke, A. Hazari, S. Yitbarek, Students' misconceptions and how to overcome them, in: *Misconceptions in Chemistry. Addressing Perceptions in Chemical Education*, Springer-Verlag, Berlin, 2009, pp. 21–36.
- [3] C. Horton (with other members of the Modeling Instruction in High School Chemistry Action Research Teams at Arizona State University), *Student Alternative Conceptions in Chemistry*, 2007, retrieved from <http://www.scribd.com/doc/52664732/student-alternative-conceptions-in-chemistry> (26 July 2013).
- [4] V. Kind, *Beyond Appearances: Students' Misconceptions about Basic Chemical Ideas* (2<sup>nd</sup> edition), Durham University, Durham, 2004.
- [5] K. S. Taber, *Chemical Misconceptions – Prevention, Diagnosis and Cure; Part 1 – Theoretical Background*, Royal Society of Chemistry, London, 2002.
- [6] K. S. Taber, *Chemical Misconceptions – Prevention, Diagnosis and Cure; Part 2 – Classroom resources*, Royal Society of Chemistry, London, 2002.
- [7] M. Stojanovska, *The Occurrence of Erroneous Notions in Textbooks and Chemistry Teaching in Macedonia and Possibility for Their Elimination*, Ph.D. thesis, SS. Cyril and Methodius University, Skopje, 2013.
- [8] S. Aleksovska, K. Stojanovski, *Chemistry for the 3<sup>rd</sup> year of Reformed Gymnasium Education*, Prosvetno delo, Skopje, 2003, p. 155 (in Macedonian).
- [9] S. Aleksovska, K. Stojanovski, *Chemistry for the 4<sup>th</sup> year of Reformed Gymnasium Education*, Prosvetno delo, Skopje, 2005, p. 42 (in Macedonian).
- [10] S. Aleksovska, *Chemistry for the 8<sup>th</sup> grade of Eighth-year Secondary Education*, Ministry of Education and Science of Republic of Macedonia, Skopje, 2010, p. 113 (in Macedonian).
- [11] P. S. Bailey, C. A. Bailey, Carbohydrates, in: *Organic Chemistry: A Brief Survey of Concepts*

- and Applications (6<sup>th</sup> edition), Prentice Hall, New Jersey, USA, 2000, pp. 313–329.
- [12] W. Reusch, *Virtual Text of Organic Chemistry*, 1999, retrieved from <http://www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/intro1.htm#contnt> (26 July 2013).
- [13] R. J. Ouellette, *Organic Chemistry: A Brief Introduction*, Prentice Hall, Englewood Cliffs, NJ, 1994, pp. 384–386.
- [14] P. Keusch, *Fehling's test for reducing sugars*, retrieved from <http://www.demochem.de/D-Fehling-e.htm> (27 December 2012).
- [15] B. Šoptrajanov, B. Podolešov, K. Stojanovski, I. Spirevska, L. Šoptrajanova, *Chemistry for the 4<sup>th</sup> year of Gymnasium Education*, Prosvetno delo, Skopje, 1993, p. 117 (in Macedonian).
- [16] M. Sikirica, K. Holenda, Carbohydrates, in: *Chemistry through Investigation*, **8**, 2000, retrieved from <http://eskola.chem.pmf.hr/udzbenik/u45/15%20ugljikohidrati.pdf> (in Croatian, 26 July 2013).
- [17] M. Monković, V. Ivanovski, V. M. Petruševski, Demonstrations as a tool for ironing-out misconceptions: 3. A note on the reaction  $\text{Pb}^{2+}(\text{aq}) + 2\text{I}^{-}(\text{aq}) = \text{PbI}_2(\text{s})$ : Exceptions from a priori expectations, *Aust. J. Ed. Chem.*, **68** (2007), pp. 17–19.
- [18] M. Stojanovska, V. Petruševski, Comment on "Spectator ions ARE important! A kinetic of the copper–aluminium displacement reaction", *J. Chem. Educ.*, **88** (2011), p. 16.
- [19] M. Stojanovska, V. M. Petruševski, B. Šoptrajanov, The concept of sublimation – iodine as an example, *Educ. quim.*, **23** (2012), pp. 171–3<sup>a</sup> F.
- [20] M. I. Stojanovska, V. M. Petruševski, B. T. Šoptrajanov, On the existence of hydrogen salts of monoprotic acids, *J. Chem. Educ.*, **89** (2012), pp. 1168–1170.
- [21] V. Petruševski, M. Stojanovska, B. Šoptrajanov, Are all types of sublimation equivalent?, *Chem. Educator*, **17** (2012), pp. 98–99.
- [22] M. I. Stojanovska, B. T. Šoptrajanov, V. M. Petruševski, Addressing misconceptions about the particulate nature of matter among secondary-school and high-school students in the Republic of Macedonia, *Creative Educ.*, **3** (2012), pp. 619–631.
- [23] M. I. Stojanovska, V. M. Petruševski, B. T. Šoptrajanov, Addressing students' misconceptions concerning chemical reactions and symbolic representations, *Chemistry: Bulg. J. Sci. Educ.*, **21** (2012), pp. 829–852.
- [24] K. Stojanoski, O. Trenčevska, *Laboratory Tutorial for Biochemistry I Course*, Ss. Cyril and Methodius University, Skopje, 2009, pp. 73–75.
- [25] K. Smith-Gratto, *Toward Combining Programmed Instruction and Constructivism for Tutorial Design*, Cameron University, Lawton, OK, 2012.
- [26] B. Mitrevski, O. Zajkov, Physics Lab, Critical thinking and gender differences, *9<sup>th</sup> Conference of the Society of Physicists of Republic of Macedonia*, Ohrid, Republic of Macedonia, 2012.
- [27] N. Krstevska, O. Zajkov, To click or not to click, that is the question, *9<sup>th</sup> Conference of the Society of Physicists of Republic of Macedonia*, Ohrid, Republic of Macedonia, 2012.

## МИСКОНЦЕПЦИИ ВО НАСТАВАТА ПО ХЕМИЈА ВО РЕПУБЛИКА МАКЕДОНИЈА ВО ВРСКА СО РЕАКЦИИТЕ НА ОКСИДАЦИЈА КАЈ МОНОСАХАРИДИТЕ

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Лесната оксидација на супстанците што содржат алдехидни групи во својот состав со помош на умерено силни оксидациони средства какви што се растворите што содржат бакар(II) или сребро(I) јони, претставува згоден начин да се открие присуството на јаглехидрати наречени *редукциони шеќери*. Меѓутоа, користејќи ги ваквите тестови, не е можно да се разликуваат алдози од кетози бидејќи во алкална средина доаѓа до тавтомеризација на  $\alpha$ -хидроксикетоните и нивна моментна оксидација, така што и глукозата и фруктозата реагираат со оксидационите средства (Толенсов и Фелингов реагенс). Всушност, реакцијата со фруктоза е дури и побрза од онаа со глукоза. Погрешното, односно нецелосното толкување на ваквите експериментални факти што е присутно во некои учебници во Република Македонија може да влијае врз наставата по хемија, создавајќи мисконцепции кај учениците и наставниците.

**Клучни зборови:** мисконцепции; моносахариди; Толенсов и Фелингов реагенс; редукциони шеќери; настава по хемија