Approaches To Determining the Oxidation State of Nitrogen and Carbon Atoms in Organic Compounds for High School Students

Kamil Jurowski, † Malgorzata Krystyna Krzeczkowska,* § and Anna Jurowska ‡

†Department of Analytical Chemistry, Faculty of Chemistry, Jagiellonian University in Kraków, R. Ingardena 3, 30-060 Kraków, Poland
‡Department of Chemical Education, Faculty of Chemistry, Jagiellonian University in Kraków, R. Ingardena 3, 30-060 Kraków, Poland
§Upper Secondary School No. 6, Waśka 7, 31-057 Kraków, Poland

ABSTRACT: The concept of oxidation state (or oxidation number) and related issues have always been difficult for students. In addition, there are misunderstandings and obscurities, which can cause improper balancing of the chemical equations (mostly in organic reactions). In particular, these problems are related to determination of the oxidation state of nitrogen and carbon atoms in organic compounds. In recent years, the Matura Exam in Poland (ending education in Upper Secondary School) puts special emphasis on verification of students’ skills of balancing of chemical equations on examples of organic compounds. In the absence of literature, methods and rules for establishing or assigning the oxidation state to nitrogen atoms in organic compounds, the authors decided to emphasize this undoubtedly important problem in this article. We present here, various approaches to determination of the oxidation state to nitrogen and carbon atoms in organic compounds. Additionally, we propose an alternative approach to determination of the oxidation state to nitrogen atoms in complicated situations (“nitrogen oxidation state trick”). Moreover, on the basis of results of our didactic studies, we indicate which method is the most popular and the best assimilable among Polish students from Upper Secondary School.

KEYWORDS: High School/Introductory Chemistry, First-Year Undergraduate/General, Organic Chemistry, Oxidation/Reduction, Oxidation State, Testing/Assessment

INTRODUCTION

The idea of oxidation state (or oxidation number) was invented by inorganic chemists for balancing redox reactions and for coordination chemistry problems. However, organic chemists only use oxidation numbers when it is necessary. When originally introduced by Wendall Latimer in 1938, the terms “oxidation state” and “oxidation number” were synonymous and both are still used in many countries. However, there are some important differences in the definitions and related rules depending on the source and teaching traditions. For example, Jensen described differences between the oxidation state and the oxidation number, but in general, they are used interchangeably. The definitions and rules for assigning oxidation states can be found in most general chemistry handbooks, and many articles related to this topic have been published in this Journal. On the basis of the literature review, we summarized all major and most significant definitions in Table 1.

One of the first common definitions of oxidation state was described by Linus Carl Pauling in his well-known handbook “General Chemistry” (1947). The International Union of Pure and Applied Chemistry provided a similar definition for the oxidation state as a measure of the degree of oxidation of an atom. Loock compared the Pauling approach to the IUPAC definition. From his point of view, an expanded definition of oxidation states builds on the knowledge of electronegativity, whereas the IUPAC definition builds on a set of rules. Steinborn recommended assigning oxidation states to atoms in molecules on the basis of their Lewis structures. Another definition and rules were proposed by Jørgensen in Oxidation Numbers and Oxidation States, where different aspects of oxidation numbers are discussed. Calzaferri described some of the unusual results that stem from assigning oxidation states to atoms in organic molecules using the IUPAC or Pauling approaches and also according to Jørgensen rules. Due to the fact that Pauling electronegativities of carbon (2.55) and hydrogen (2.20) are very similar, he recommended that hydrogen should be assigned an oxidation state of zero when bonded to carbon. Additionally, he recommended an oxidation state of...
Table 1. Definitions of the Oxidation State and Rules Related with Them

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Definition and rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pauling$^5$</td>
<td>The oxidation state of an atom is a number that represents the electric charge that the atom would have if the electrons in a compound were assigned to the atoms in a conventional way. The assignment of electrons is somewhat arbitrary. An oxidation state may be assigned to each atom in a substance by the application of not completely unambiguous and simple rules: 1. The oxidation number of an atom in an elementary substance is zero; 2. The oxidation state of a monatomic ion in an ionic substance is equal to its electric charge; 3. In a covalent compound with a known structure, the oxidation state of each atom is the charge remaining on the atom when each shared electron pair is assigned completely to the more electronegative of the two atoms sharing it. An electron pair shared by two atoms of the same element is usually split between them. 4. The oxidation number of an element in a compound with an uncertain structure may be calculated from a reasonable assignment of oxidation states to the other elements in the compound$^7$.</td>
</tr>
<tr>
<td>IUPAC$^6$</td>
<td>&quot;Oxidation state is defined as the charge an atom might be imagined to have when electrons are counted according to an agreed-upon set of rules: 1. The oxidation state of a free element (uncombined element) is zero; 2. For a simple (monatomic) ion, the oxidation state is equal to the net charge on the ion; 3. Hydrogen has an oxidation state of 1 and oxygen has an oxidation state of ~2 when they are present in most compounds. Exceptions to this are that hydrogen has an oxidation state of ~1 in hydrides of active metals, e.g., LiH, and oxygen has an oxidation state of 1 in peroxides, e.g., H₂O₂; 4. The algebraic sum of oxidation states of all atoms in a neutral molecule must be zero, while in ions the algebraic sum of the oxidation states of the constituent atoms must be equal to the charge on the ion&quot;.</td>
</tr>
<tr>
<td>Jørgensen$^7$</td>
<td>The concept of oxidation state as a purely formal tool for the purpose of book-counting of redox is based on some perfect or approximate separation of an integral number of electrons from all the other electrons in the rest of the universe. 1. The sum of the oxidation states of the atoms in a monoatomic or polyatomic entity is the electric charge of the entity in protonic units; 2. If there are no serious reasons to do otherwise, identical oxidation numbers are ascribed to atoms of the same element in a given compound; 3. Oxidation numbers can be ascribed by analogy (substitution of similar atoms or groups) to compounds where the oxidation numbers are determined from the specific rules; 4. Reactions of an entity with the characteristic acid or base of a solvent (hydrated H₂O and OH⁻ in aqueous solution) does not modify the oxidation numbers of the individual atoms.</td>
</tr>
<tr>
<td>Calzafferi$^8$ and Gupta$^9$</td>
<td>&quot;An oxidation state is assigned by applying a set of as few rules as possible, which should be simple and clear and lead to unambiguous and chemically reasonable results, if possible (is based on modification of Jørgensen rules): 1. The sum of the oxidation numbers of the atoms in a monoatomic or polyatomic entity is the electric charge of the entity in protonic units; 2. If there is no serious reason to do otherwise, identical oxidation numbers are ascribed to atoms of the same element in a given compound; 3. Oxidation numbers can be ascribed by analogy (substitution of similar atoms or groups) to compounds where the oxidation numbers are determined from the specific rules; 4. Reactions of an entity with the characteristic acid or base of a solvent (hydrated H₂O and OH⁻ in aqueous solution) do not modify the oxidation numbers of the individual atoms. Gupta et al.$^10$ proposed a generalised form of the Calzafferi rules$.^{10}$</td>
</tr>
<tr>
<td>Atkins$^10$</td>
<td>&quot;Oxidation number is a parameter obtained by exaggerating the ionic character of a bond$. It can be regarded as the charge that an atom would have if the more electronegative atom in the bond acquired the two electrons of the bond completely$^{10}$. The oxidation state is the physical state of the element corresponding to its oxidation number$. Thus, an atom may be assigned an oxidation number and be in the corresponding oxidation state$^{10}$. Oxidation numbers are assigned by applying the rules$^{10}$: 1. The sum of the oxidation numbers of all atoms in the species is equal to its total charge; 2. For atoms in the elemental form, it is zero; 3. For elements of group I: +1, and for elements of group II: +2; 4. For elements of group III (except C): +3 for M³⁺, and +1 for M⁺; For elements of group IV (except for C and Si): +4 for M⁴⁺, and +2 for M²⁺; 5. For hydrogen +1 in combination with nonmetals and -1 in combination with metals 6. For fluorine -1 in all compounds 7. For oxygen -2 unless combined with F, -1 in peroxides (O₂⁻), -1/2 in superoxides (O₂⁻), -1/3 in oxonides (O₃⁻).&quot;</td>
</tr>
</tbody>
</table>

zero for hydrogen bonded to silicon (1.90), germanium (2.01), and boron (2.04). The suggested simple modification of the Jørgensen rules$^{17}$ makes it easier for students to learn and to fruitfully use the concept of oxidation numbers. Gupta
proposed a generalized form of the Calzaferri rules. Atkins et al.\textsuperscript{20--22} described chosen generally standard rules.

\section*{THE PROBLEMS WITH DETERMINATION OF THE OXIDATION STATE IN ORGANIC COMPOUNDS}

In organic chemistry and biochemistry, oxidation process are usually defined as "loss of hydrogen" and "addition of oxygen", while reduction is described as "loss of oxygen" and "addition of hydrogen". On the basis of Pauling electronegativities,\textsuperscript{25} carbon atoms are more electronegative than hydrogen atoms, but less electronegative than oxygen atoms. Any element(s) in an organic compound will receive electron(s) if there is a "loss of oxygen" or "addition of hydrogen", and will lose electron(s) if there is a "loss of hydrogen" or "addition of oxygen". However, the main question is which atom receives and loses the electrons? In most cases, this is the carbon atom, although the nitrogen atom also can receive and lose the electrons. For example, the simple reaction of reducing nitrobenzene to aniline using Sn(II) as a reductor is a redox reaction where two elements take part in redox process. However, there exist organic reactions (like haloform reaction) where more than two elements changes oxidation states.

Considerations of the oxidation--reduction reactions in organic chemistry are closely related to determination of oxidation states. Knowledge of the oxidation state has two useful functions in practice:

- it is one of the bases of inorganic and organic compound classification;
- it facilitates balancing of organic chemical equations.\textsuperscript{26--29}

The conceptual problem of assigning the oxidation state to atoms in organic compounds was mentioned about 40 years ago by Jørgensen et al.\textsuperscript{17} This problem is connected with several issues, primarily the richness reflected by the homopolar nature of C–C and C–H bonds. As was presented in Table 1, the idea of the oxidation state has been discussed by several authors, but usually there are not enough examples of organic compounds.

On the basis of our school practice, determination of oxidation states in organic compounds is a big problem for students and teachers. For example, at the Matura Exam in chemistry in 2012 (Poland), the results of examples shown in Box 1 indicate that score was characterized by an ease rate of 26%.\textsuperscript{30} The Polish Central Examination Commission gives this definition of ease rate:

\begin{quote}
Ease rate can be defined as the number of students which answered correctly for the given question in relation (ratio) to all students answering for this question. Additionally, this term can be also defined as arithmetic mean of good answer for question expressed in percentages. In Poland these statistics studies are a part of evaluation of matura exam by the CKE (Centralna Komisja Egzaminacyjna) - the Central Examining Commission.
\end{quote}

This low score indicates Polish students in the Upper Secondary School find balancing chemical equations for organic reactions to be challenging. Moreover, a review of the literature indicates that teaching organic chemistry at the first year of chemistry studies has made it obvious that understanding oxidation–reduction processes may be difficult and sometimes traumatic for students.\textsuperscript{26,31--33} Only three sources\textsuperscript{34--36} that include rules for assigning oxidation states to atoms in organic compounds (only carbon and hydrogen atoms) exist in Poland.

\section*{METHODS FOR CALCULATING THE OXIDATION STATE OF CARBON AND NITROGEN ATOMS IN ORGANIC COMPOUNDS CONTAINING NITROGEN ATOMS}

On the basis of a literature review, we present below chosen methods and rules possible to use for determination of the oxidation state of carbon and nitrogen atoms in organic compounds.

\subsection*{Method 1 (Based on the IUPAC Rules)}

The most commonly used, and also the simplest, method for determining the oxidation state that can be applied for determination of oxidation states of nitrogen and carbon atoms is based on the IUPAC rules (Table 1).

However, as was mentioned by Loock\textsuperscript{24} the main advantage of the expanded definition (mentioned in the introduction part) lies in its application to organic compounds. For example, in substituted aromatic compounds like \textit{m}-nitrotoluene (example A) in Table 2, the phenyl carbon atoms have different oxidation states.

The oxidation state for carbon atom C\textsubscript{1} is 0; for atoms C\textsubscript{2}, C\textsubscript{4}--C\textsubscript{6}, it is $-1$, and for C\textsubscript{3}, it is $-3$ according to surroundings by other atoms (see also IUPAC rules, Table 1). However, in this situation, we have a problem with assigning oxidation state to two atoms in the C–N bond. Hence, we propose a useful approach that can be named "nitrogen oxidation state trick" (NOS trick). This simple, but very useful, trick makes it possible to assign oxidation state to the nitrogen atom in the C–N bond by replacing the C–N bond by a H–N bond; see an example in Scheme 1.

This method was applied by us in many different situations, and it seems to have irrefutable and universal applications. After this step, it is possible to assign oxidation state to the last carbon atom (carbon atom from C–N bond): C\textsubscript{5} for example A and C\textsubscript{6} for example B from Table 2. In these cases, for \textit{m}-nitrotoluene, it is +1 and for propylamine it is +1. For summarization, we presented the idea of this method in "step by step" mode in the recapitulation part.

\subsection*{Method 2 (ESM/Lewis Structure Method)}

The "exploded structure method" (ESM) was first described by Kauffman\textsuperscript{37} in 1986, and it can be also called "Lewis structure method". This approach is one of the most promising methods for assigning the oxidation states to all atoms in organic compounds. There is no doubt that students often meet classic rules of oxidation state before the concept of electronegativity, which is the rationale for them, is encountered, and it is not perceived.
as a difficult topic. If the skill of writing Lewis structures is mastered and the concept of electronegativity introduced, the students can derive the oxidation number of each molecule or ion by a slight variation of the method. For an atom with a formal charge, count the number of electrons on each atom by pretending the bonding elections belong to the more electronegative atom, and compare with the number of valence electrons of the neutral atom. Hence, in the most general cases, first, we need to draw Lewis structure and then, to assign bonding electrons located between nonequivalent atoms to the most electronegative atom. Next, we must assign bonding electrons located between equivalent atoms to the two atoms evenly. In summary, the oxidation state can be calculated from the following formula:

\[
\text{oxidation state} = \left( \text{[valence electrons]} - \text{[assigned electrons]} \right)
\]

Box 2 presents a calculation for each atom in \textit{m}-nitrotoluene molecule according to ESM/Lewis structure method (compare with Lewis structure, example A, Table 2).

It must be emphasized that the calculation of assigned electrons must be made very carefully, particularly for aromatic carbon atom bonded with nitrogen. In this case, the carbon atom has three electrons from the two other carbon atoms bonded with it (see gray dotted arrows in aromatic ring, example A, Table 2).

An analogous calculation can be carried out for each atom in propylamine molecule (see example B, Table 2). This method seems to be very useful; however, the calculation of assigned electrons must be very scrupulous.

**Method 3 (Average Oxidation Method)**

In organic oxidation—reduction reactions, carbon atoms almost always receive and lose the electrons. In average oxidation number method described by Menzek,\textsuperscript{28} the idea is that the oxidation state of every carbon atom in the analyzed molecule can be considered to be the average oxidation number. Then, the average oxidation numbers of the carbon atoms in different compounds can be compared. If the average oxidation number of the carbon atoms is increased in any reaction, the compound is oxidized; if it is decreased, the compound is reduced. The rules for calculating the oxidation number of atoms consist of few steps described in the recapitulation part. First, a Lewis structure can be drawn, if necessary (depending on the complexity of the molecule). The next step consists in assigning the oxidation state to atoms having self-evident oxidation states (H, O, N), according to the rule that the oxidation number of an atom is the number of necessary electrons that are accepted or donated in order for it to have an octet; reminder: consider also exceptions in the octet rule for elements from third period.
What is important is that F, O, Cl, N, and Br atoms are more electronegative than C atom; hence, these atoms are negatively charged in their organic compounds. However, according to Pauling, electronegativities of S, I, and C atoms are similar: S (2.58), I (2.66), and C (2.55). Furthermore, in such compounds as RSH, RSR, and RI (where R is the alkyl group), S and I atoms are more negative than carbon atom. Hence, these atoms should be negatively charged in their organic compounds. When electron-withdrawing moieties, such as oxygen and chlorine, are bonded to nitrogen and sulfur, these are less electronegative in their compounds than carbon. Hence, they are less electronegative than carbon in RNO₂ (nitro alkanes), RSCl (sulfenyl chlorides), RSOR (sulfones), RSO₂R (sulfoxides), and RSO₂H (sulfonic acids).²⁸,³⁷ Even in these compounds, they were considered negative. Box 3 illustrates the application of the mentioned rules for determination of the average oxidation numbers of all the carbon atoms for m-nitrotoluene and propylamine according to the average oxidation method

Box 3. Illustration of application of the rules for determination of the average oxidation numbers of all the carbon atoms for m-nitrotoluene and propylamine according to the average oxidation method

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>m-nitrotoluene</td>
<td>C = 0</td>
</tr>
<tr>
<td>propylamine</td>
<td>C = -2</td>
</tr>
</tbody>
</table>

rules for determination of average oxidation numbers of all the carbon atoms for example A and example B from Table 2.

The rules for calculating the oxidation states of atoms may assign both electrons in a shared pair to the more electronegative atom, although an electron transfer from one atom to another does not fully occur in covalent compounds such as organic molecules. This method seems more accurate than that based on the oxidation-reduction of carbon solely in a localized site in a molecule. Proposed method is quite efficient for small molecules, but may be more complex for large molecules. This method is suitable only for determining oxidation states of carbon atoms in organic compounds, the oxidation state of nitrogen atoms are constants (−3).

■ STUDENTS’ DILEMMAS CONNECTED WITH THE CHOICE OF METHOD FOR DETERMINATION OF THE OXIDATION STATE OF NITROGEN AND CARBON ATOMS IN NITROGEN-CONTAINING ORGANIC COMPOUNDS

The presented methods seem to be very helpful in teaching practice, but how do students respond to the different strategies? To investigate this, we worked with about 130 students from one of the upper secondary schools in Warsaw.

Evaluation of Study Design and Methods

Overview. A pre-test/post-test format was used for the statistical evaluation of the student’s examination (experimental group); however, a control group does not exist due to the kind of research—evaluation of methods applied for assigning oxidation state to nitrogen and carbon atoms in organic compounds. The performance was evaluated in May/June 2014.

During the chemistry lessons, four groups (97–108 students/class) completed a pre-test (Box 4), including also examples from

Box 4. Pre-test and post-test questions - "Stopień uświęcenia atomów azotu i węgla w związkach organicznych"

Table 2. Before this lesson, all students were acquainted with common acceptable rules (Table 1, Atkins rules). All questions were identical in the pre-test and post-test. Moreover, all students were informed at the beginning of the testing that their responses would be confidential, and would not affect their course grades and will be applied and published in didactic studies. The pre-test survey was given at the beginning of the first lesson about oxidation-reduction reaction in organic chemistry. The studies included four groups:

- 1st group (n = 103) was acquainted with method 1 (based on IUPAC rules);
- 2nd group (n = 97) was acquainted with method 2 (EMS/Lewis structure method);
- 3rd group (n = 98) was acquainted with method 3 (average oxidation method);
- 4th group (n = 108) was acquainted with all described methods.

The post-test was given during the last lesson in all classes. All students had 20 min to complete all exercises (two exercises). Moreover, the fourth group had also an additional
question in post-test: “Which method is the best for you and why?”

Students Characteristics

All investigated students (n = 406) come from a public urban Upper Secondary School in Warsaw (capital of Poland). The students do not come from the same geographical area. Only students enrolled in the second semester of second year (16–17 years old), who completed both the pre-test and post-test, were included in these studies. All groups contained similar proportions of male and female students (1:1), and also similar numbers of students (97 < n < 108). Differences in the level of participation are the same due to the fact that, in all classes, the same curriculum (program) is applied.

Statistical Analysis Techniques

Group data (results of pre-test and post-test questions) are reported as mean ± standard error of the mean (SEM). To determine any significant difference between pre-test and post-test scores of the investigated groups, paired sample t test is used.

RESULTS

The pre-test and post-test results are presented in Table 3.

Answers of the fourth group students to the question "Which method is the best for you and why?" are presented in Figure 1 as histograms, and the examples of answers to the second part of question are presented in Box 5.

The Analysis of Variance can be used in this case where there are more than two groups. This tool is a collection of statistical methods (e.g., Lewis structure method) seem to be very useful and alternative for complex examples. Presented methods are very sophisticated […] for me, the best method is the Lewis structure method, because it is easy to remember.

The nitrogen oxidation state trick seems to be a very useful approach for nitrogen-containing organic compounds.

DISCUSSION

Table 3 indicates that, when the pre-test and post-test mean scores of the investigated group were compared, in all groups post-test mean scores were higher than pre-test mean scores and the difference between the groups was statistically significant (p < 0.05).

These results indicate that the EMS/Lewis structure method improved students’ knowledge more than the other methods, as the difference in means between methods remains significant. Hence, this means that if one "normalizes" to the pre/post-test score, then the post-test difference between the means remains statistically significant. These results indicate that the most useful and the best assimilable is the EMS/Lewis structure method.

Furthermore, the analysis of histograms (Figure 1) and opinions of students (Box 4) indicate that the most popular

Table 3. Comparison of Obtained Results for Investigated Students

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-test/Post-test</th>
<th>n</th>
<th>Mean ± SEM</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>group 1</td>
<td>pre-test</td>
<td>103</td>
<td>3.3 ± 0.9</td>
<td>-2.525</td>
<td>0.017</td>
</tr>
<tr>
<td>(method 1)</td>
<td>post-test</td>
<td></td>
<td>6.3 ± 0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>group 2</td>
<td>pre-test</td>
<td>97</td>
<td>2.98 ± 0.6</td>
<td>-2.038</td>
<td>0.043b</td>
</tr>
<tr>
<td>(method 2)</td>
<td>post-test</td>
<td></td>
<td>9.45 ± 0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>group 3</td>
<td>pre-test</td>
<td>98</td>
<td>3.13 ± 1.0</td>
<td>-2.184</td>
<td>0.021b</td>
</tr>
<tr>
<td>(method 3)</td>
<td>post-test</td>
<td></td>
<td>7.72 ± 0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>group 4</td>
<td>pre-test</td>
<td>108</td>
<td>3.46 ± 0.8</td>
<td>-2.321</td>
<td>0.041b</td>
</tr>
<tr>
<td>(all methods)</td>
<td>post-test</td>
<td></td>
<td>9.89 ± 0.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

“Values reported are mean ± SEM with statistical results (t and p-values from Student t test). bp < 0.05.

Box 5. Examples of students opinions for the second part of the question: “Which method is the best for you and why?”

For me, the best method is that based on Lewis structure due to the fact that it is very logic for me - based on structure.

In my opinion, the most useful method is the EMS method, however, average oxidation method is very interesting.

IUPAC rules are well-known for me, however the presented methods (e.g., Lewis structure method) seem to be very useful and alternative for complex examples.

Presented methods are very sophisticated […] for me, the best method is the Lewis structure method, because it is easy to remember.

The nitrogen oxidation state trick seems to be a very useful approach for nitrogen-containing organic compounds.
method among the fourth group of students is (also) the EMS/Lewis structure method

# SUMMARY

How to determine the oxidation state of nitrogen and carbon atoms in nitrogen-containing organic compounds? As was described in the manuscript, there are a few methods possible to apply in school practice. Some of them are more or less popular among teachers, and also among examined students. A closer look at the obtained results provides far-reaching conclusion that the most popular among students and best assimilable method is the EMS/Lewis structure method.

To answer the mentioned earlier question and to summarize the described methods, we presented all mentioned methods and their ideas in Table 4. We also hope that the presented methodology for determination of the oxidation state of nitrogen and carbon atoms in nitrogen-containing organic compounds will be adopted for common use in school practice by teachers and students.

# AUTHOR INFORMATION

**Corresponding Author**

*E-mail: krzeczko@chemia.uj.edu.pl.*

**Notes**

The authors declare no competing financial interest.

The graphic abstract includes authors’ characters made by Bitstrips application (http://bitstrips.com), from left: Dr. Małgorzata Krystyna Krzeczkowska, Kamil Jurowski M.Sc., Anna Jurowska M.Sc.

The calculation was carried out using Statistica v.10.0 software licensed by Jagiellonian University in Kraków, Kraków, Poland.

# ACKNOWLEDGMENTS

This article was made by the support of Kamil Jurowski and Anna Jurowska scholarship by the Marian Smoluchowski Kraków Research Consortium “Matter-Energy-Future” granted the status of a Leading National Research Centre (KNOW). The Authors wish to express their thanks to Conrad L. Stanitski (distinguished Emeritus Professor of Chemistry at the University of Central Arkansas—UCA, currently Visiting Professor at Franklin and Marshall College) for valuable suggestions and comments during writing this article. The authors wish to express their thanks also to the teacher and all students from one of the Upper Secondary Schools in Warsaw, who wishes to remain anonymous.

# REFERENCES

(35) Persona, A. Chemia w testach; WSiP: Warsaw, Poland, 1998; Vol.I.