REVIEW

CHEMISTRY - THE JOURNEY FROM CENTRAL SCIENCE TO CHEMOFOBIA; HOW SHOULD WE ADDRESS THIS?

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Abstract. *Even though chemistry is sometimes recognized as the core science due to its importance in many fields of our life, it has a bad reputation in school, being classified as an abstract and boring science. The paper outlines the journey of chemistry from central science to chemofobia and how should school and teachers can address this. The paper emphasizes how chemophobia is amplified and suggests that in most cases it is not interrelated with difficulties encountered in learnig of chemistry. Some of the most common misconceptions related to chemophobia such as "many cancers are related to synthetic chemical compounds", "food and collor additives are very toxic", "the food is contaminated with a lot of dangerous chemicals", etc., are discussed and it was demonstrated their little supportive evidence. The paper highlights the importance of school (chemistry teachers, in particular) to clarify the fundamental terms such as natural or synthetic chemical compounds, food additives, drugs, artificial sweeteners, etc.*

Keywords: *chemophobia, synthetic chemical compounds, natural compounds, food additives, cancer, artificial sweetener*

1. INTRODUCTION

Chemistry is sometimes called the "central science" as a recognition of its importance in various fields such as biology and botany, geology, geomorphology and archeology, astronomy, medicine and biochemistry, molecular genetics, engineering and materials science and many other areas of study [1].The fundamentals of these interconnections is one of the hot topics in the scientometrics and in philosophy of chemistry [2, 3][2]. Due to progress, achievements and contribution of chemistry to humankind, the United Nations declared 2011 the International Year of Chemistry (IYC), the International Union of Pure and Applied Chemistry (IUPAC) and UNESCO being the pioneers of this initiative [4]. Under the motto "Chemistry – our life, our future" the activities carried out under the aegis of IYC were aimed, *inter alia*, to highlight the importance of chemistry in our lives and in solving world's issues, as well as increase interest and motivation of young people in chemistry. Last but not least, another important goal was to promote the understanding and appreciation of chemistry's achievements by the public [5, 6].

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2. CHEMISTRY IN SCHOOLS. IS IT IS ATTRACTIVE TO START LEARNING CHEMISTRY?

Despite the recognized role of chemistry in our lives, teaching of chemistry often proves to be a difficult task. Chemistry has a reputation for being an intricate and sometimes a boring science.The students claim that chemistry (organic chemistry in particular) is a complex and abstract subject, having a highly elaborated semantics and symbolism that requires too much effort to be understood and assimilated [7, 8]. Apparently, these statements seem to be correct. Chemistry has a certain "code" that you can not get familiar within few days. Moreover, anxiety related to working with chemicals especially acids, manipulating laboratory materials and equipment, potential laboratory accidents cannot be neglected [9, 10]. All these aspects are barriers that prevent students from learning chemistry. As a consequence, the decreasing number of students studying chemistry seems to become a common aspect in many countries.

To counteract these stereotypes, the role of teachers is crucial. They can encourage young people to learn chemistry by arguing that:

- All known matter – gas, liquid and solid – is made of chemical elements or of compounds related to these elements.
- Most probable, chemistry explains the best the world around us. Food that we eat (more or less processed), our clothes, what we drink, the air we breathe, the medicines, cooking, cleaning, environmental issues are all chemistry or strongly related to chemistry.
- Students wanting to become doctors, pharmacists, nurses, nutritionists, engineers, material science specialists, geologists, archaeologists, geneticists, astronomers are required to have strong background in chemistry.
- A degree in chemistry can offer many carrer opportunities.

However, all these arguments may become vulnerable when a student first contacts the structure of a rather complicated molecule. Even so, the teachers can be convincing, mirroring semantics and symbolism from other areas. For instance, they can make a simple comparison between an electrocardiogram (a visual representation of the heart beat - Fig. 1) [11] and a synthesis route of an organic dye, called BCS-1 [12, 13]:

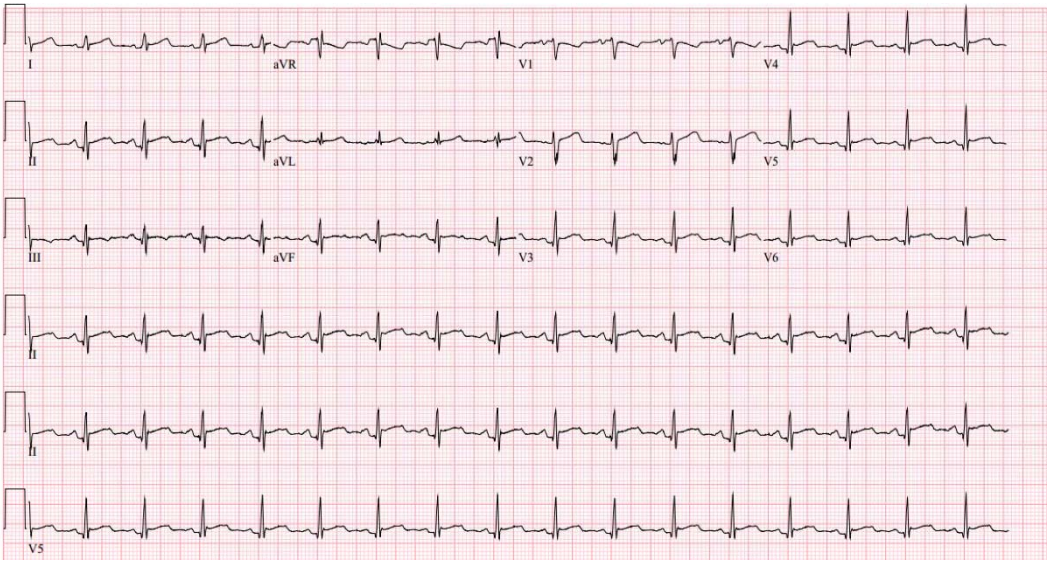


Figure 1. A fragment from an electrocardiogram.

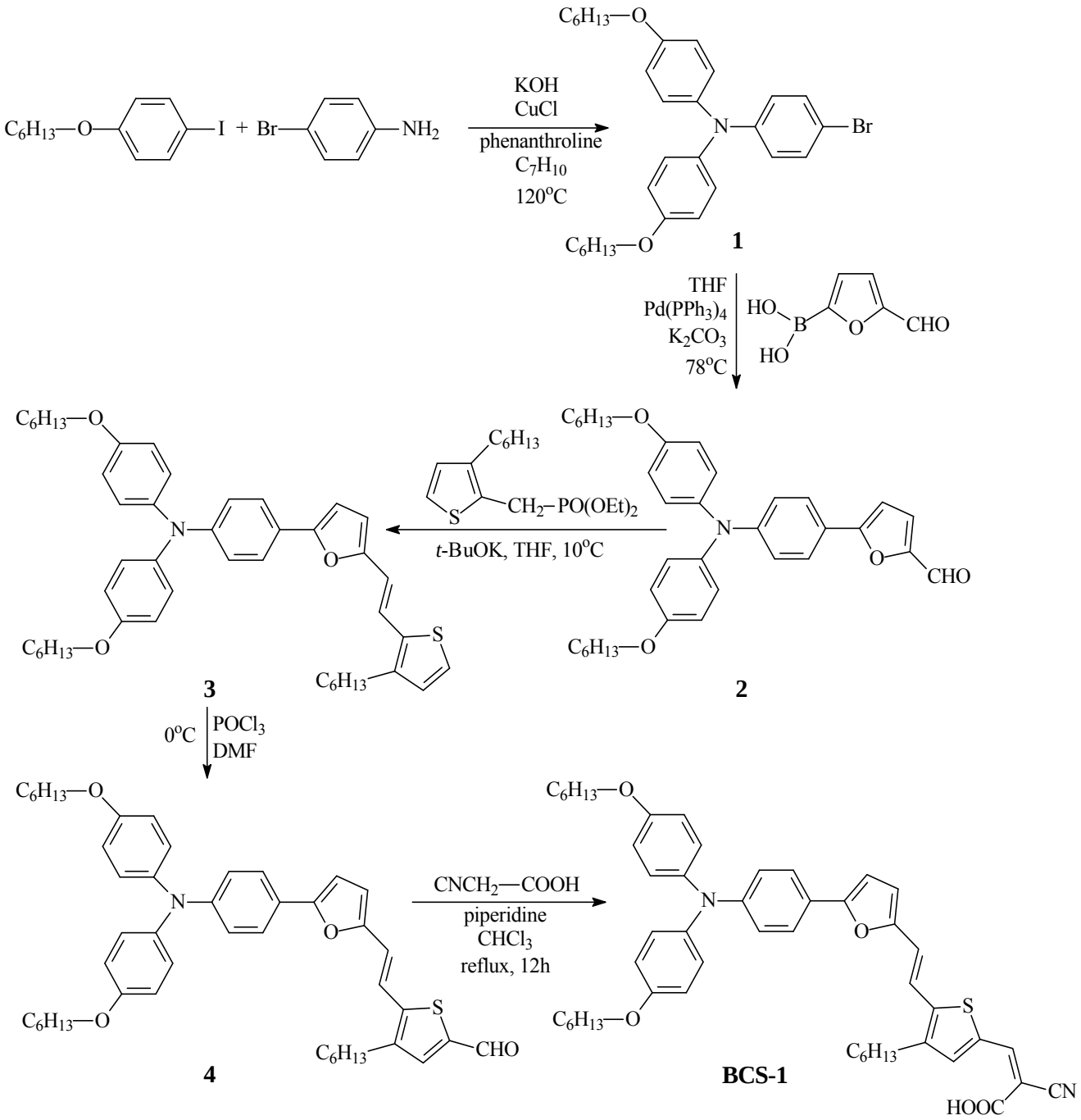


Figure 2. Synthesis route of BCS-1 organic dye: 1) 4-bromo-N, N-bis(4-(hexyloxy)phenyl)aniline; 2) 5-(4-(bis(4-(hexyloxy)phenyl)amino)phenyl)furan-2-carbaldehyde; 3) N,N-bis(4-hexyloxy-phenyl)-N-(4-(5-(2-(3-hexylthiophen-2-yl)vinyl)furan-2-yl)phenyl-aniline); 4) 3-{5-[2-(5-{4-[bis(4-hexyloxy-phenyl)-amino]-phenyl}-furan-2-yl)-vinyl]-3-hexyl-thiophen-2-yl}-2-carbaldehyde; BCS-1: 3-{5-[2-(5-{4-[bis(4-hexyloxyphenyl)-amino]-phenyl}-furan-2-yl)-vinyl]-3-hexyl-thiophen-2-yl}-2-cyanoacrylic acid.

Or it can be compared a simple text with Chinese characters (Fig. 3) [14] with a representation of mechanism reaction in organic chemistry (Fig. 4) [15].

种固相化学反应制备纳米金属单质的方法，其是通过金属盐与还原剂研磨或球磨发生固相化学反应，一步法制得纳米金属单质的。在反应过程中可加入表面活性剂来调节产物的尺寸和形貌。本发明所使用的原料廉价易得，反应操作简单，耗时少，易于进行大批量生产。由本发明方法所制备的纳米金属单质可用作优良的电子、催化、光学和电化学材料等，具有广阔的应用前景。

Figure 3. A text written in Chinese characters.

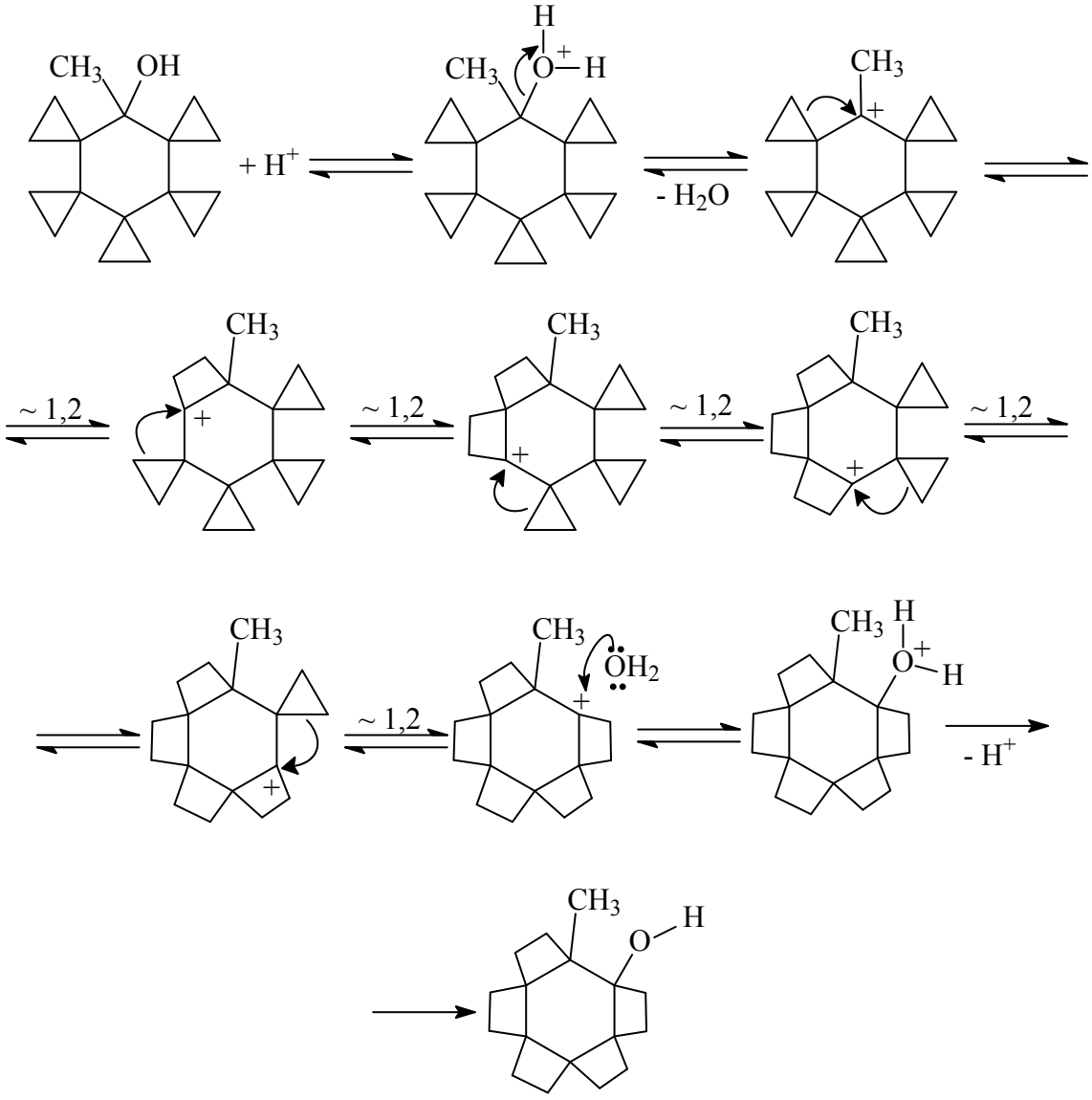


Figure 4. Representation of a reaction mechanism in organic chemistry.

If we look carefully, we will notice that not only chemistry, but every field has its own language, and, at first glance, it seems to be a collection of cryptograms. Thus, every step towards understanding of a discipline, chemistry or other science, must be associated with an effort.

Moreover, chemistry is one of the disciplines where by acquiring a minimal set of knowledge, you can anticipate and create a lot.

For instance, by learning and understanding the periodic table and its trends, it is possible to decode the formulas and properties of many inorganic compounds. Understanding the electronic effects from molecules (inductive effect, electromeric and resonance effects and hyperconjugation) may lead to the elucidation of reaction mechanisms, the reactivity of the organic compounds or their acid-base properties. Hundreds of organic compounds can be synthesized by using just few chemical reactions [16, 17].

Thus, the role of teachers can be of a paramount importance in offering the appropiate tools for students to learn and understand the fundamental concepts of chemistry.

It is important to emphasize that besides a standard program, chemistry teachers have an additional and difficult task, namely to prevent so called chemophobia.

Chemophobia (*chemphobia* or *chemonoia*) is an aversion to or prejudice against chemicals and/or chemistry [18, 19]. There are differing wiewpoints on the appropiate usage of the term *chemophobia*. The International Union of Pure and Applied Chemistry (IUPAC) defines *chemophobia* as an "irrational fear of chemicals" [20]. According to the American Council on Science and Health "chemophobia is a fear of synthetic substances arising from "scare stories" and exaggerated claims about their dangers prevalent in the media [21]. Sometimes chemophobia can occur with the beginning of chemistry study (sometimes due the perception that chemistry means, first of all, an inaccessible domain with very sophisticated language). However, we suspect that in many cases chemophobia has no direct connection with the difficulties encountered in learnig of chemistry (Fig. 5).

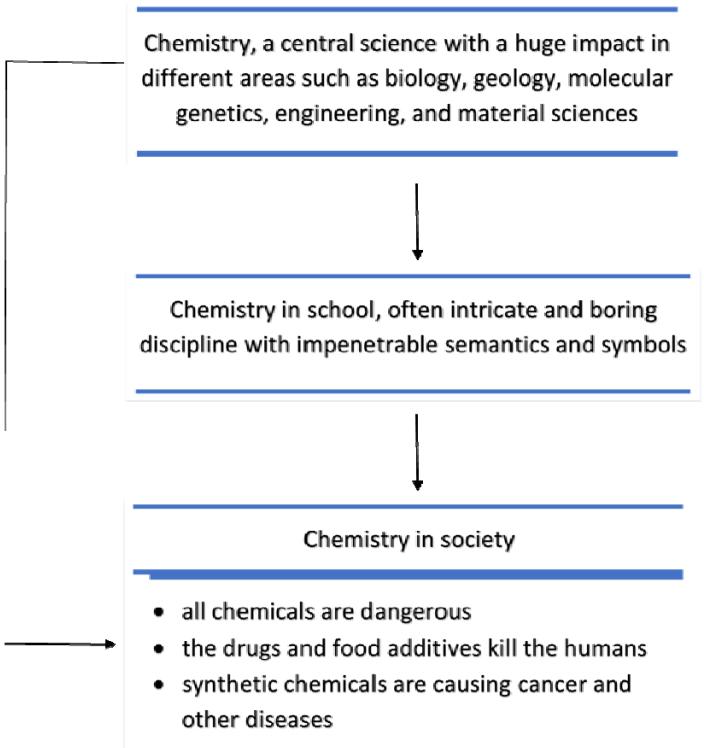


Figure 5. – Misunderstanding of chemistry produces chemophobia.

After graduation, chemophobia is amplyfied by many factors such as:

- **Industrial accidents, involving chemical manufacturing.** The most terrible chemical accident in history was the 1984 Bhopal disaster (India), when more than 3,500 people (official goverment estimation now refer to 15,000 deaths over the years) had died after a highly toxic methyl isocyanate (MIC) was accidentally released at a Union Carbide India Limited pesticide factory [22]. The Minamata disaster (1932-1968, caused by the

dumping of methylmercury in the industrial wastewater in Minamata Bay, Japan) [24, 25], the largest exposure to dioxin in the United States' history (1972-1976, Times Beach, Missouri) [26, 27], Baia Mare (Romania) cyanide spill [28, 29], Chernobyl disaster (April 26, 1986) [30, 31] are some of the well known and strongly mediatized industrial accidents involving chemical compounds with huge negative impact to society.

- **Natural accidents, involving chemical compounds.** A limnic eruption at Lake Nyos in Cameroon (21 August 1986) which released of about 100,000–300,000 tons dense cloud of carbon dioxide and killed over 1,700 people and many livestock [32, 33]. A similar limnic eruption occurred at Lake Monoun (August 15, 1984) located in Cameroon, also, that killed 37 people [34].
- **Chemical warfare (*CW*).** This involves the use of the toxic properties of some chemical compounds as weapons. According to Chemical Weapons Convention (CWC), chemical weapons are defined as toxic chemicals and their precursors, munitions and devices, and any equipment especially designed for use directly in connection with such weapons [35]. Utilization of natural or synthetical chemical compounds as chemical weapons has a long history. According to Sarah Everts: "For more than 2,000 years human ingenuity has turned natural and synthetic poisons into weapons of war" [36]. The structure of the two of the most mediatized compounds used as chemical weapon (ricin, a natural compound found in castor beans - Fig 6, [37, 38] and Sarin, a highly toxic synthetic organophosphorous compound - Fig.7. [39, 40] are presented below:

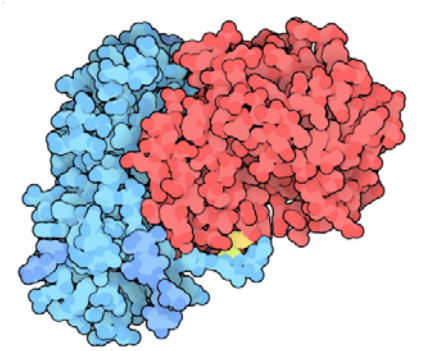


Figure 6. The structure of Ricin with cell-targeting B chain in blue and the toxic A chain in red Protein Data Bank (PDB-101).

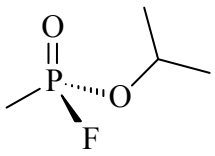


Figure 7. The structure of Sarin.

- **Environmental issues** such as huge concentration of plastic in the oceans [41], stratospheric ozone depletion [42], global warming [43], coral bleaching [44] are related, more or less, to chemical compounds.
- **Controversy about drug marketing and lobbying** [45, 46].
- **Concerns about food additives** based on the idea that they are hazardous chemicals, lead to inappropriate situations when people do not buy processed food, as they are not actually aware of their benefits. [47]
- **Agricultural pesticides use** [48] played a significant role both in the increase of production efficiency, and in the quality increase of production. However, though they are developed to function with reasonable certainty and minimal risks to human health and the environment, there are still encountered concerns about risks from exposure of farmers, as well as from non-occupational exposure of the population to residues found on food and drinking water. As a consequence, intensive research is constantly performed to develop new pesticides with novel modes of action and

improved safety profiles. Also, implementation of alternative cropping systems that are less dependent on pesticides is under scientist's preoccupation, envisaging to minimize the exposure to pesticides.

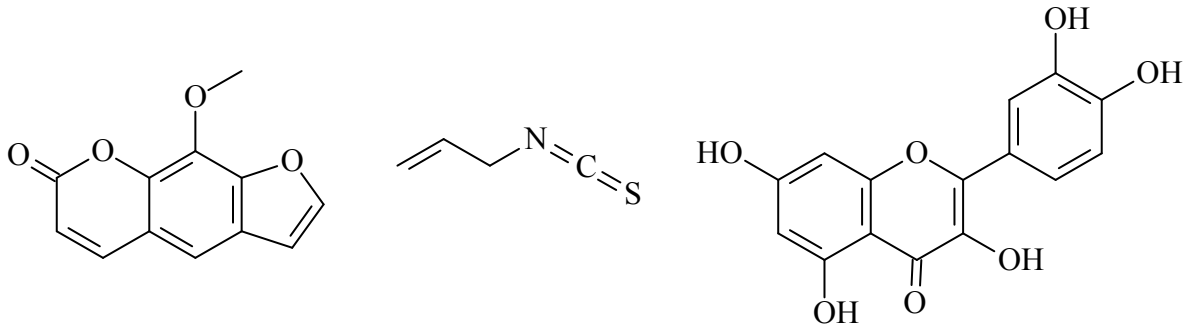
- **Online dissemination on environment of innacurate information related to the chemical compounds with major impact on our lives** [49, 50].

3. MISCONCEPTIONS RELATED TO SYNTHETIC CHEMICAL COMPOUNDS

General public attitude is that chemical synthetic compounds are something that must be avoided or eliminated. The most significant misconception about chemicals are:

3.1. MANY CANCERS ARE RELATED TO SYNTHETIC CHEMICAL COMPOUNDS

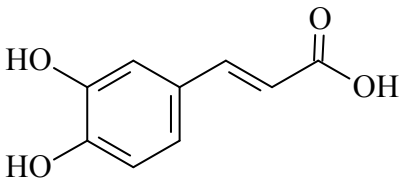
Cancer is a group of diseases characterized by uncontrolled division of cells with the potential to invade or spread to other parts of the body. There are more than 100 types of cancer reported in the literature to affect the humans [51, 52]. There are some misconceptions that link synthetic chemical compounds and increased cancer incidence. For instance, a lot of people think that synthetic pesticides found in fruits and vegetables and water pollutants are major causes of a cancer. However, advanced research and analyses do not support this hypothesis [53]. Surprisingly, about half of natural or synthetic chemicals compounds that have been tested in standard, high dose, animal cancer tests, have been shown to be rodent carcinogens [54-56]. Though it sounds trivial, there are just a few people knowing and realizing that most ingested chemical compounds are natural (*Nota bene:* 99.9% from the ingested chemicals). Despite the common opinion that synthetic pesticide residues are among the tough enemies for the humans in modern era, the ingested amounts of these chemical are insignicant when compared with the ingested amount of natural pesticides produced by fruits, vegetables, herbs and spices we eat [57, 58]. But a lot of the natural pesticides which were tested are rodent carcinogen. A rough estimation claims that on average Americans ingest about 5000 to 10,000 different natural pesticides and their breakdown products. Statistics on the ingested amounts of pesticides show that 1500 mg of natural pesticides are ingested in comparison with 0.09 mg synthetic pesticides / per person / per day. Some examples of the natural pesticides which rodent carcinogens and their occurrence are are presented in Fig. 8 [59].



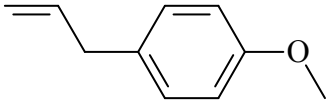
8- methoxy psoralen (celery, parsley)

allyl isothiocyanate (AITC) (cabbage, radish, cauliflower, mustard)

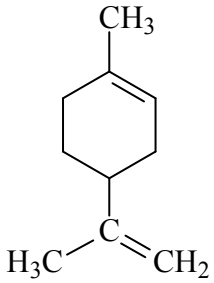
quercetin (capers, carob, cranberry, fennel leaves)



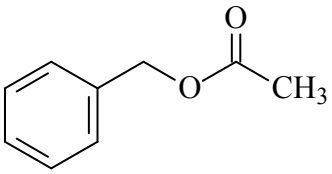
caffeic acid
(apples, celery, potato, carrots)



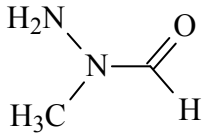
estragole
(basil)



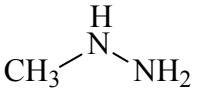
D-limonene
(orange, grapefruit, lemon, lime)



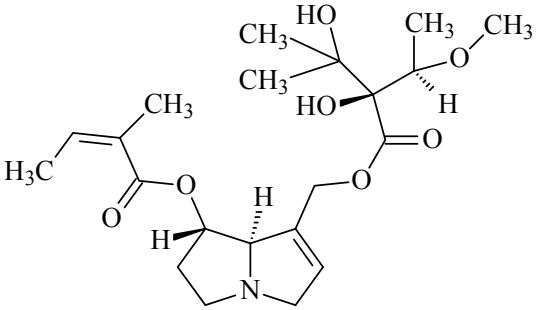
benzyl acetate
(basil)



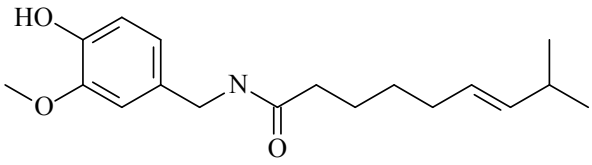
N-formyl-N-methylhydrazine
(mushrooms)



methyl hydrazine
(mushrooms)



lasiocarpine
(heliotropiumlasiocarpium)



capsaicin
(chili peppers)

Figure 8. Examples of natural pesticides which are rodent carcinogen and their natural occurrence.

As one can see, to avoid ingesting synthetic pesticides, would mean not eating fruits and vegetables, which could be a bad idea. Natural pesticides which are rodent carcinogen are ubiquitous in the nature, so a diet free of rodent carcinogens is virtually impossible [60, 61]. Moreover, significant connection between low vegetables and fruits intake and high cancer incidence is well documented in the literature [62 – 64].

Roasted coffee, used for preparation of one of the most popular beverages consumed by people from all over the world, is, *inter alia*, a cocktail of rodent carcinogens. Among these, one can be mentioned benzaldehyde, benzo[a]pyrene (Fig. 9), isoprene, benzofurane, dibenzo[a, h]anthracene (Fig. 10) [65].

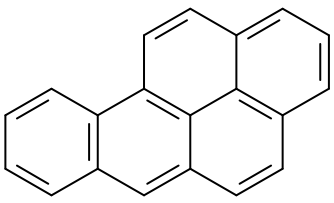


Figure 9. The structure of benzo[a] pyrene.

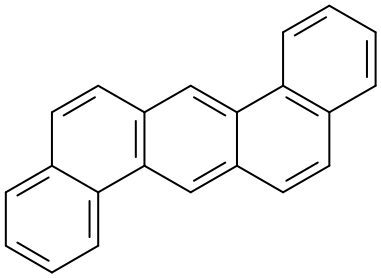


Figure 10. The structure of dibenzo[a, h]anthracene.

However, recent studies have generally found no association between coffee consumption and an increased risk of cancer. Despite the fact that a lot of natural chemicals found in fruits, vegetables, herbs spices, etc. are positive in high dose rodent cancer tests, these results are not relevant at low doses of human exposure.

Several studies conducted and published in the last decades, highlight that the major causes of cancer (other than smoking) do not involve exogenous chemical carcinogens. The major risks factors for increased incidence of cancer are genetic factors, age, dietary imbalances, sunlight, hormonal factors, immunosuppresion, radiation, infection-related inflammation [66].

3.2. SYNTHETIC CHEMICALS ARE MORE DANGEROUS THAN NATURAL CHEMICALS

This is one of the most encountered misconception related comparison man-made chemicals / natural chemical. The fact that a substance is natural does not automatically mean that it is safe to humans. Botulinum toxin (BTX) is one of the most relevant examples. This is a protein produced by the anaerobic, Gram – positive, bacterium Clostridium botulinum, one of the most dangerous neurotoxins known to date. Eight types of botulinum toxin (A, B, C [C1, C2] D, E F, G, H) are known. The human median lethal dose (LD-50) is 1.3-2.1 ng / kg body weight for intravenous or intramuscular administration and 10-13 ng / kg body weight for inhaled toxin [67, 68]. To better understand the toxicity of this natural molecule, it is enough to emphasize that a single teaspoon of protein could kill a quarter of the world's population.

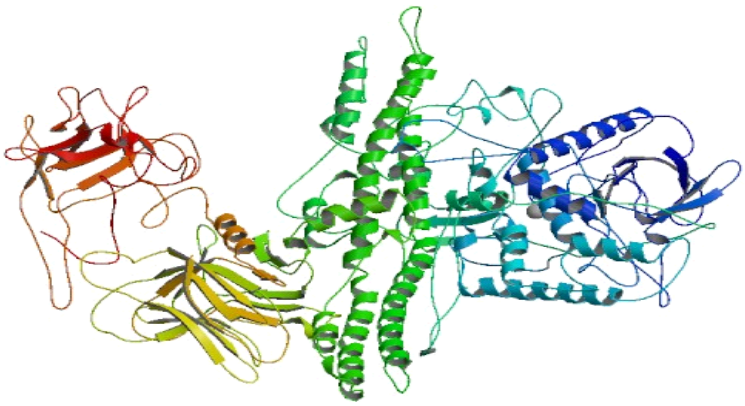


Figure 11. The crystalline structure of botulinum toxin (type A) (Protein Data Bank ID: 3BTA).

Botulism is a rare but very serious disease, occuring due to ingestion of botulinum toxin-contaminated foods (usually home-made canned, salted or home-smoked fish, home-made sausages) [69].

Despite its high toxicity, botulinum toxin is the most widely used therapeutic protein. It is effective as therapeutic option for the treatment of many diseases and syndroms such as: hemifacial spasm, cervical dystonia, blepharospasm, headache, sialorrhea, anal fissures, bruxism, diabetic neuropathies, etc. [70]. In recent years, botulinum toxin is used in dermatocosmology to treat facial wrinkles, correct facial asymmetries, hyperhidrosis, etc. [71].

Among the most toxic natural chemical compounds one can mention tetanus toxin A [72], diphtheria toxin [73], muscarine, a toxic alkaloid found in mushrooms such as *fly agaric* or *fly fungus* [74], bufotoxin**,** a toxic steroid lactone that occurs in the parotoid glands and skin

of many toads [75], etc. It is important to note that ten of the seventeen most deadly known compounds occur in nature [76].

As one can see, Nature is a very creative organic chemist, which synthesize a lot of molecules, some of these being, however, very dangerous. Despite of this evidence, a lot of people believe that natural compounds are better than synthetic molecules in all the circumstances.

The molecule, natural or man-made, are not good or bad. As we already seen, botulinum toxin, the most toxic molecule in the world (still natural!) has a lot of therapeutical applications. As Paracelsus said, "All things are poison, and nothing is without poison, the dosage alone makes it, so a thing is not a poison". The principle highlights that all chemicals (water and oxygen, also) can be toxic, potentially fatal, if too much is eaten, drunk, or absorbed [77 – 79].

3.3. Food and color additives are very toxic, the food is contaminated with a lot of dangerous chemicals.

This is one the the most used statement about food additives. For many people this is a hot and an emotional topic; they claim that a lot of food additives are cancerigen, mutagen, neurotoxic, induce childhood hyperactivity, etc. Although these hypotheses have been debated from the decades, none of them have been confirmed.

Moreover, a lot of food and color additives generally used are, in fact, natural compounds and some are even essential nutrients. Ascorbic acid and its salts are some examples:

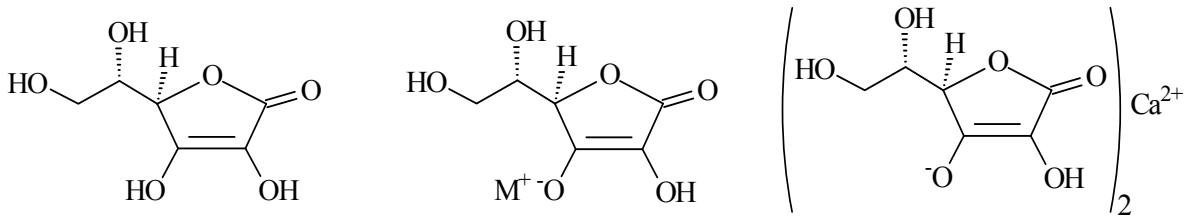


Figure 12. The structure of some ascorbic acid and its salt- based food additives.

Actually, the use of food additives brings us multiple benefits being key ingredients in maintaining food qualities and characteristics such as safety, taste, color, texture, freshness. Finally, it is important to mention that food and color additives are strictly studied and monitored by responsible authorities in the field, all over the world.

Thus, according to FDA," Federal regulations require evidence that each substance is safe at its intended level of use before it may be added to foods. Furthermore, all additives are subject to ongoing safety review as scientific understanding and methods of testing continue to improve. Consumers should feel safe about the foods they eat" [80].

3.4. ARTIFICIAL SWEETENERS ARE TOXIC FOR HUMANS, CAUSING SEIZURES, HEADACHES, MOOD DISTURBANCE, AND, SOMETIMES, CANCER

Artificial sweeteners are used in a wide variety of food, beverages, drugs and personal care products [81]. However, the mass media have reported about their potential cancer risks, neurotoxicity and other health hazards, in particularly for the children [82].

This is another highly emotionally charged urban mith related to synthetic chemical compounds from our lives. Thus, artificial sweeteners such as acesulfame K, aspartame, sucralose, D-tagatose, saccharin are considered by many people among the most important enemies of health [83]. Each artifical sweetener is associated with different health hazard, but these accusations are false or fanciful in the vast majority of cases. Aspartame (Fig. 13) is a good example in this regard.

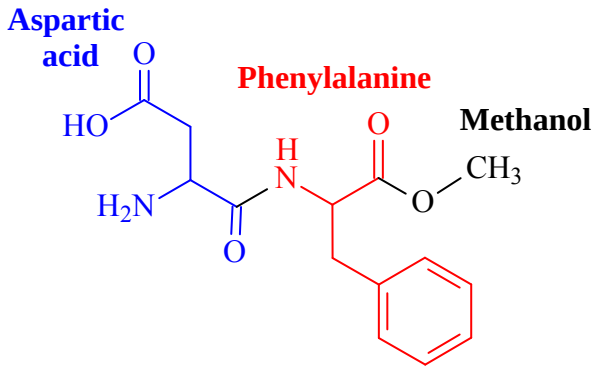


Figure 13. The structure of Aspartame.

Aspartame (L-Aspartyl-L-phenylalanine methyl ester) is one of the most common and most-studied artificial sweeteners. As many other chemical compounds used extensively in our food and drinks, Aspartame has been "embedded" in a lot of controversies concerning its safety. Different concerns related to Aspartame (risk of leukemia, lymphoma, and multiple myeloma, neurotoxicity due to the breakdown products) circulate on the Internet [84].

Despite of these rumors, dozens of studies performed by reserchears agencies in all the world that have evaluated and monitored Aspartame have found it safe for use in the food industry. Excepting people with PKU (phenylketonuria, a rare condition that requires restriction of many dietary proteins), there is no conclusive evidence that ingesting aspartame poses any health hazard [85].

Actually, Food and Drug Administration (FDA) regulates the use of aspartame and in 2007 stated the following [86]: “Considering results from the large number of studies on aspartame's safety, including five previously conducted negative chronic carcinogenicity studies, a recently reported large epidemiology study with negative associations between the use of aspartame and the occurrence of tumors, and negative findings from a series of three transgenic mouse assays, FDA finds no reason to alter its previous conclusion that aspartame is safe as a general purpose sweetener in food”.

3.5. DRUGS ARE TOXIC, TRUE POISONS TO HUMANS AND MUST BE AVOIDED

This statement can open a new list with some other common misconceptions. Actually, the drugs have changed the paradigm of life [87]. Simple or complex molecules, old and new synthetic drugs (three examples are presented below) represent a special chapter and has cardinal importance in modern man's life.

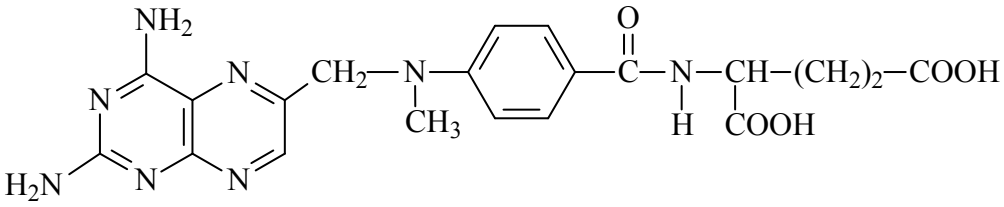


Figure 14. The structure of Methotrexate, a chemotherapy agent and immune system suppressant [88].

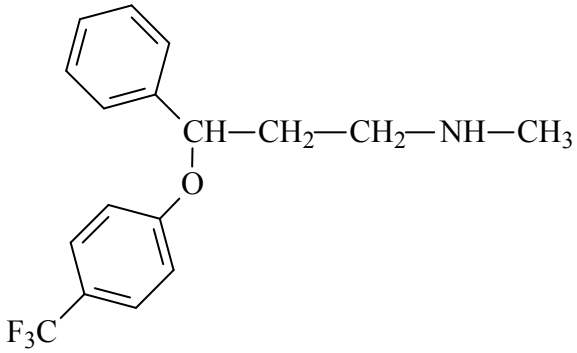


Figure 15. The structure of Fluoxetine marketed under the name of Prozac, an antidepressant drug [89].

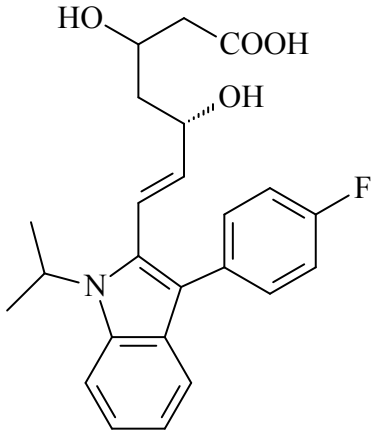


Figure 16. The structure of Fluvastatin, a statin used to treat hypercholesterolemia and to prevent cardiovascular disease [90].

Professor Franz Lichtenberg of Columbia University, New York, estimates that about 30% of the spectacular rise life-expentancy in the last century is due to modern medicine, that has replaced the old one [91].

Decreasing the time spent in hospital for different illnesses, increasing the quality of life, decreasing the number of patients with disabilities are hust a few of the benefits of the use of the latest generation drugs.

3.6. SYNTHETIC CHEMICALS BIOACCUMULATE IN OUR BODIES

Natural compounds such as fat-soluble vitamins A and D can accumulate in our bodies, too [92].

4. HOW SHOULD THE SCHOOL AND CHEMISTRY TEACHERS ADDRESS THESE MISCONCEPTIONS?

As one can see, a lot of misconceptions related to synthetic chemical compounds are encountered and we listed some of them.

Chemistry teachers should have a fundamental role in dispelling of the most common urban myths related to synthetic chemical compounds as well as in a clear explanation of the notions that often lead to serious confusions.

First, the teacher may explain the difference between a natural and a synthetic compound and the reasons why a natural compound is not preferable, *de plano*, to a synthetic one. Then he/she may emphasize the contribution of chemistry and chemical synthetic compounds to the humanity progress over time.

An important responsibility of the educator is to show that the modern world is strongly connected to the notion of molecule, and that molecules are not, *ab initio*, good or bad, panacea or poisons, and that the dose, use and purpose are fundamental criteria in their critical assessment [93 – 96].

Furthermore, the educator must check the validity of the information source and highlight the tools which can be used to discriminate between accurate, scientific data and fanciful and dangerous statements.

5. CONCLUSIONS

The aim of this paper is to emphasize the significant discrepancy between the importance of chemistry to humankind and its recognition as a core science and how, on the other hand, chemistry is perceived in school and society. The paper highlights the reasons why chemistry has a reputation as an incomprehensible and how teachers can counteract these general concerns. The paper suggests how chemophobia is usually amplified after graduation and reviews and dispels some of the most common misconceptions related to synthetic chemical compounds.

The paper highlights the importance of school (chemistry teachers, in particular) in preparation of students able to clearly understand fundamental notions such as natural or synthetic chemical compounds, food additives, drugs, artificial sweeteners.

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