On the associations of music and chemistry

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"...there is a growing need of some substance, of something that has a weight, that appeals not only through expedients, or technical tricks, but through something more" - W. Lutosławski[1]

Of the many forms of art, music seems to have special connections with exact sciences, particularly with mathematics – may we just mention Pythagoras, a philosopher with merits in both fields.[2] But what connects chemistry, a science of substances and their transformations, with music? Alexander Borodin, the author of the famous *Polovtsian Dances* from the opera *Prince Igor* and of symphonies and string quartets, was a professor of organic chemistry, and Lejaren A. Hiller, precursor of computer music, applied the same simulation methods to study polymer conformations and to compose music. Sir Edward Elgar, perhaps the best-known English composer, devoted his free time to chemical experiments, the traces of which have survived on some of his musical scores. By studying available sources, one may become convinced that there were more chemists-composers, and that the connections between chemistry or alchemy and music are not just a matter of conferring "chemical" titles to musical compositions.[3]

Faust motifs

Alchemists' secret experiments, the use of secret writing, explanation of observed phenomena using concepts of Greek philosophy (this is how alchemy emerged in Hellenistic Egypt) have always excited imagination of artists, musicians included. Modern times artists who interpret Renaissance music, like Lutz Kirchhof [1], are of the opinion that lute music, which aroused ecstasy of soul, must have also been the favourite music of alchemists and 'witches', the latter meaning originally women who had the wisdom that enabled them to heal others. These women were often depicted holding musical instruments.

In our pondering over the connections of music and alchemy we must not miss out the most famous sorcerer and alchemist of the turn of the 15th and 16th centuries, Johann Faust, who around 1500 was allegedly a student of the Cracow Academy. There were several mentions of Faust studying in Cracow. One of them, which eventually was not confirmed, comes from the book *Locorum communium collectanea* written by Johannes Manlius in 1562. The legend, however, lived on for a long time.

Johann Wolfgang von Goethe made Faust a philosopher, who possessed all knowledge, scared by neither hell nor devil, but deprived of all joy. Goethe is said to have started writing his greatest masterwork in Cracow. Robert Schumann, inspired by Goethe's drama, composed music to the scenes in *Faust*, and the Franz Liszt's *Faust Symphony* is deemed the most outstanding piece of programme music. The best-known opera, on the other hand, based on Michel Carré's play loosely associated with Goethe, is *Faust* by Charles Gounod. Berlioz proposed another perspective on Faust in his *Damnation of Faust*, showing a man who sacrifices redemption for love.

Fig. 1. Etching by Rembrandt, *Doctor Faust*, 1652–1653. (Source: en.wikipedia.org.)

One of the best-known operas by Feruccio Busoni is *Doktor Faust* (1924÷25) with the libretto written by the composer himself. In the first part of the opera, Faust, Rector of the University of Wittenberg, is paid a visit by three students from Cracow(!), who bring him a book. With the help of this book he can summon the devils. When Faust heard where the students have come from, he raised his eyes and recalled his memories: „Oh my old, my dear Cracow! / Your figures call the youth back to me. / Dreams! Plans! How much had I hoped for!" The scenic design of the opera staged during the 2006/2007 season in Zurich included a chemical laboratory. Doctor Faust was a chemist(!), and his rector's office room was surrounded with shelves with coloured chemicals and laboratory glassware.

In 1661, precisely 350 years ago, Robert Boyle published the book *The Sceptical Chymist* [2]. This Irish nature researcher removed two letters from the word alchemy, discipline much disrespected by the members of the Academy. Upon abandoning alchemy Boyle stated that the foundation of chemistry as a science is scepticism consisting in criticism of theorems and conclusions drawn from observations. Chemists, however, were not appreciated by the public straightaway. For a long time still to come people were more interested in the 'miracles' of alchemists. In this climate, the Queen's Theatre in London staged in 1710 a very popular play by B. Johnson *The Alchymist*. During intervals between the acts, the orchestra played Georg Friedrich Haendel's (1685-1759) suite, which the composer initially wrote as an overture for his first Italian opera *Rodrigo*. The suite gained much popularity and it was ascribed the title *The Alchymist*, under which it is known even today [3]. Handel (the composer changed his name after

[1] Interview by E. Markowska (1990). Potrzeba substancji (W kompozytorskiej pracowni), Polskie Radio, PRCD 182, 2004.

[2] Pythagoras discovered that there was a strict relationship between abstract worlds of sounds and numbers. The philosophy of Pythagoras was near and dear to the Greek composer and architect Iannis Xenakis, who said that "we all are Pythagoreans".

[3] E.g. Gold und Ophir ist zu schlecht (aria form Cantata BWV 64) by J. S. Bach, Golden Sonata by H. Purcell, Density 21.5 (for solo platinum flute) by E. Varese, or Fluorescence by K. Penderecki.

attaining success in England), added splendour to royal ceremonies of King George I of Great Britain. In 1749, after the signing of the Treaty of Aix-la-Chapelle, which ended the War of the Austrian Succession, a pyrotechnic display was staged, that is a performance by practising chemists. The display was accompanied by Handel's music. The King wished to listen to military music, played on wind instruments and kettledrums, but he finally accepted the composer's vision. The suite *Music for the Royal Fireworks* was also played on string instruments. What else could have better rendered the sparks falling from the sky?

Borodin, Elgar and Votoček

One of the outstanding composers of the Romantic Period was Alexander Borodin (1833÷1887), a chemist and surgeon by profession [4,5]. He was interested in music as a child, he played the piano, flute and cello. The first noted work, polka for piano 4 hands (*Polka Hélène*), Borodin composed as a 10-year old boy in love with his older dance partner; his first major composition, a concerto for flute and piano, was created when he was 14. To much extent he was a self-taught composer, although he took lessons from Balakirev. The best-known works of Borodin, which have entered the canon, include 3 symphonies, symphonic poem dedicated to F. Liszt *In the Steppes of Central Asia* (1880),[4] the opera Prince Igor with the famous *Polovtsian Dances* (1875) chamber and piano music, and songs.

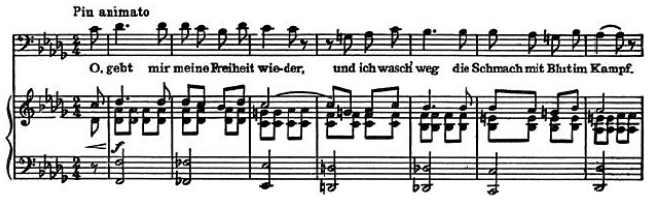

Fig. 2. Excerpt of the score from *Prince Igor,* act II, Igor's aria[5] [5]

Borodin was a member of the Mighty Handful (Rus. Могучая кучка), along with Mily Balakirev (the leader), Cesar Cui, Modest Mussorgsky and Nikolai Rimsky-Korsakov. This group of composers had contributed to the crystallisation of the national style in Russian music. This is how Rimsky-Korsakov remembered his friend, Borodin, in his *Chronicle of My Musical Life*:

Fig. 3. Founders of the Association of Russian Chemists (1868), Petersburg. Borodin, standing, fifth from the left; Mendeleev, second from the right (Source: ru.wikipedia.org.)

'He was the most cordial, educated, kind and, in his way, humorous interlocutor. During my visits to him, I frequently found him in his laboratory, which was connected with his apartment. When he stood over some flasks filled with some colourless gas, transferring it by means of a tube from one vessel to another, I joked that he was pouring from empty into void. When he finished we went to the apartment. We began to play music or to converse, during which he usually jumped up, ran again to his laboratory to see whether something had not burnt or boiled over, at the same time singing in the corridor some incredible sequences of ninths and sevenths. Then he came back and we continued playing or conversing' [4].

Borodin defended his doctoral thesis, *On the chemical and toxicological analogy of arsenic acid and phosphoric acid*, in 1858. He specialised in organic chemistry (Fig. 4). He discovered, independently of Wurtz, the aldol condensation reaction, important for organic synthesis, which leads to the formation of new C–C bonds, and the reaction of silver carboxylates decarboxylation in the presence of bromine (called Borodin-Hunsdiecker reaction). Studies of amide compounds led him to the invention of an apparatus for determining urea. He also was the first to describe the synthesis reaction of a fluoroaromatic compound: benzoyl fluoride[6]. Borodin treated chemistry as a serious and responsible work, and most of his time he devoted to science and teaching. His lectures as the professor aroused much interest.

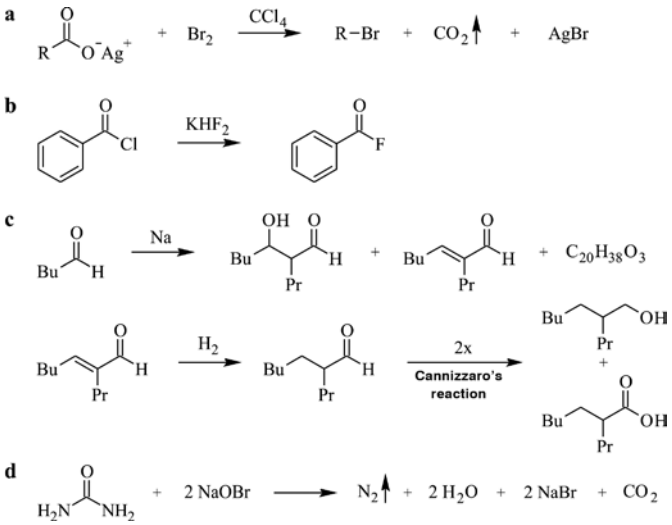

Fig. 4. Chemical reactions described by Borodin: (a) decarboxylation of silver salts, (b) synthesis of benzoyl fluoride, (c) condensation of valeraldehyde, (d) urea determination

Although he sometimes called himself a „Sunday musician", his attitude with regard to composing music was no less serious and enthusiastic. His wife wrote in her memoirs that 'in such moments he completely lost touch with the ground. He could sit down for ten hours and forget everything else'. With no doubt, he was an outstanding composer and a deserving chemist, but above all he was a warm-hearted man, full of joy, always ready to help others. One of the most famous Russian string quartet ensembles, *Borodin Quartet*, was named in his honour. In 2005 the Quartet celebrated its 60th anniversary.[7]

Sir Edward Elgar (1857-1934), one of the most outstanding English composers since the times of Henry Purcell, author of the orchestral *Enigma Variations* (1989), well known to music lovers, and the famous march *Land of Hope and Glory* of the series *Pomp and Circumstance* (1901), played as the finale of London promenade concerts, in his free time experimented in his home laboratory at Plas Gwyn in Hereford [6]. The composer was particularly interested in acoustic effects of chemical reactions. One day he prepared a larger than usually portion of a mixture of red phosphorus and potassium chlorate, which

[4] Borodin played this composition, arranged for piano 4 hands, together with Ferenc Liszt in Weimar. There he also saw *Faust* by Gounod.

[5] "O, give me my freedom back, and I'll wash away the shame with blood in fight."

[6] This was possible because of a rare set of platinum vessels in the laboratory in Pisa, where Borodin conducted research.

[7] A record issued on this occasion (Onyx Classics, 2005) included two compositions by Borodin: *String Quartet No.* 2 and miniature for string quartet *Serenata alla Spagnola*.

unexpectedly exploded. This is how that incident described Elgar's friend, composer and conductor William Henry Reed: „writing in horn and trumpet parts, and mapping out woodwind, a sudden and unexpected crash, as of all the percussion in all the orchestras on earth, shook the room" [7]. One important achievement of this chemistry enthusiast was the design of a device for generating hydrogen sulphide (*Elgar Sulphuretted Hydrogen Apparatus*) which he patented.

The best-known works of Elgar, in addition to those already mentioned, include a violin and cello concerto and two symphonies. It is worth mentioning the Polish accents in Elgar's music. Elgar, asked by the Polish conductor and composer, Emil Młynarski, wrote the symphonic prelude *Polonia* (1915), which included quotations from the Polish national anthem, Warszawianka and other patriotic songs. The work also includes themes from Chopin's *Nocturne in G minor* and from *Fantasie Polonaise* by Ignacy Jan Paderewski. Besides lessons taken from G. Politzer in London, Elgar was principally a self-taught musician.

The outstanding Czech chemist Emil Votoček (1872-1950) was also a composer [8, 6]. His scientific interests included organic, inorganic, analytical chemistry and phytochemistry. He specialised in chemistry of sugars (Fig. 5), he is regarded as the author of the concept of epimerism. For his scientific achievements he was awarded numerous honorary doctorates and he was a candidate for the Nobel Prize. He was a polyglot, spoke fluent Polish, Serbo-Croatian, French, Italian, Spanish, German and English. He was an author of a number of chemical dictionaries, such as *the Polish-Czech Chemical Dictionary inclusive of Mathematics, Physics, Geometry and Mineralogy*, and also the

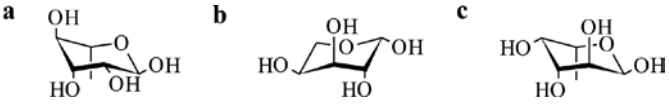

Fig. 5. Sugars (6-deoxy hexoses), studied by Votoček: (a) L-ramnose, (b) D-fucose, (c) L-fucose

Music Dictionary of Foreign Words and Phrases. In the years 1921-1922 Professor Votoček was the Rector of the Czech Technical University. In 1929, together with Jaroslav Heyrovsky (who later was awarded the Nobel Prize) he founded the magazine *Collection of Czechoslovak Chemical Communications*.

He was interested in music as a child, he could improvise on several instruments. As an amateur he played double bass in the public. He studied music with František Špilka only after he was 30. He wrote nearly 60 compositions, among them piano sonatas and chamber music: *Theme and Variations for piano and soprano* (1934), *Trio for violin, cello and piano* (1938), *Serenade for horn and string quartet* (1943), and orchestral works.

Fig. 6. Emil Votoček in his chemical laboratory [8]

Mutual inspirations

There is an anecdote that when Dmitri Mendeleev (1834-1907) listened to Robert Schumann's *Piano Quintet*, he got a flash of inspiration that helped him organise chemical elements into the periodic table [9]. The repeatability of the seven-tone melody in the second theme of the first part (Allegro brillante) of the *Quintet*, played first by the piano, then by the cello, and the periodic relationship between chemical properties of elements and their atomic mass is an analogy here. It is worth noting that the favourite composer of the discoverer of the periodic law was Ludwig van Beethoven, author of the *Piano Concerto in E-flat major* (1810). This beautiful concerto, from the turn of the Classic and Romantic Periods, was said to be the background of the love affair between Mendeleev and young pianist Anna Ivanovna Popova, which became the second wife of the great chemist. This was not the first case of music affecting chemist's emotions: Alexander Borodin, incidentally Mendeleev's friend, also married a pianist (Ekaterina Sergeyevna Protopopova), who amused Borodin the first day they met, playing Chopin and Schumann.

One of the empty spaces in Mendeleev's table was filled in by an outstanding French chemist, Georges Urbain (1872÷1938), professor of inorganic and coordinate chemistry at Sorbonne, discoverer of the chemical element lutetium (1907).[8] Urbain was a talented pianist and composer (he wrote, among others, several piano suites and pieces for organ), who saw the connection between music and chemistry like this:

„The musician combines sounds in the same way the chemist combines substances. The note is the musical element as the simple body is the chemical element […] It is true that musician and chemist reason in their respective fields in the same way, despite the profound difference of the materials they use" [9].

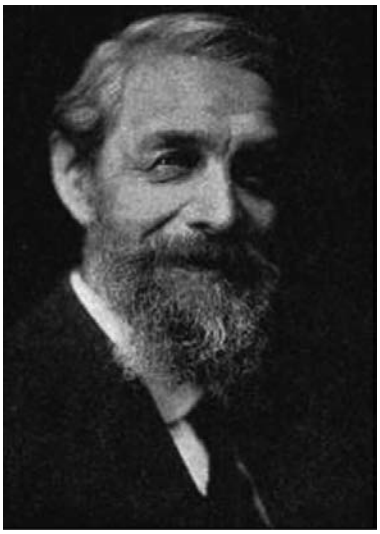

Fig. 7. Georges Urbain [9]

In 1924 Urbain wrote in an essay that music is more intellectual than emotional, it can therefore be subject to scientific analysis. The composer was particularly interested in the works of Bach, Wagner, Cesar Franck and Debussy. It is worth noting that he was not only a chemist, musician, author of a book on music, but also a valued sculptor and painter.

Lejaren A. Hiller Jr. (1924÷1994) was also a known chemist and composer [10]. He started studying chemistry and music in 1941. He defended his Ph.D. thesis entitled "The Chemical Structure of Cellulose and Starch" at the Princeton University when he was only 23. Then he worked for DuPont. At that time he invented a method of selective dying of synthetic fibres (e.g. Orlon). Together with R.H. Herber he wrote a textbook entitled *Principles of Chemistry* (1960). Hiller concerned himself with physicochemistry of polymers. He applied Monte Carlo simulation methods not only to study polymer

[8] Independent of Carl Auer von Welsbach and Charles James. The name of the element is derived from the Roman name of Paris (*Lutetia Parisiorum*).

conformations, but also in the process of music creation. He was a precursor of computer music, and his string quartet *Illiac Suite* (1957), written in collaboration with another chemist, Leonard M. Isaacson, is considered to be one of the first works generated with the use of a computer. The composer recalled lively:

„Leonard Isaacson and I did this *Illiac Suite* completely as a bootleg job at night on the *Illiac*. The programming came about because I actually adapted some of the rubber molecule programming to the writing of counterpoint. In other words, I had an idea one day when I was hanging around the chemistry lab just doing I don't know what, when I thought, 'Well, you know, if I change the geometrical design of this random flight program I've written' […] 'Change the parameters – the boundary conditions, so to speak – I can make the boundary conditions strict counterpoint instead of tetrahedral carbon bonds'. And that's how it all started" [11].

In 1958 Lejaren A. Hiller obtained his degree in musical arts at the University of Illinois, where he started the Experimental Music Studio. In 1968 he was appointed professor of composition at the State University of New York, Buffalo. His works were published by renowned record labels, like Deutsche Grammophon and Nonesuch. The result of his collaboration with the known composer John Cage was *HPSCHD* (contracted harpsichord), a composition for 1-7 harpsichords and 1-51 computer-generated tapes.

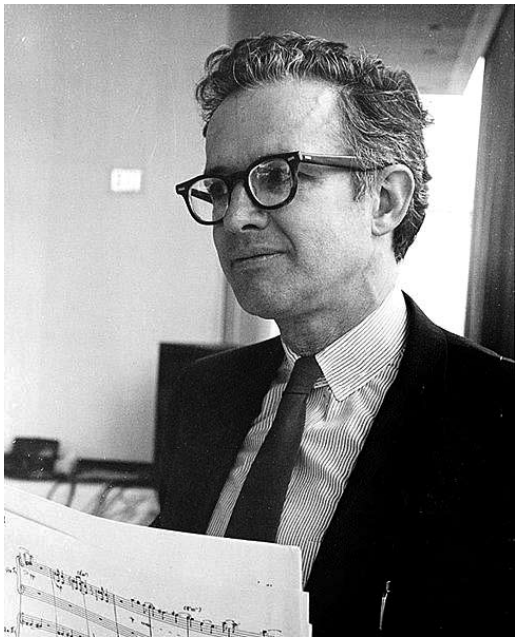

Fig. 8. Lejaren Arthur Hiller holding a score (Source: State University of New York at Buffalo)

In 1973 Hiller visited Warsaw as Fulbright lecturer. In the Experimental Studio of the Polish Radio in Warsaw tape parts were realised for *A Portfolio for Diverse Performers and Tape* (1974) – a composition commissioned by the Polish Radio. From that period was also an inspiration to write the *Diabelskie Skrzypce* (*Devil's Fiddle*) (1978) for stringed instrument and harpsichord.

The structure of the periodic system had clearly inspired Andrew Stiller (born 1946), one of Hiller's students, and composer Morton Feldman. In his work *A Periodic Table of the Elements* (1988), Stiller applied an algorithm consisting in the transformation into the musical language of information included in the modern periodic system, such as abundance, density, chemical activity, chemical affinity, physical state, metallic character. The premiere of this work, written for an alto flute, English horn, bass clarinet, bassoon, two trumpets, horn, trombone, percussion and five solo strings, was given in 1990, and the chemical elements appear therein according to their decreasing atomic number [9].

Another student of Hiller and Feldman, Peter Gena, wrote, with the help of Charles Strom, a geneticist, a series of works based on amino acid sequence in DNA (*Musical Synthesis of DNA Sequences*) of living organisms. In accordance with the algorithm developed, the composer converted physicochemical properties, using dissociation constants and molecular weight of amino acids or melting points of individual bases, into the language of music [12].

Piotr Drożdżewski is a contemporary Polish chemist and composer, as well as a violinist and organist. He specialises in coordination chemistry and spectroscopy as a professor at the Wrocław University of Technology. He studied musical composition at the Academy of Music in Wrocław. The individual style of Piotr Drożdżewski is influenced by his fascination with Bach and baroque polyphony. His *Sonata a due Violini* (1983), performed by Bartłomiej Nizioł and Jarosław Pietrzak, was released on a compact disk titled *Polish Violin Duos* (DUX, 2002).

Interesting are Drożdżowski's reflections on the phenomenon of expansion transferred onto the language of music in the orchestral work *Expansion* (1986), which the artist himself explains as follows: „The phenomenon of expansion, so common in the surrounding world, may take on different courses, scale and consequences, which are sometimes difficult to foresee. This phenomenon is not unknown in music itself – that is one of the reasons for attempting to make its sound presentation. The most recent work by the composer is *Four coloured variations on Planck constant* for a string quartet (2010) [13].

We must remember that in producing beautiful sounds by musical instruments, important role is played by polymeric materials, both of natural origin (wood - that is cellulose and hemicellulose) as well as artificial (strings). The quality of the generated sound depends on the structure and properties (mechanical and viscoelastic). It's not only chemists, who are interested in solving the puzzle of the exceptional sound and beautiful appearance of Stradivari. The microchemical composition of the finish of five violins from the Stradivarius workshop has recently been studied closely by a team headed by Jean-Philippe Echard, who specialises in conservation [14]. The results obtained have undermined the belief that the varnish used to coat the violins had a substantial effect on the sound properties of the instruments; the secret was rather in the wood used.

Fig. 9. Cover of the *Angewandte Chemie* magazine with article by J. P. Echard

Chemist's Musical Canon

The examples of the relations between music and chemistry given in this paper have been included in the programme of a seminar titled *Chemist's Musical Canon*, conducted by the authors of this paper. It is a new arts subject proposed to first year students at the Faculty of Chemical Engineering and Technology of the Cracow University of Technology. Dr Danuta Augustyn, a violonist and lecturer at the Academy of Music in Cracow, has been invited to collaborate. Her participation enables the students to meet an instrumentalist and perceive live music. Seminar participants listen to fragments of compositions of the classical music canon and get familiar with the elements of musical aesthetics.

Fig. 10. Logotype of the new seminar

The programme also includes participation of students in selected concerts of chamber or symphonic music and a meeting with a composer of the young generation. This year the guest of the seminar was composer Stanisław Bromboszcz (Academy of Music in Katowice). By shaping the musical sensitivity and consciousness we strive to broaden the scope of students' interests and to contribute to comprehensive development of future graduates of a technical university. The interdisciplinary nature of the *Chemist's Musical Canon* also incidentally helps impart knowledge of chemical phenomena. The effect of sounds on emotions may facilitate the absorbing and memorising mutually coupled themes. Such approach seems to be an interesting proposal of a didactic method.

During the first seminar, students had a chance to become convinced that music can fully create a mood (it allegedly has an effect on the secretion of dopamine, colloquially called the hormone of happiness), when we listened to *Adagio assai* from Ravel's *Piano Concerto in G major* interpreted by Krystian Zimerman and the Cleveland Orchestra conducted by Pierre Boulez. This composition, of extremely rich harmonics and colours, is now among students' favourite musical pieces. Pieces of chamber music by Borodin also aroused interest (see note 7). Quite different were the emotions aroused by the music presented during the concerts called the *Quartet Alchemy* (performed by Airis Quartet), organised by us at the Teatr Zależny of our university.[9] These concerts were an occasion to get familiar with the richness and beauty of quartet literature – starting from the depth of romantic phrase (*Quartet in F minor* by Mendelssohn-Bartholdy,[10] particularly appreciated by Borodin), through the sonority and unconventional use of string instruments, to the synthesis of art, music and theatre. During the concert took place the world premiere (!) of *Mouths & Strings* composed by the young Romanian Alin Gherman. This time the students liked most *Caixa de Dolços* of the Dutch composer Chiel Meijering, who incidentally has also been touched by Faust's magic – one of his compositions is titled *Dr. Faust's Hell-Master*.

Perhaps there will come a day when we create, together with students of chemistry, a composition on the border of the so-called concrete music, using the instruments of a chemical laboratory. Of high hopes is particularly one of us (P. R.), who does experiments not only in a chemical lab, but also in the space of sound.

[9] Photographs available at: http://www.galeria.pk.edu.pl/index.php?album=320-muzyczny-kanon-chemika-koncert-kwartetu-airis

[10] *Nb.:* Mendelssohn' son, Paul Mendelssohn-Bartholdy, was a chemist an co-founder of *Aktien-Gesellschaft für Anilin-Fabrikation* (AGFA).

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Stefan S. KUREK – Ph.D., is a graduate of the Faculty of Chemistry of the Cracow University of Technology. There he was also awarded his Ph.D. degree. Now an Associate Professor at the Department of Physical Chemistry of the Faculty of Chemistry at the Cracow University of Technology. Conducts research in molecular electrochemistry and electrocatalysis. He is a music lover, particularly fond of music of the first half of the 20th century. Recently, inspired by preparations to classes with students on the new subject, *Chemist's Musical Canon*, fascinated by Faust motives in music.