Music of the elements†‡

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Do the chemical elements, Mendeleev or the Periodic Table play any role in the world of music? Here are a few preliminary notes for an answer to that question, maybe just the tip of an iceberg. Some suggestions are offered on music that is worth listening to, although some of the works commented on may require more of a good sense of humour than musical sensibility from the reader.

Le savant et l'artiste créateurs sont, d'un point de vue intellectuel, des frères jumeaux.§

Georges Urbain (1924)

Sei que a arte é irmã da ciência
Ambas filhas de um Deus fugaz
Que faz num momento
E no mesmo momento desfaz.¶

Gilberto Gil (1997)

Introduction

Is there really any relationship between music and chemistry? Let us see. We start by reminding the reader that Newlands[1] made reference to the musical scale when he proposed the law of octaves, an important precedent for Mendeleev's periodic system: *members of the same group stand to each other in the same relation as the extremities of one or more octaves in music*. Mendeleev himself had a strong faith in the periodic classification of the elements because nature is periodic (day and night, the seasons), and so are "all types of vibrations", and there cannot be music without vibrations. He recognized, though, that the periodicity of the elements was somehow more complicated than that of sound waves.[2] In music, when the same note is played two octaves higher its frequency is multiplied by four. Similarly, the elements of a triad, separated by two periods in the periodic table, bear a relationship between their atomic weights of approximately four. The word triad itself is used in music for a chord of three notes with a harmonic relationship.

Some musical instruments are made from pure chemical elements. That is the case with silver, gold or platinum flutes, silver horns and trumpets, and violins, violas and violoncellos made of carbon fibers. The pipes of organs are generally made from alloys containing variable proportions of lead and tin, but pure metals such as zinc, gold, silver, aluminium, copper or iron have also been used for that purpose. Other less conventional uses of the elements in making music can be found, for instance in *Fluorescences* by Krzysztof Penderecki, which makes use of pieces of tin, along with wood, glass, a siren and a typewriter. Alexandr Mosolov, in the orchestral work *Zavod* (Steelworks, 1927), employs a steel plate to simulate the sounds of a steel forge. An important contemporary application of aluminium is its use for the storage of digital information in compact discs.

The aim of this essay, however, is not to go more deeply into the relationships involved in the physical generation or storage of music, but to find out if the elements, the periodic system and Mendeleev have been a source of inspiration for composers throughout the last few centuries. Thus we will look with equal interest at music of quite different styles and ask the indulgence of the reader whenever reference is made to pieces that may not be the kind of music he or she would like to listen to. In return, I hope that everyone might find suggestions for some interesting musical passages, and inspiring or funny lyrics. Literature on this topic seems to be scarce, mostly brief notes dedicated to analyzing the relationships between chemistry and music in pop and rock songs.[3] Some more information is available on the related topic of chemists as composers,[4] but those sources hardly mention the chemical elements.

When the elements were four (or five)

In classical music, references to the elements are found mostly in the baroque period, contemporary to Boyle's definition of a chemical element[5] and long before Dalton's published the atomic theory and probably the first table of elements.[6] It is just natural that such compositions are dedicated to the four classical elements: earth, fire, water and air. The proposal of those elements as the basic constituents of all matter is attributed to Empedocles of Agrigentum (490–430 BC), who thought they were composed of very small and immutable particles, along the lines of the atomic theory of Leucippus.[7] It is up to the reader to speculate about a possible correspondence between the four material elements and the four elements of musical composition: rhythm, melody, harmony and timbre.[8]

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‡ The HTML version of this article has been enhanced with colour images.

§ The scientist and the creative artist are, from an intellectual point of view, twin brothers.

¶ I know art is the sister of science/Both daughters of a fleeting God/Who makes and in the same moment unmakes.

A list of musical works devoted to the elements is shown in Table 1. It is interesting to see that composers of the 19th and 20th centuries are more often inspired by the four elements than by the elegant organization of matter in the periodic table or by the discovery of many new elements within a relatively short period of time.

In 1681 Charpentier composed the music for the comedy *La Pierre Philosophale*, by Thomas Corneille and Jean Donneau de Visé, a *pièce à machines*‖ *avec agréments musicaux* in five acts and a prelude. The title refers to the Philosopher's Stone, which two of the main characters try to discover. In the middle of a Rosicrucian rite, a man even offers marriage to the daughter of one of the alchemists with a peculiar declaration: *Je suis un élément léger*.** The four elements dance in celebration, while water and fire proclaim that the strength of love is able to unify the contraries. In barely eight minutes, this work depicts humanized and Epicurean elements, especially in two *chorales of the four elements*.

Another remarkable baroque composition devoted to the elements is a symphony by Jean-Féry Rebel (Fig. 1). Its first movement, *Le Cahos*, is breathtaking and sounds modern even today. According to conductor Reinhard Goebel, this movement is the first free orchestral composition in the history of music. The most gentle of baroques is recovered in the subsequent movements devoted to earth, water, fire and air, represented by the bass, flutes, violins and by high trills, respectively. Then nightingales and love are also incorporated, and the symphony finishes with dance movements (*Loure*, *Sicilienne* and *Caprice*).

André-Cardinal Destouches, a disciple of Lully, composed the opera-ballet *Les Éléments*, based on a plot by Pierre-Charles Roy, that was first represented on December 31, 1721 at the Paris Opera, with some dance solos interpreted by Louis XV himself. While the Overture represents the birth of the elements, the music of the Zephyrs recalls the air, the Nereids' dances refer to water and the Chaconne to fire. Again, interesting music for lovers of the baroque.

Antonio de Literes, native of Artà, on the island of Mallorca, pursued a musical career in Madrid. There he composed *Los Elementos* based on a text by an unknown author that he called an *ópera armónica al estilo ytaliano*.†† Following a common practice at that time, practically all the solos are assigned to six sopranos, including some male characters. Handel, though, often did the opposite, assigning female roles to countertenors, as in *Ariodante* or *Rinaldo*. The text is actually an ode to nature and bears little relationship with the character of basic components of matter attributed to the four elements. Here is a small sample:

And the fire tenacious
Groans all voracious,
The weighty Earth
Creaks irritably.
The stormy ocean
Seethes and swells.
And the sad accent
of the air so violent...

The music more than compensates for the unattractive lyrics, as can be appreciated in a delightful version recorded by Eduardo López Banzo and his group *Al Ayre Español* in 1998.

The next work devoted to the four elements appears well into the 20th century, from the hand of Frank Martin, a Swiss composer whose music went against the current of the atonal movement that dominated the musical panorama between 1950 and 1970. His work *Les Quatre Éléments* was composed to celebrate the 80th birthday of conductor Ernest Ansermet. Another contemporary work, *Elements*, composed by Tully Cathey in 1997 for a mandolin quartet was inspired by the transforming power of those four forces of nature in the region of the Yellowstone National Park and the Rocky Mountains.

Fig. 1 Jean-Fery Rébel, author of *Les Élémens*.

A short piece entitled *Inlets*, by John Cage, has the four elements as protagonists. It is interpreted by three musicians with four shells and a bucket of water each.‡‡ The music is produced by the air bubbles made by the shells as they are submerged in water. After a while, fire takes the place of water in a recording of the sound of burning pines. Water takes over again and then air blows through another shell producing the sound of a trumpet.

Some of the works in Table 1 refer to five, not four elements. These are the elements of Chinese antiquity, described in *Shu Ching*, a book of the Chou Dynasty (722–221 BC): earth, water, fire, wood and metal.[7] Unlike the ones

Table 1 Works of classical music devoted to the elements

Marc Antoine Charpentier (1643–1704): ***La Pierre Philosophale*** (1681)
Jean-Féry Rebel (1666–1747): ***Les Élémens*** (*Simphonie nouvelle pour 2 violins, 2 flutes & continuo*)
André-Cardinal Destouches (1672–1749): ***Les Éléments*** (Opera-ballet)
Antonio de Literes (1673–1747): ***Los Elementos*** *(Opera armónica al estilo ytaliano)*
Frank Martin (1890–1974): ***Les Quatre Éléments*** (1963–64)
John Cage (1912–1992): ***Inlets*** (1977)
Andrew Stiller (1946–): ***A Periodic Table of the Elements*** (1988)
Tully Cathey (1954–): ***Elements*** (for mandolin quartet)
Tan Dun (1957–): ***Symphony 1997***
Steve Heitzeg (1959–): ***Nobel Symphony*** (2001)
Zhou Long (1953–): ***Five Elements*** (for dizi, clarinet, pipa, erhu, cello and percussion, 2002)

‖ This expression is used to designate a theatrical piece that relies heavily on a spectacular *mis en scene*, with abundance of what we nowadays call "special effects".
** I am a light element.
†† Harmonic opera, in the Italian style.
‡‡ While writing this manuscript I had the chance to attend a concert entitled *Elements* by the group Percussions de Barcelona that interpreted this work of Cage, along with some pieces devoted to one of the classical elements by contemporary composers such as Lou Harrison, Keiko Abe and Pere Josep Puértolas.

proposed by Empedocles, these could be interconverted, much in the same way as Plato associated the four elements with regular polyhedra that interconverted, retaining the polygonal faces as their immutable basic components. Thus, Tan Dun's *Symphony 1997*, commissioned to commemorate the reunification of Hong Kong and China, contains movements dedicated to four of the five elements. Born in Hunan (China) and resident in New York, Tan Dun is one of the most widely acclaimed composers of the last few decades, and his operas *Marco Polo* and *Ghost Opera* have been performed around the world.

Zhou Long (Fig. 2) studied at the Central Conservatory of Music in Beijing and worked as a composer-in-residence of the National Broadcasting Symphony Orchestra of China. Currently a citizen of the United States, he has taught in several North American universities and conservatories. His music is characterized by an innovative blend of the Chinese and western musical traditions. Each of the five movements of *Five Elements* is dedicated to one of the elements of the Chinese tradition. Of them we could single out the first and longest one, *Metal*, which starts with the sound of a forge, replicated by the echo of the *pipe*, to which wind and strings are added to create a texture that symbolizes extraction and refinement.

We can finally mention in this section the *Nobel Symphony* of the North American composer Steve Heitzeg (Fig. 3), written on commission to commemorate the centennial of the Nobel prizes in 2001. The fifth movement of this symphony, dedicated to the Nobel Chemistry Prize and titled *Chemistry: Anthem and Elements*, consists of an anthem and variations for metals and percussion, dedicated, among others, to Pauling, the Curies, tungsten and carbon 14. It starts with the rhythmic crackling of a sheet of plastic bubble wrap, accompanied in the variations by stones, aluminum foil, kernels of organic corn, bean pods and a gourd.

Fig. 2 Zhou Long, composer of *Five Elements*. Photograph courtesy of Zhou L.

Fig. 3 Steve Heitzeg, North American composer of the *Nobel Symphony*. Photograph courtesy of S. Heitzeg.

Music for a solo element

We could consider the number of musical pieces named after a chemical element as an indication of the degree of knowledge that the society has about that element and its properties. Some information can be obtained from the Webster's dictionary's web page,[9] that under the names of some elements includes a link to a list of records in a cyberstore. A few more connections between works of classical music and the names of the elements, though not direct, can be found in a recent article.[10]

The option chosen here to calibrate the presence of the elements in the music market consists of searching in a music cyberstore for the names of each element in English and Spanish. The nature of the store chosen may favor popular over classical music. Besides, many classical works are named after their form (concert, sonata, symphony...), especially before the 20th century, decreasing the probability of finding the names of the elements in the titles of instrumental works. The results of such searches can be seen in the *spectrum* of Fig. 4, representing the number of times that the name of an element was found as a function of the atomic number.

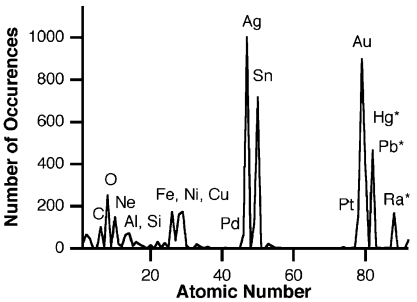

Fig. 4 Frequency of appearance of the chemical elements in the titles of musical works found in a cyberstore. The figures of the elements marked with an asterisk are biased by their polysemic nature.

The numbers presented in such a spectrum should be taken with care. There is a good deal of redundancy associated with the different versions of the same piece, specially for classical music, and some elements are overweighted because of the polysemic character of their name. This is the case for indium and radium in Spanish, of lead in English or of mercury in both languages. As an example, the ballet *Mercury* composed by Eric Satie, that refers to the god, not to the element, and the movement named *Mercury* in Holst's *The Planets*, should also be ruled out. In contrast, we should consider the *Mercury* symphony of Haydn, because the name here refers to the "mercurial" or densely fluid character of the main theme.

The first feature that can be appreciated in Fig. 4 is the presence of a valley for atomic numbers over 32, interrupted only by some sharp peaks. We could deduce that, with the exception of some metals, the heavier elements are much less well known than the lighter ones. Disregarding the false maxima commented on above (In, Hg, Pb and Ra), the most frequently cited elements are, in decreasing order, Ag, Au, Sn, O, Cu, Fe, Ni, Pt, Ne, C, Si, He, Al and Pd. In other words, except for oxygen, the most popular elements are the metals that have been present throughout history and in daily life, even though aluminum does not seem to be represented in a proportion that would correspond to its importance in our society. In contrast, those elements that do not appear in a single title should be considered as

practically unknown, as happens with Be, Ga, Ge, Rb, Ru, Rh, La, Hf, Re, At and Fr, as well as with most of the rare earths. Let us comment now on a few specific elements and the music dedicated to them.§§

Platinum

Density 21.5, a solo flute piece by Edgard Varése (Fig. 5), was composed in 1936 on the occasion of Georges Barrère's first performance with his new platinum instrument. The density of this metal, 21.5 g cm^{-3}, is the source of the name of a virtuoso work that explores the extremes of the instrument's register. More than just an anecdotal datum, this number indicates that platinum is one of the heaviest metals, with a density roughly twice that of lead and second only to iridium, osmium and the artificial elements with atomic numbers between 106 and 111.

Iron

Given the preeminent role of iron in the development of civilizations, it is not surprising to find this element much more frequently than others in musical themes. In Handel's *Messiah*, for instance, the tenor sings in an aria (psalm 2:9),

Thou shalt break them with a rod of iron,
thou shall dash them in pieces like a potter's vessel.

It is also iron that is most often recalled to showcase the association between metals and rock and roll of varying degrees of hardness. Just remember the names of bands such as Iron Maiden or Iron Butterfly, and the titles of songs by Judas Priest (*Hard as Iron*), Black Sabbath (*Iron Man*), or Dire Straits (*Iron Hand*).

Oxygen

The Sweet, a group representative of the lightest early pop, included in their repertoire the song *Love is Like Oxygen*. The analogy is to be found in the chorus:

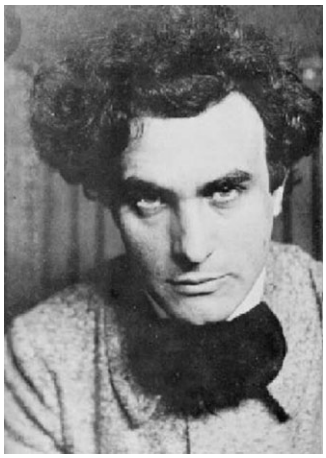

Fig. 5 Edgard Varése (1883–1965), author of a composition dedicated to platinum, *Density 21.5*.

Love is like oxygen:
you get too much, you get too high,
not enough and you're gonna die.
Love gets you high.

More recently, the *Spice Girls* also sang to a love that is as vital as oxygen in their song *Oxygen* (*Forever*, 2003). A similar approach was adopted by the "Christian music" group *Avalon* in the song of the same name that gives title to an album:

You are my oxygen
I breathe You in
I breathe You out
You are my oxygen
You are my love
You are what life's about.

In brief, these and many other pop songs share a perception of science as secondary to the really important things in life, especially love (see, *e.g.*, the song *The Scientist*, by Coldplay). An unequivocal declaration can be found in *Wonderful World*, a song that was repopularized by the persuasive voice of Sam Cooke when it was included in the film *Witness*, with Harrison Ford playing the main character:

Don't know much about history,
Don't know much biology,
Don't know much about a science book,
Don't know much about the French I took.
But I do know that I love you,
And I know that if you love me, too,
What a wonderful world this would be!

To compensate for the hyperventilation with pop oxygen, you could obtain some relaxation with the gentle suite *Oxygen* for solo guitar, composed and performed by the classical guitar player Sulaiman Zai. Or maybe tap your feet to the salsa rythm of Willy Chirino's *Oxígeno*. Born in the Cuban province of Pinar del Río, Chirino is one of the most popular artists of the Cuban community in Miami, which has even dedicated a street to the musician.

Esa mujer me da oxígeno
con su sonrisa simpática
con su presencia magnífica
¡Ay! oxígeno
para mi sangre y mi espíritu
con la locura en el máximo
con el control en el mínimo
con su sonrisa magnética...¶¶

The author probably knew enough chemistry to understand that paramagnetic oxygen goes hand in hand with a magnetic smile.

The most successful music dedicated to this element is *Oxygène*, of the French author Jean Michel Jarre. This electronic instrumental suite, recorded in 1976, marked the coming of age of electronic instrumental music. Both the title of the composition and the cover image represent an early call of attention to nature and to environmental issues.

Silver and gold

These two metals share the podium of the most popular elements (Fig. 4) and they have similar relationships to the world of music. Their presence in the songbook is associated with their role as raw materials for a great variety of objects, with their character of symbols of wealth, luxury and power, and with their metallic shine, as well as for the many metaphors that make use of those properties.

As an example of the ubiquity of these metals in everyday language we need only search for the names of songs in which silver appears as an adjective. In many instances it just indicates the

§§ It must be noted, though, that not all the information presented here has been obtained from the cyberstore search that resulted in Fig. 4.

¶¶ That woman brings me oxygen/With her nice smile/With her magnificent presence/Oh! Oxygen/For my blood and my spirit/With foolishness at maximum/With control at minimum/With her magnetic smile.

Table 2 Some works of classical music that refer to gold or silver

J. S. Bach	*Gold und Ophir ist zu schlecht* (aria from the cantata BWV 64)
L. von Beethoven	*Hat man nicht auch Gold beineben* (Fidelio)
H. von Bingen	*Veri floris sub figura*
V. Bellini	*Vaga luna che inargenti*
A. Bliss	*The Golden Cantata*
J. Brahms	*Gold überwiegt die Liebe* (lieder, Op. 48)
F. Delius	*See, The Silver Moonlight kisses The Woods* (A Village Romeo and Juliet)
J. Desprez	*Faute d'Argent* (song)
A. Dvořák	*The Golden Spinning Wheel* (symphonic poem)
	O Silver Moon (Rusalka)
O. Gibbons	*The Silver Swan*
G. F. Handel	*Gold Within the Furnace Try'd* (Susanna)
	Gold is Now Common (Solomon)
	Sound an Alarm! Your Silver Trumpets Sounds (Judas Maccabaeus)
J. Hanus	*Salt is Better than Gold*
F. Lehár	*Gold und Silber* (vals)
P. Mascagni	*O Gentle Flower of Gold* (Cavalleria Rusticana)
H. Purcell	*Golden Sonata*
E. Satie	*Poudre d'or* (piano solo)
D. Shostakovich	*Zolotoy Vek* (*Golden Age*)
J. Sibelius	*Give me no splendour, gold or pomp* (5 Christmas songs, Op. 1)
G. Verdi	*Oro, Quant'oro* (Ernani)
R. Wagner	*Das Rheingold*

material of which an object is made (*e.g.*, crown or coin), but often it applies to unlikely silver objects, such as satellites, sockets or sandals. In other cases it just recalls in a figurative way the qualities of the metal, such as its metallic luster, cold feel to the touch, color or high value. How could one otherwise explain that some songs are about silver heart, sickness, navel or dreams? The same use as a qualifier appears associated with a variety of natural phenomena (night, beach, storm, sunset) or even to more intangible objects such as spirals, words, memories or sounds.

In pop-rock and jazz the list is also long and includes Bad Company, the Beatles, Eva Cassidy, Chick Corea, The Cult, Bob Dylan, Earth, Wind and Fire, the Electric Light Orchestra, Brian Eno, Fairport Convention, Fleetwood Mac, Genesis, Stan Getz, Amanda Lear, Hugh Masekela, Don McLean, Nico, Elvis Presley, Spandau Ballet, Status Quo, Paquito D, Rivera, The Rolling Stones, Sting, Tangerine Dreams, Andreas Vollenweider, Stevie Wonder and Neil Young.

Unlike other elements, gold and silver are abundantly cited in the world of classical music, as can be seen in the compilation in Table 2. We should stress among those works Wagner's opera *Das Rheingold*, in which a golden ring gives both power and a curse.

Boron

Since boron is obtained by reducing borax and the main deposits of this mineral are in California, the music of this element can be no other than a classic cowboy song, *Borax Bill*, recorded by Slim Critchlow in *Cowboy Songs: The Crooked Trail to Holbrook*. It talks about a legendary character, expert on the secret borax sites:

For Borax Bill knew every hill
Where borax lays a-hidin'
And they say that every moonlight night
His ghost goes borax ridin'.

Lithium

Nirvana was a Seattle-based group of worship in the 1990s. Its leader, Kurt Cobain, suffered depressions that ultimately led to his death. The usual therapy for that sickness is based on lithium salts (Fig. 6), and this is probably the reason why Cobain dedicated his song *Lithium* to that element, describing the changing moods that affect a person with bipolar disorder. The lyrics of that song remind us of the masterly description given in the poem *Llega el litio* by José Agustín Goytisolo:

...Mucho haloperidol; pinchazos de antabús
probó electroterapia veinte veces
y salió disparado hacia una vida
que ahora ya no recuerda: quince años
hasta que llegó el litio: quince años
perjudicando a todos los que amaba
pues gastó su dinero y el ajeno
en alcohol en viajes y en delirios.
Pero el litio llegó y está en su sangre

Fig. 6 Medicine based on lithium carbonate. Photograph by the author.

y ahora es su compañero de por vida
hasta la oscuridad o la luz total.‖‖

Another view of the same topic is given by Sting in *Lithium Sunset*:

I've been scattered, I've been shattered
I've been knocked out of the race
But I'll get better
I feel your light upon my face.
Heal my soul
Oh Lithium Sunset...

Carbon

Even if lithium heals depressions, a girl's best friend is another element, carbon. That is what Lynda Williams, *The Physicist Chanteuse*, thinks, according to her song *Carbon is a Girl's Best Friend*. It is a paraphrase of the song immortalized by Carol Channing in the Broadway musical *Gentlemen Prefer Blondes* and popularized by Marilyn Monroe in the film of the same name.*** Williams talks about the carbon cycle, diamond, graphite, carbon 14 assays, nanotechnology and fullerenes. Who can give more? Well, actually Brazilian composer Francisco Mignone managed to do a whole opera based on one allotropic form of carbon: *O contratador de diamantes* (The Diamond Contractor), represented for the first time in Rio de Janeiro in 1924. Even if less well known to the public than his fellow countryman Villa-Lobos, the

‖‖ ...Lots of haloperidol; stings of antabus/ tried electrotherapy twenty times/and was shot out to a life/that he doesn't remember now: fifteen years/until lithium arrived: fifteen years/doing harm to all those he loved/since his and others' money was spent/on alcohol, on trips and on delusions. /But lithium arrived and is in his blood/and is now his mate for life/ until total darkness or light.

*** The author thanks an anonymous referee for providing the information on the Broadway representation of this play.

Mignone's production stands among the most remarkable Brazilian music. An orchestral part of this opera was interpreted prior to its premiere by the Vienna Philharmonic Orchestra under the direction of Richard Strauss, and his best known composition, *Festa das Igrejas* was recorded by Toscanini.

In contrast with the glamour associated with the diamond, the less valued forms of carbon have been a source of suffering for miners and their families, as sung by the flamenco cantaor Antonio Núñez, "El Chocolate", in *Cuando salgo de la mina* (When I get out of the mine).

Fluorine

Dr Snark is a small group from Boston. Their mastery of the concept of electronegativity and their knowledge of the chemical properties of fluorine helped them in composing *Fluorine Atom*. It is a song about unrequited teenage love, from which two representative fragments follow:

She's a fluorine atom!
She never stays in a single state for long!
She bonds energetically with the next cute guy she sees!
Oh, how come this next guy is never me?
She's element nine on the Periodic Table!
...
She's a halogen, symbol is the letter "F"
She's the most electronegative ion
Always needin' a guy to tie on...

Assorted elements

Ornette Coleman's *Allotropes, Elements Different Forms or Same* is a peculiar case of music dedicated to a property of several elements. It can be found in a piano solo version by Joachim Kühn but has not been recorded by its composer, the controversial and innovative saxophonist and creator of the *harmolodic* movement. Although no information has been found on the origins of the title of this piece, it seems clear that Coleman had a higher than average interest in chemistry and the structure of the elements.

In two cases we can find several songs on the same record devoted to one element each. *Opportunity Crosses the Bridge*, by the instrumental trio Forever Einstein is one of those. They play twelve elements: Sb, B, C, En, Eu, H, Hg, Ne, O, P, Ra and Sn. Wouldn't it be interesting to learn what kind of connection they find between the music and the elements? While Neon reminds us of the sound of a music box with a ballerina, hydrogen plays the chimes, boron simulates a lazy hurdy-gurdy, oxygen gets close to an attack of hysteria and antimony brings resonances of a tropical forest.

Elements, by Noxious Emotion, devotes electronic songs to nine elements. The lyrics have nothing to do with the elements and could be qualified as philosophical-oneiric (in *Uranium*, for instance, they ask whether a computer dreams when it is unplugged). They have just used the chemical elements to title the songs in order to be able to write the name of the group with the corresponding chemical symbols (Fig. 7), including X for an undetermined element when required. Their taste for art is reflected on the CD itself, which reproduces an image from Goya's *Saturn Devouring His Children*, as well as on the cover, that shows a fragment of Michelangelo's *The Creation of Adam*.

Among songs that refer to several elements we find a trio formed by oxygen, nitrogen and argon in *Aire*, from the Spanish pop group Mecano. Another trio is found in *Grand Coulee Dam*, from the father of North American folk music, Woody Guthrie. He sang to a dam that generates electricity for chromium, manganese and aluminum factories in Washington and Oregon.

Fig. 7 Noxious Emotion's CD titled *Elements*.

Chamber music for several elements

For a quartet of elements we must turn to *The Demi Song*, interpreted by Pete Seeger (Fig. 8), another mythical representative of the North American folk movement. *Demi* is the colloquial name for a laboratory supervisor, and the song elaborates on the experience of many chemistry students throughout the world, when they face a mixture the composition of which they must determine through chemical analysis. The structure and the music of this song were borrowed from the popular English song *12 Days of Christmas*, in which every verse adds a new line to the previous one. Thus, the second to last verse says:

The eighth time I made it up,
The demi said to me:
"Try another mixture,
What was that explosion?
Have you tried a flame test?
No fluoride,
Who said manganese?
Iron's there in traces,
Chloride isn't there,
And there's one metal more in Group 3."

In the same spirit, the last verse adds yet another line, but in a completely different mood: the demi loses his temper and asks the student to switch to physics.

From the factory of Kraftwerk, a representative group of what was known as techno-pop, we find in *Vitamin* a septet of elements (K, Ca, Fe, Mg, Zn, Se and Co), with accompaniment of organic compounds and a rhythm that may electrify your neurons.

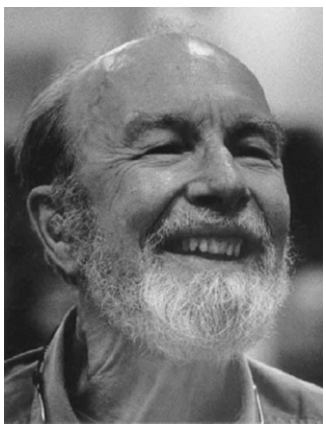

Fig. 8 Pete Seeger, folk singer.

Music for small elemental orchestras

Blackalicious employs up to seventeen elements in their hip-hop theme *Chemical Calisthenics*. Calisthenics comes from the Greek words *kallos*, strength, and *stenos*, beauty, and designs the set of gymnastic exercises needed to make one fit. But the lyrics of that song have more than names of elements and mental exercise. It is a cocktail of words from the fields of physics and chemistry that, at times, seems like elementary scientific pedagogy. For instance: "The theory is that all matter is composed of at least three fundamental particles: protons, electrons, neutrons". Other passages, in contrast, are hard to decipher: "I am calcium plus potassium, magnesium, sodium periodic, sulfate".

Diego Carrasco (Fig. 9), a flamenco *cantaor* from Cádiz, makes word games with the periodic table in *La Química*. In that song the elements form a small orchestra with twenty-four components. There is no waste in the lyrics written by Jesús Bola:†††

Si entre tú y yo existe la Química
Si somos isótopos, niña
Si entre núcleo y corteza
Existe un gran espacio vacío,
Libera mi energía hacia una órbita interior
y combinémonos para hacernos molécula
Covalente, iónica o metálica, me da igual
No quiero catalizadores,
Sólo el efecto de la temperatura.
Dame arsénico, si quieres
pero azufre tú también.
Llevo bario días que belirio por tí
y me siento bisminuto
Me enaboro de tí y no bromeo
Cadmio mío, si a calcio me quieres,
te lo digo en cerio, zinc tí me siento estaño...

Fig. 9 Diego Carrasco, flamenco *cantaor* and performer of the song *La Química*, a word game based on the names of the chemical elements.

The polyfacetic Tom Lehrer (Fig. 10) sang *The Elements*, a real classic among chemists in England and the US. It is told that he performed the song at Harvard, before an audience of university students, accompanying himself at the piano and reciting, at a dizzying pace, the names of the first ninety-two elements. The breathing pauses give a theatrical air to this memorable song, and the only text added to the elements list are two final premonitory sentences:

These are the only ones of which the news has come to Harvard,
And there may be many others but they haven't been discovered.

Fig. 10 Tom Lehrer, famous for his song *The Elements*, in a picture dated 1960.

The periodic table writes its own music

Lejaren Hiller (1924–1994) was a chemist and composer who applied Monte Carlo techniques to the study of the conformations of polymers and to musical composition with computers, a method that was also explored by the Catalan chemist and composer Josep Maria Mestres Quadreny. Andrew Stiller (Fig. 11), disciple of Hiller on the musical side, composed not long ago *A Periodic Table of the Elements*, a literal translation into musical language of the periodic table. Premiered on October 28, 1990 in Philadelphia, it is written for alto flute, English horn, bass clarinet, bassoon, two trumpets, horn, trombone, percussion and five solo strings. A recording can be found on the CD *A Descent into the Maelstrom* performed by the Orchestra 2001.

This work is based on an algorithm that transforms the information concerning each chemical element into a musical fragment, establishing a correspondence between its properties (natural abundance, density, chemical reactivity, chemical affinities, radioactivity, valence, physical state and metallic character) and its musical expression (duration, harmonic density, intensity, orchestration, percussion, note, register and key, respectively). The elements appear in decreasing order of atomic number, starting from Dubnium (element 105) down to hydrogen. Since radioactivity is more frequent among the heavier elements and abundance in nature is greater for the lighter ones, the music is more

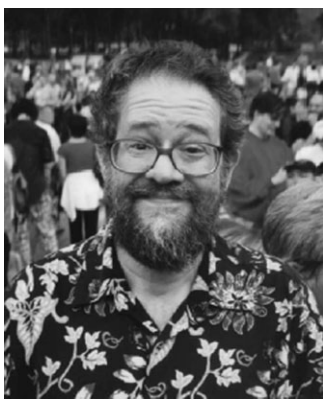

Fig. 11 Andrew Stiller (Washington, DC, 1946), author of *A Periodic Table of the Elements*. Photograph courtesy of A. Stiller.

††† If there is Chemistry between us/If we are isotopes, baby/If between nucleus and cortex/there is a large empty space,/Free my energy to an inner orbit/And let us combine to make ourselves a molecule/Covalent, ionic or metallic, I don't care/No catalysts, please,/only a temperature effect. Give me arsenic if you wish/but suffer [sulfur] you too./I have been in a belirium for several [barium] days/and I feel minute [bismuth]/I am in love [boron] with you and not joking [bromine]/My dear [cadmium], if you should [calcium] love me,/I am serious [cerium], without [zinc] you I feel strange [tin].

syncopated and rich in percussions at the beginning and becomes progressively more melodic as it progresses.

Even if it can at first meet with some resistance from more classical ears, this short piece (barely six minutes long) is seasoned with moments of lyricism.

Mendeleev and music

Mendeleev's connection with the world of music has scarcely been studied, while the interest his work holds for literature and painting is much more extensively documented.[11] We know, though, that in his evening soirées music had an important place and that Beethoven was his favorite composer.[12] In the novelistic biography published by Posin, the musical background to his romance with the young art student Anna Ivanovna Popova was precisely the *Emperor Concerto*, played at the piano by herself. Anna Ivanovna eventually became his second wife.[13]

A story is told that Mendeleev was inspired to organize the elements in his periodic system while listening to Schumann's piano quintet.[14] In the first movement of that chamber work, the second theme repeats a seven-note melody played first by the piano and then by the violoncello. Finally the viola interprets an inversion of the same melody. What seems hard to accept is the part of the story that claims that the piece was being performed by Mendeleev's wife and children, since at the time of the discovery of the periodic table (1869) the children were one and three years old. Even if the story is apocryphal, the analogy of the seven-note melody repeated in different ways by three instruments with the repetition of chemical properties after seven elements‡‡‡ in a list ordered by atomic weight is a pleasing one.

Another musical connection of Mendeleev is Borodin, the best known chemist composer. Borodin settled in Heidelberg in 1860, where he worked with Erlenmeyer and met Mendeleev. The spring of that year they travelled together to Italy (Venice, Verona and Milan), Germany and Switzerland, participated in September in the historical Karlsruhe conference and visited Genoa and Rome during the fall.[15] In spite of the close relationship between the two Russian chemists, Mendeleev's discovery does not seem to have inspired any musical composition by Borodin. Maybe after the chemist composer returned to Russia, at the end of 1862, they lost contact and Mendeleev's publication of the periodic system in 1869 was overlooked by his former friend. Another interesting coincidence is that one of Mendeleev's colleagues in Saint Petersburg was en engineer named Dmitri Boleslavovich Shostakovich, whose son Dmitri Dmitrievich would later become one of the most prominent Russian composers of the 20th century.

To find some music dedicated to Mendeleev we must move to 2002, when Michael Offutt recorded a CD titled *Chemistry Songbag*, probably one of the most interesting "filk" music albums.§§§ Offutt not only wrote the lyrics and music of the songs, but also sings and plays the guitar, the banjo, the bass and the keyboards. Among songs such as *Electron Configuration Polka* or *Redox Blues*, we find *Mendeleev*, a homage to the author of the periodic system. Here are two of the most characteristic strophes:

Who told the elements where to go? Mendeleev!
Who put them in columns and in rows? Mendeleev!
Who was ready, who was able to make a periodic table,
Who was that chemist? Mendeleev!
He wondered if Nature really had a master plan,
If the elements had a pattern that one could understand,
So he bought a bunch of cards and on each one wrote the name
Of an element and its weight, and then he played the game.

Given the scarcity of works devoted to the father of the periodic system, we may also cite here the instrumental piece *Mendeleev* by the Australian group Elaex, which defines it as instrumental chill out music with rock guitar.

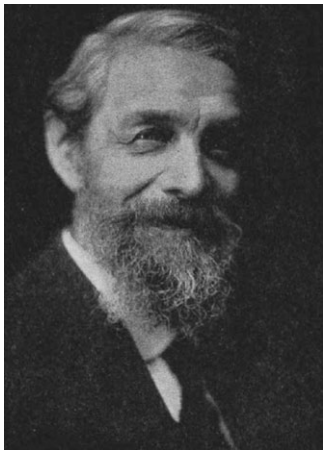

Fig. 12 Georges Urbain (1872–1938), discoverer of lutetium, pianist and composer.

One of the chemists that filled an empty space left by Mendeleev in his periodic table was Georges Urbain (Fig. 12), professor at the University of Paris, specialist in rare earths and discoverer of lutetium in 1907.[16] He also authored texts in such diverse areas as spectrochemistry, coordination chemistry and the theory of chemical reactions, as well as a general chemistry treatise and essays with a theoretical or even philosophical tinge.[17] Apart from his scientific stature and his incursions in painting and sculpture, for his dual role of musician and element discoverer he deserves some comment in this article.

Urbain learned piano in his infancy and conserved his interest in music, especially the works of Bach, Wagner, César Franck and Debussy, but it was after 1921 that his musical vein started to bear fruit. He composed works such as *A la veillée*, *Chanson d'Automne* and *Sur l'herbe*, the latter two based on poems by Verlaine. Later works include several piano suites and pieces for organ. In an essay published in 1924 he claimed that music is more intellectual than sensorial and is, therefore, susceptible to scientific study.[18]

Epilogue

In his book *The Two Cultures*,[19] often cited as a call for a greater interaction between the worlds of science and humanism, C. P. Snow actually writes only about the mutual ignorance of scientists and writers. The only mention

‡‡‡ We must not forget that the noble gases were still unknown and unforeseen.

§§§ A "filk" song is one that is related to science or science fiction and takes the music from a folk song (J. Hartman, www.swil.org/FILKS/Filklore.html, consulted on 5/1/2007).

he makes of music refers to scientists in this way:

Remember, these are very intelligent men. Their culture is in many ways an exacting and admirable one. It doesn't contain much art, with the exception, an important exception, of music.

Unfortunately, he doesn't tell us what data support such an assertion.

The same spirit was manifested by van't Hoff in the opening lecture when he took his chair at the University of Amsterdam, in 1878.[20] The father of stereochemistry argued that imagination plays an important role in scientific activities, as it is required to establish relationships between cause and effect. He also asserts that artistic leanings are a healthy expression of imagination, and quotes several scientists, most of them outstanding for their literary inclinations: Newton, Haüy, Malus, Lalande, Galileo, Poisson, Watt, Davy and Ampère. Among the scientists cited, only the count of Lacépède, zoologist and writer, made incursions in the world of musical composition and published a book entitled *Poétique de la musique*, as well as several books on natural history and physics.[21] It is surprising that van 't Hoff does not refer to his contemporary Borodin, also an organic chemist, who had already had a couple of symphonies performed in public.

In summary, it seems that the most practical of sciences and the most abstract of arts have had even less interaction than scientific and literary cultures, even if some well known exceptions should not be forgotten.[22] This is the case of Urbain, commented on above, who offers this vision of the relationship between music and chemistry:

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.[18]

My limited knowledge of the vast universe of music makes me very cautious about drawing conclusions from the collection of works commented above. Nevertheless, it seems clear that the presence of chemistry in everyday life does not find a correspondence in the titles and contents of the music of the last two centuries. It is particularly surprising that a variety of contemporary composers have been inspired by the classical elements but not by the discovery of the real constituents of matter, by their organization in one of the best known scientific visual representations or by its principal author, Mendeleev. Should we take this as a sign of a lack of scientific culture in our society?

The various genres of popular music seem to be more permeable to the influence of chemistry, as illustrated by the examples collected in this article. For want of a detailed and rigorous sociologic study, two preliminary conclusions could be outlined. First, there is a wide ranging tendency to take scientific terminology lightly, using chemistry as a metaphor for empathy, oxygen as a physical counterpart for an intangible love, or magnetism as a synonym of sexual attraction, always forgetting that poles of the same sign repel each other as strongly as opposite poles feel attraction. On the other hand, an analysis of the song titles, the names of musical groups or of recording companies suggest that a far from negligible portion of the chemical terminology has been incorporated in popular culture.

It would be presumptuous to extrapolate the modest relationship between classical music and chemical elements to other fields of science. It is obvious that there are much closer links between music and physics or mathematics. Let me cite just the outstanding examples of René Descartes, who wrote the book *Compendium musicae* (1650), and of William Herschel, who studied oboe and was a conductor, organ player and composer.[23] In a recent paper by Root-Bernstein the reader can find a more detailed discussion of the relationships between scientific and musical creativities, as well as more references to scientist composers.[24]

From the world of chemistry we can ask ourselves: do we really make efforts to establish connections between our profession and the art forms that bear some relationship to it? Do those of us who teach chemistry in high schools or universities try to stimulate our students to realize that a chemical element, a compound or a reaction can also belong to the world of art? Will a day arrive in which a search for a given compound in chemical databases will provide us with information on paintings, films, and musical or literary works connected in one or another way with that compound?

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