Attempt to Express Scientific Laws through Music

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Abstract

We have made attempt to express scientific laws through music. Title of our first musical work is “From 0 to 31”. We converted decimal numbers from 0 to 31 into musical notes by way of binary numbers form. The work has a structure of a, a', b, a" with Cello Quintet style. Title of our second musical work is “Periodic Table in C major” which is a piano piece for seven hands. In the second work, we converted number of electrons in each electron shell structure of chemical elements from H (Hydrogen) to Uuo (Ununoctium) into the musical notes. We assigned different pitch extent from lower to upper for K, L, M, N, O, P, Q electron shells from inner to outer in the atom. The lowest register C1～D1 is assigned for K shell and one octave higher register C2～F2 is assigned for L shell. Similarly, we assigned C3～G3 for M shell, C4～A4 for N shell, C5～A5 for O shell, C6～G6 for P shell, and C7～F7 for Q shell. We also employed binary numbers form just before conversion into musical tones. We further attempted to express chemical compounds with music. Expressing science through music would shed light on the beauty of science and is expected to broaden science more accessible to ordinary people from different direction scarcely attempted ever.

1. Introduction

In the literature, some methods for composing music on the basis of mathematics or scientific laws have been reported. One of the most famous is reported by Iannis Xenakis (1922 ～ 2001 Greek based French composer, architect) [1]. His piece "Eonta" is composed on the basis of the physics law of Brownian motion. Another piece "Nomos Alpha" is an unaccompanied Cello music made with highly sophisticated mathematics. S. Ohno [2], Japanese biologist, tried to compose DNA-music, where DNA nucleotide sequence is transferred to sequence of music notes. Alex Altair [3] composed a piano piece in which player simulates finger movement for counting binary numbers on the piano keyboard. The piano performance and the sheet music are released through the Internet YouTube;(https://www.youtube.com/watch?v=JcJWbFRPkx8).

However, those reports seem to concentrate on the music itself, and not much intention has been put to express scientific laws through music or to make science more accessible to ordinary people.

In this report, we have composed two pieces of music; “From 0 to 31” and “Periodic Table in C major”, inspired by Alex Altair's Binary Music and extending his method. By expressing science with music, scientific laws are expected to become hearable, and beauty of science can be expressed by the music. Our final goal is to attract people's interests more to science through music.

In composition, we kept some points in mind. If the music was too much complicated which requires highly sophisticated technique, there would be no one to play our work. Therefore, we tried to compose our music which can be played casually even by an amateur player as leisure activity. We then adopted tonal music so as for everyone to feel sympathy to our pieces.

2. Opus 1 "From 0 to 31" A minor, Cello Quintet

2-1. Conversion method from decimal numbers into music

In this work we converted decimal numbers from 0 to 31 into binary numbers, and made up them into Cello Quintet. We adopted the conversion method from numbers to music as follows.

First, we convert decimal numbers from 0 to 31 into

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binary numbers as shown in Fig. 1. Secondly, horizontal digit sequence is rearranged vertically (Fig. 2), so as for the first digit to sit at the lowest position. Thirdly, we separate each digit into individual part as in Fig. 3. Fourthly, "0" is converted to a rest, and "1" is converted to some note (Fig. 4). Fifthly, lines of respective digits (from the first to fifth) are treated as independent five Cello parts (Fig. 5).

Fig. 1 Conversion of decimal numbers from 0 to 31 into five digit binary numbers.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
00000	00001	00010	00011	00100	00101	00110	00111	01000	01001	01010	01011	01100	01101	01110	01111

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
10000	10001	10010	10011	10100	10101	10110	10111	11000	11001	11010	11011	11100	11101	11110	11111

Fig. 2 Rearrangement of horizontal digit sequence of Fig. 1 into vertical notation, so as for the first digit to sit at the lowest position.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
00000	00001	00010	00011	00100	00101	00110	00111	01000	01001	01010	01011	01100	01101	01110	01111

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
10000	10001	10010	10011	10100	10101	10110	10111	11000	11001	11010	11011	11100	11101	11110	11111

Fig. 3 Separating respective digits into five individual parts.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

Fig. 4 The digit of "0" is converted to a rest, and "1" is converted to some note.

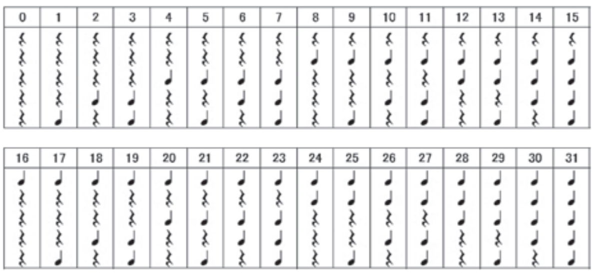
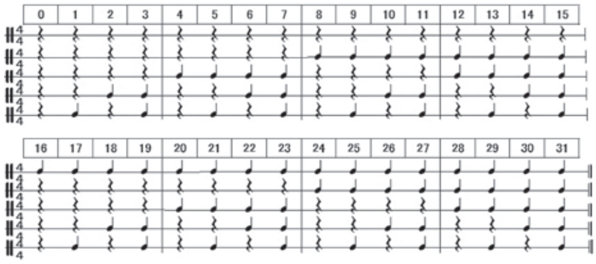


Fig. 5 Lines of respective digits (from the first to fifth) are treated as independent five Cello parts. We adopted metric structure of four (4) quarter-note (4) beats.



If "1" continues side by side, notes can be merged. Or it is even possible to divide "1" into finer multiple notes (Fig. 6). While "0" should be a rest, "1" can be made into any melody or rhythm as long as there exist any notes (Fig. 7).

Fig. 6 In order to make our piece more musical, we decide rhythm, pitch, tonality and melody arbitrarily. If "1" continues side by side, notes can be tied. Or it is even possible to divide "1" into finer multiple notes.

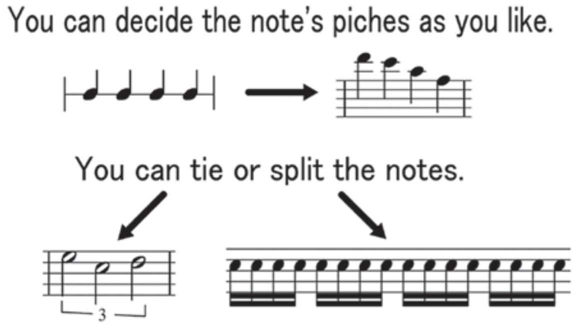
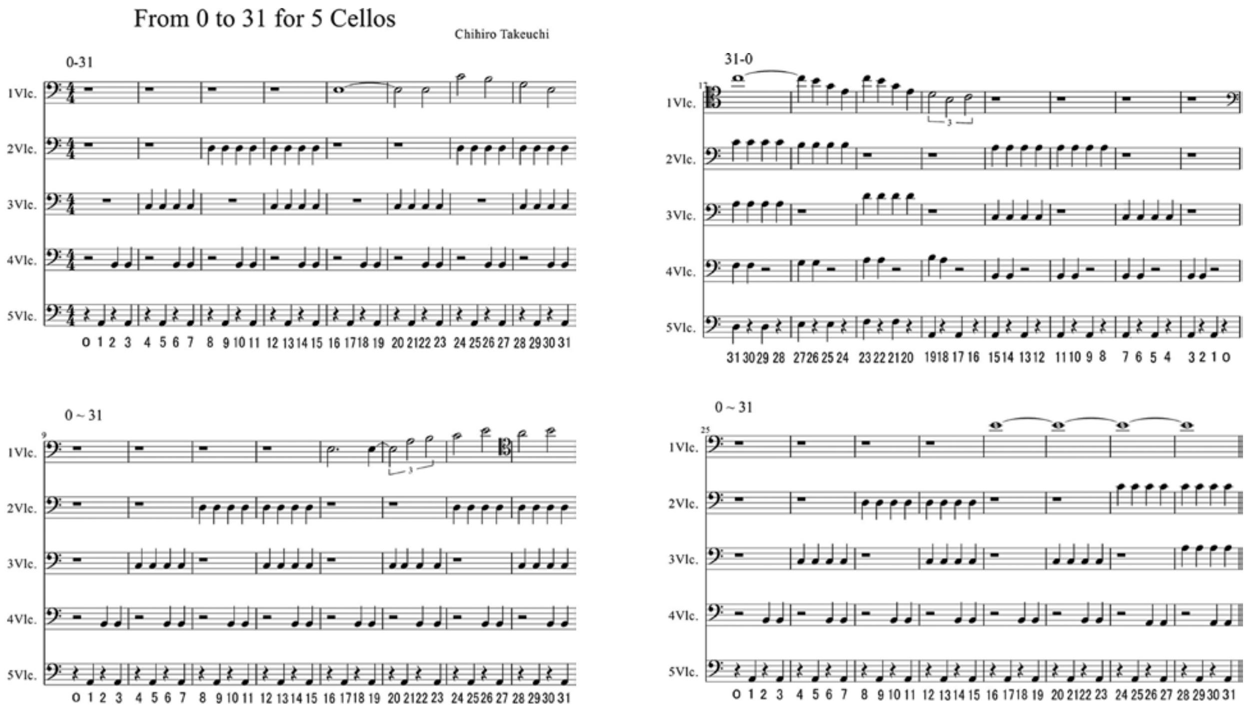


Fig. 7 Sheet music in A minor produced by converting decimal numbers from 0 to 31.

2-2. Tonality, harmony and structure

In order to make the piece more musical, we decide rhythm, pitch, tonality and melody arbitrarily. The completed whole musical score of our piece, "From 0 to 31", is represented in Fig. 8. The work is in A minor with four (4) quarter-note (4) beats. From 2nd to 5th Cello parts play machine-like beats and 1st Cello part plays lyric melody based on the A minor arpeggio. The music goes

Fig. 8 Completed whole musical score with 8 bars phrasing. Here, our music goes sequence from 0 to 31 twice, then go backward from 31 to 0, and finally repeats the sequence from 0 to 31. This makes the music as such structure of a, a', b, a". Although we do not specify playing tempo, suggested tempo is about ♩ = 100.



sequence from 0 to 31 twice, then goes backward from 31 to 0, and finally repeats the sequence from 0 to 31. This makes the music as such structure of a, a', b, a". The total number of bars is 32. At the end the piece is resolved with a tonic chord. Although we do not specify playing tempo, suggested tempo is about ♩ = 100.

If five cellists start to play this music, they would notice that 5th cellist makes sound in every 2nd and 4th beats in a bar, while 4th cellist plays in every 3rd and 4th beats. And then, they would notice that 3rd cellist plays all 4 beats in every 2nd bar, while 2nd cellist makes sound of all 8 beats in the 2 consecutive bars after complete rest in 2 bars. In this way, the player would naturally learn characteristics of binary number mathematics! We also hope that players can enjoy clear contrast between significantly mechanical (mathematical) rhythm and lyric melody. Although our piece can be played by any instruments, we made our music as a Cello Quintet. It may be further arranged or recomposed to be a piano piece, duo with violin and piano, string quintet, woodwind quintet, percussion ensemble, and so on.

3. Opus 2 "Periodic Table in C major", piano piece for seven hands

Periodic table is the very basic item for every materials scientist, first proposed by Dmitri Mendeleev [4]. The periodicity of more than 100 chemical elements originates from the very fundamental physics, i.e. quantum mechanics and Pauli exclusion principal. Every element consists of positively charged central nucleus and surrounding negative electrons attracted by Coulomb's electrical force. According to the quantum mechanics, electrons in any atom can take only separate (quantized) energy states and form the so-called electron shell structure.

The quantum state of an electron is identified by four quantum numbers *n, l, m*, and *s*. Electron main shells are named as K, L, M, N, O, P, Q, R, and so on, corresponding to n = 1, 2, 3, 4, 5, 6, 7, 8, and so on, respectively. In general, the electron distance from the nucleus increases with *n.* Electrons are also nicknamed as *s, p, d, f, g, h*, and so on, respectively according to l = 0, 1, 2, 3, 4, 5, and so on, which form subshell structure (called like 3*d* subshell). Smaller *n* or *l* roughly means lower energy where electrons tend to take energy levels as low as possible. However, due to Pauli exclusion principal, only one electron can occupy any given quantum state designated by one set of four quantum numbers. Thus, there are maximum numbers for electrons to be able to reside in each shell and subshell, example of which is given in Table I. This is the origin of the periodicity of chemical elements.

Table I : Example of maximum number of electrons in each shell and subshell

Shell	Spectroscopic notation	Subshell maximum number of electrons	Shell maximum number of electrons
K	1s	2	2
L	2s	2	8
	2p	6	
M	3s	2	18
	3p	6	
	3d	10	
N	4s	2	32
	4p	6	
	4d	10	
	4f	14	

In this work, we convert number of electrons in each shell to the musical tone, prepare the periodic table of sound and then composed a piano piece for seven hands.

3-1. Conversion method from electron numbers to music

In order to convert electron numbers to music, we assigned different pitch extent from lower to upper for K, L, M, N, O, P, Q shells from inner to outer in the atom. The lowest register C1~D1 is assigned for K shell and one octave higher register C2~F2 is assigned for L shell. Similarly, we assigned C3~G3 for M shell, C4~A4 for N shell, C5~A5 for O shell, C6~G6 for P shell, and C7~F7 for Q shell. Figure 9 shows allocated registers for 7 shells on the piano keyboard. Thus, the 1st piano player performs the Q shell part, 2nd player performs the P shell part, and so on. The largest atomic number so far reported, which is identical with the total number of electrons in the atom, is 118 for Uuo (Ununoctium), which is the last one of the 7th period in the periodic table. Therefore, it is enough for us to consider up to 7 shells and seven piano players for our work.

Fig. 9 Different pitch extent from lower to upper assigned for K, L, M, N, O, P, Q shells from inner to outer in the atom. The lowest register C1~D1 is assigned for K shell and one octave higher register C2~F2 is assigned for L shell. Similarly, we assigned C3~G3 for M shell, C4~A4 for N shell, C5~A5 for O shell, C6~G6 for P shell, and C7~F7 for Q shell.

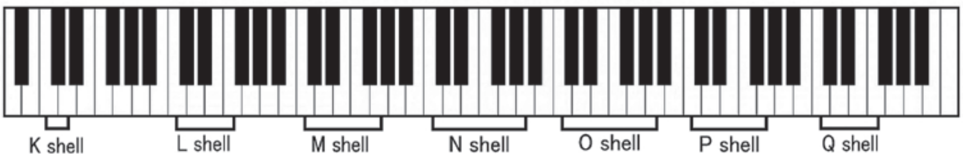
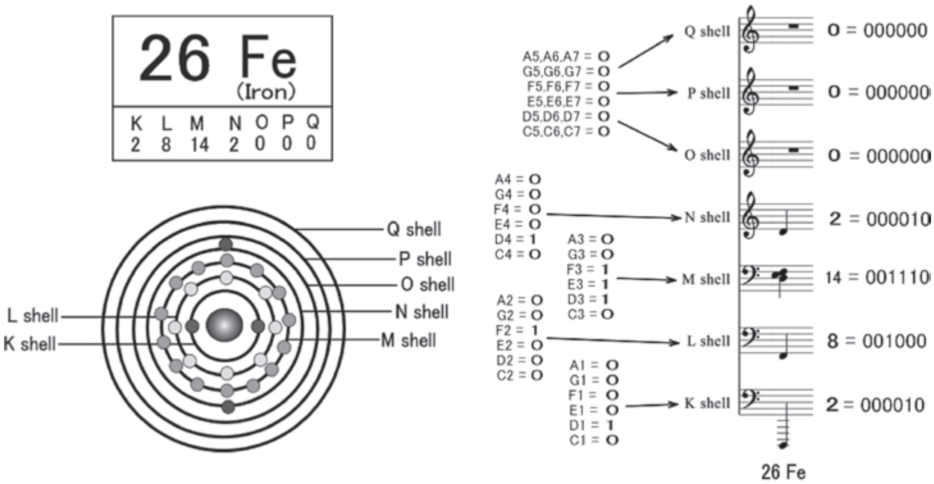


Fig. 10 Example of conversion from number of electrons into actual note in the case of iron (^{26}Fe). In K shell, the number of electrons is 2 which is 000010 in binary expression, and D1 is assigned for the K shell piano part (7th piano player). In L shell, the number of electrons is 8 which is 001000 in binary expression, and F2 is assigned for the L shell piano part (6th piano player). In M shell, the number of electrons is 14 which is 001110 in binary expression, and thus, D3, E3, F3 are assigned for the M shell piano part (5th piano player). In this way, chords often appear especially in M, N, and O shells.



Next, similarly to Opus1, we convert decimal number of electrons in each shell into binary number which is then rearranged vertically so as for the first digit to sit at the lowest position. Further, if the number of the relevant digit is "1"; we then allocate specific pitch (solfa) to each digit, namely, C(do) for the 1st digit, D(re) for the 2nd digit, E(mi) for the 3rd digit, F(fa) for the 4th digit, G(sol) for the 5th digit, and A(la) for the 6th digit. On the other hand, if the number in the digit is "0", it should be a rest.

The actual example is illustrated in Fig. 10 in the case of iron (^{26}Fe). Iron is a familiar metallic element with the atomic number of 26. Although 24 electrons are accommodated in K, L, and M shells in turn from lower energy levels, electron-electron interaction prevents the last 2 electrons from residing at the M shell and forces to put them into the next N shell. This is a common phenomena observed in the so-called transition metal.

In K shell, the number of electrons is 2 which is 000010 in binary expression, and D1 is assigned for the K shell piano part (7th piano player). In L shell, the number of electrons is 8 which is 001000 in binary expression, and F2 is assigned for the L shell piano part (6th piano player). In M shell, the number of electrons is 14 which is 001110 in binary expression, and thus, D3, E3, F3 are assigned for the M shell piano part (5th piano player). In this way, chords often appear especially in M, N, and O shells, although they may be dissonant.

Figure 11 summarizes assigned tones in the N shell which has the largest number of electrons in it. Note that, because of previously mentioned electron-electron interaction, the last tone, A4 (32 electrons in the N shell), does not appear until ^{70}Yb. According to the above mentioned method, we finally composed our music for the periodic table as indicated in Fig. 12. The total number of bars is 118. Although we do not specify playing tempo, suggested tempo is about ♩ = 60〜120.

Fig. 11 All assigned tones in the N shell. Note that, because of electron-electron interaction, the last tone, A4 (32 electrons in N shell), does not appear until ^{70}Yb.

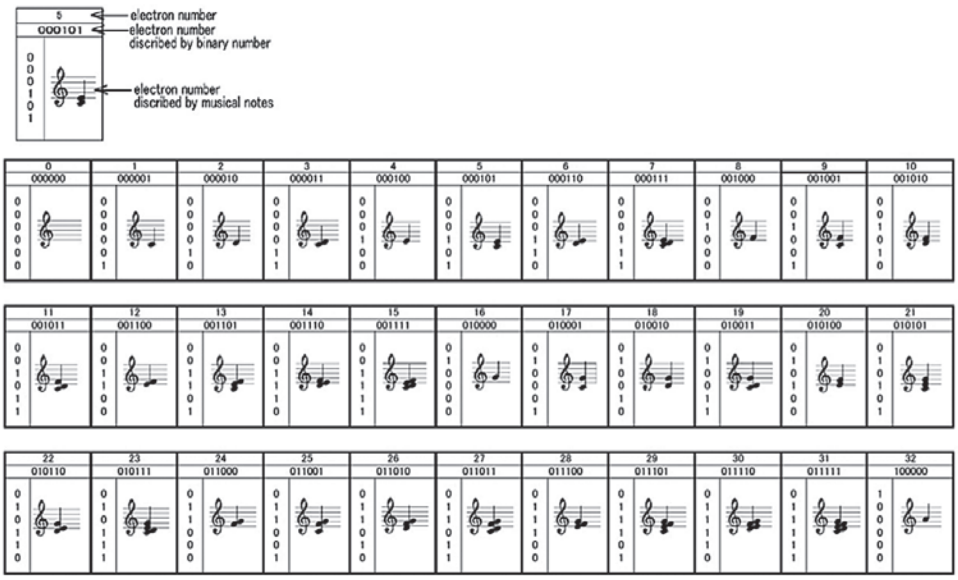
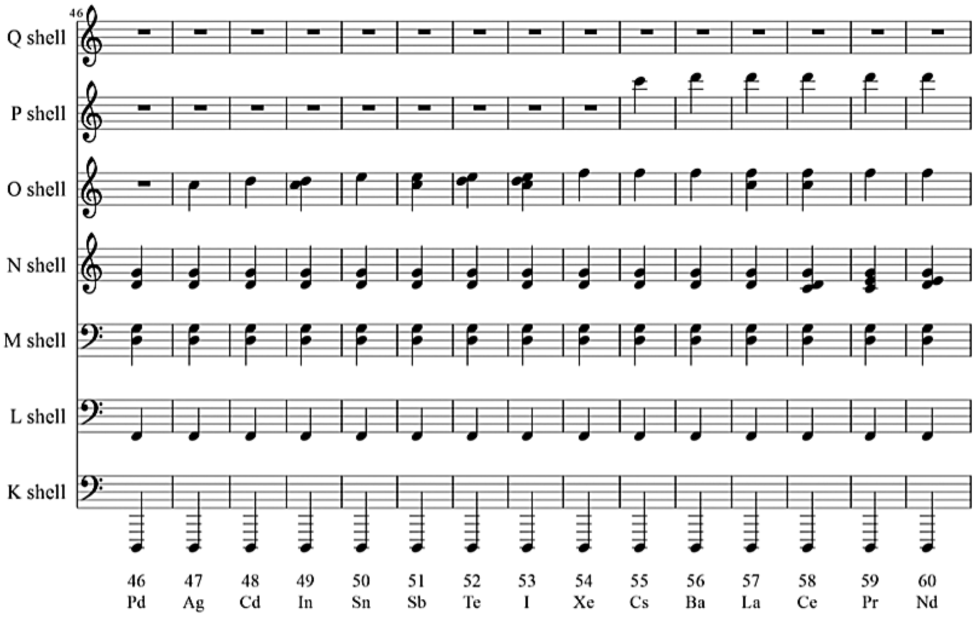
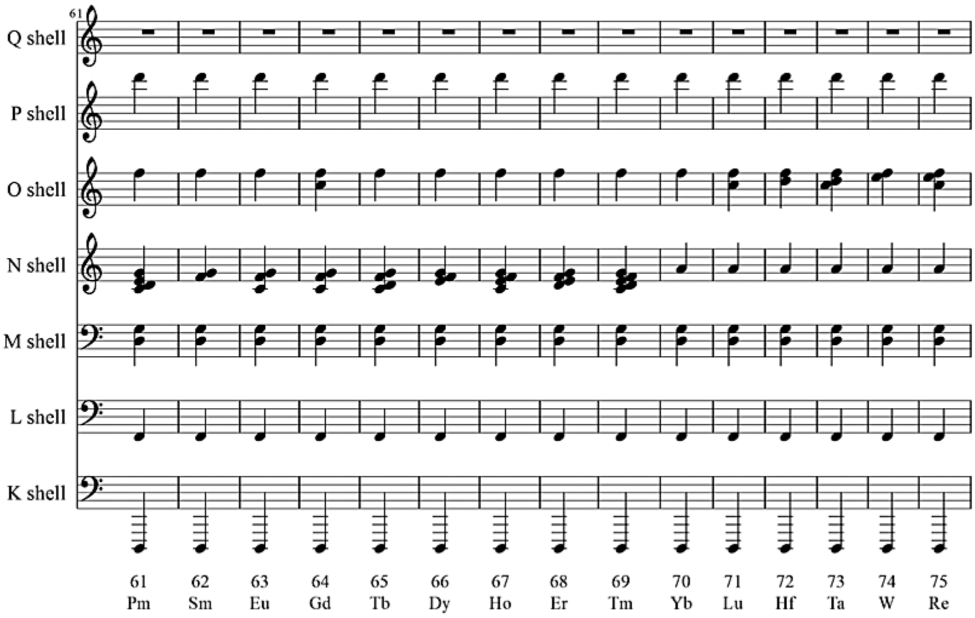
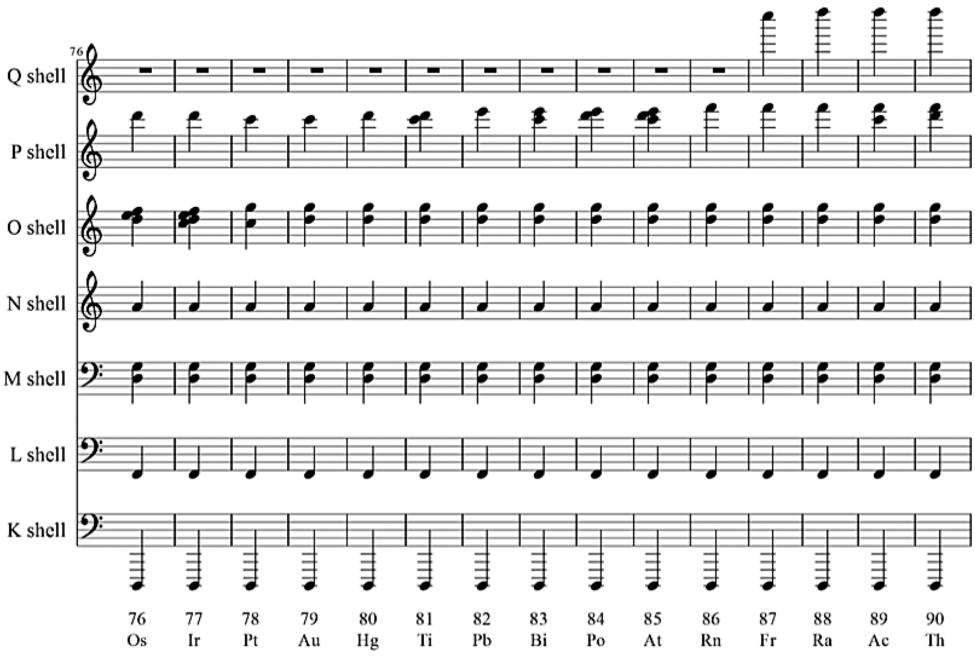


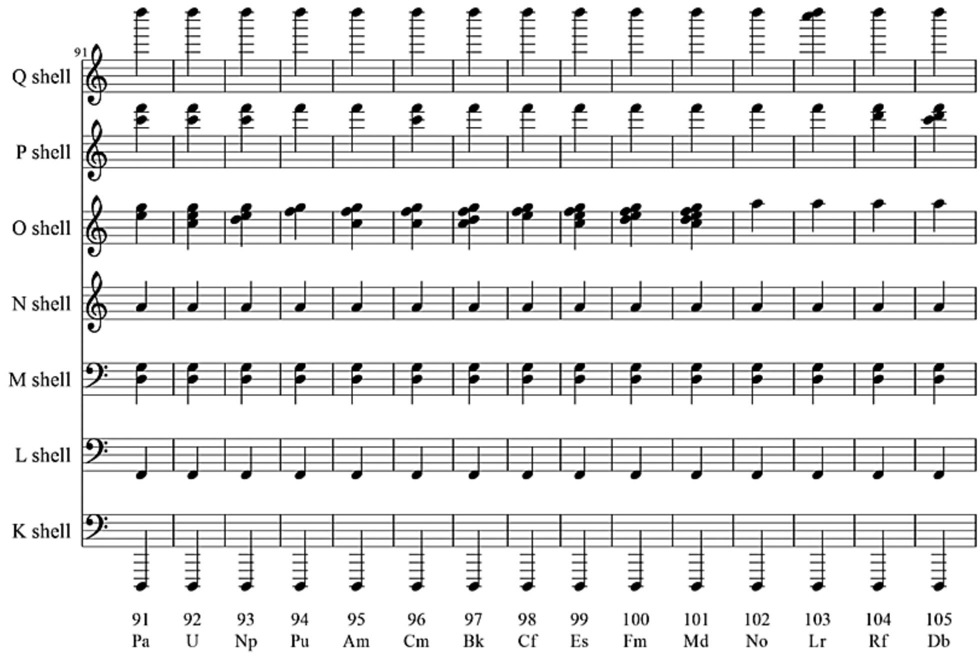
Fig. 12 Completed music score of the Periodic Table in C Major. The total number of bars is 118. Although we do not specify playing tempo, suggested tempo is about ♩ = 60 ～ 120.


31
Q shell
P shell
O shell
N shell
M shell
L shell
K shell
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh


46
Q shell
P shell
O shell
N shell
M shell
L shell
K shell
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
57 La
58 Ce
59 Pr
60 Nd


61
Q shell
P shell
O shell
N shell
M shell
L shell
K shell
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
72 Hf
73 Ta
74 W
75 Re


76
Q shell
P shell
O shell
N shell
M shell
L shell
K shell
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Ti
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
89 Ac
90 Th


91
Q shell
P shell
O shell
N shell
M shell
L shell
K shell
91 Pa
92 U
93 Np
94 Pu
95 Am
96 Cm
97 Bk
98 Cf
99 Es
100 Fm
101 Md
102 No
103 Lr
104 Rf
105 Db


106
Q shell
P shell
O shell
N shell
M shell
L shell
K shell
106 Sg
107 Bh
108 Hs
109 Mt
110 Ds
111 Rg
112 Cn
113 Uut
114 Fl
115 Uup
116 Lv
117 Us
118 Uuo

3-2. Expressing chemical compounds with music

We further attempted to express chemical compounds with music. The method of translating compounds into music is rather straightforward because we have already obtained the *musical periodic table* for every atom as shown in Fig. 12, which would act as an "element-music dictionary". Examples of music for compounds are shown in Fig. 13 for water (H_2O), salt (NaCl), and iron rust (Fe_2O_3) which are common materials in a daily life. In the case of Fe_2O_3, the sound for Fe is played twice and the sound of O is played three times. Although note value is rather arbitrary, a quarter note is used for Fe, and triple O is converted into triplet of quarter notes. Figure 14 indicates the music for the famous high-T_c Y123 superconductor [5]. Seven oxygen atoms are expressed by the septet. In this way, chemical compounds are rhythmically expressed and expected to become fun to learn chemistry and physics. If we further express chemical reaction with music or combine several kinds of compound music, we may be able to produce musical work even telling some story, e. g. nuclear reaction or lifetime of stars.

4. Producing music video

We further produced music videos of our works, "From 0 to 31" and "Periodic Table in C major", in order to demonstrate composition process of the work, and to facilitate to attract public interests to our works. By visualizing composition process and resultant music, relation between music and scientific laws will become easy to understand. Beauty and joy of science and mathematics will be presented by the videos with entertaining atmosphere, too. Everyone in the world will be able to see the videos through the Internet by YouTube or website. Our present two works are released in the following YouTube sites;

From 0 to 31
https://youtu.be/_SJtOjVL4z8

Periodic Table in C major
https://youtu.be/m5AOjtnTGEI

4-1. Equipments for making music video

Video movie was shot with Sony digital HD video camera recorder (HDR-CX535) and the movie was edited by the software "PowerDirector" (Cyberlink). Illustrations

Fig. 13 Further attempt to express chemical compounds with music. The method of converting compounds into music is rather straightforward because we have already obtained the *musical periodic table* for every atom as in Fig. 12. Examples of music for compounds are shown here for water (H_2O), Salt (NaCl), and iron rust (Fe_2O_3) which are common materials in a daily life. In the case of Fe_2O_3, the sound for Fe is played twice and the sound of O is played three times. Although note value is rather arbitrary, a quarter note is used for Fe, and triple O is converted into triplet of quarter notes.

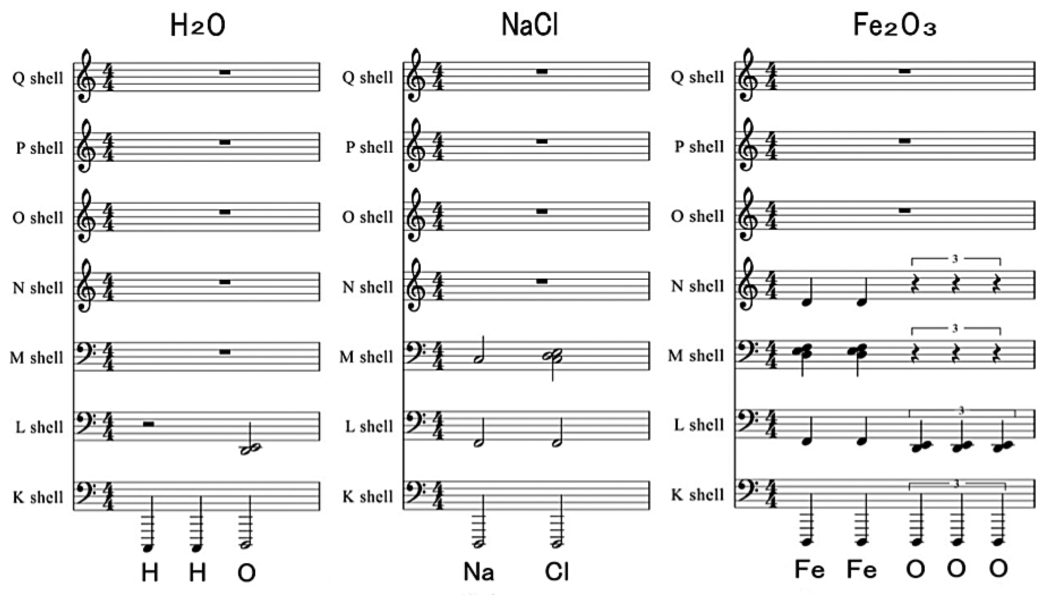
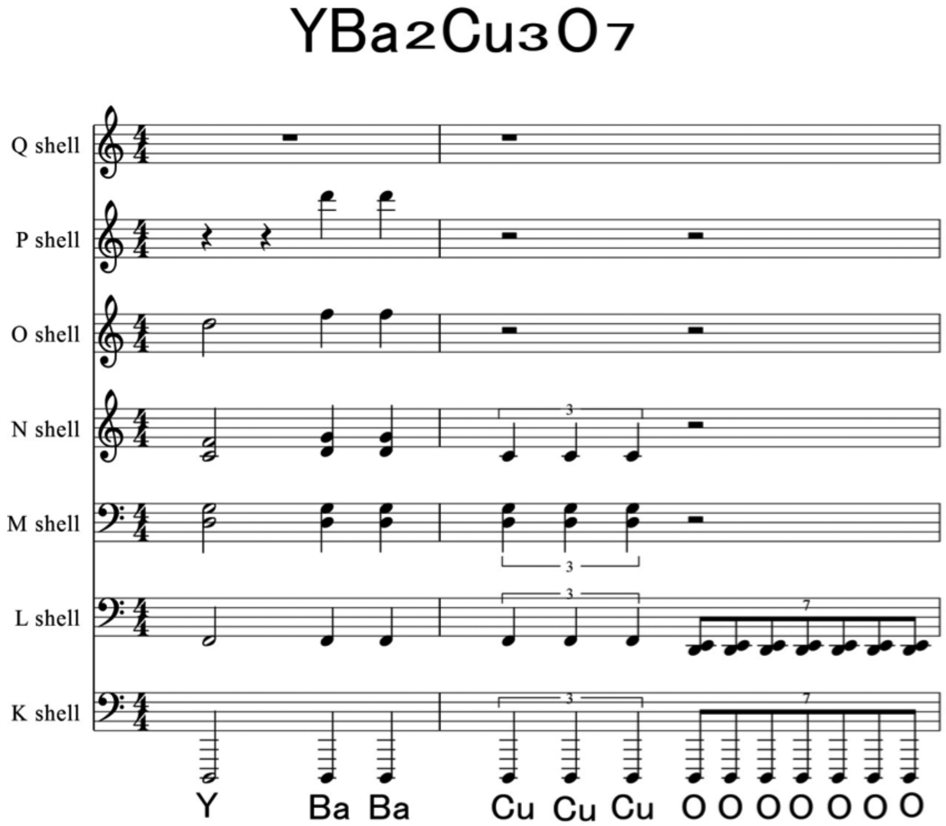


Fig. 14 Music for the famous high-T_c Y123 superconductor. Seven oxygen atoms are expressed by the septet. In this way, chemical compounds are rhythmically expressed and expected to become fun to learn the periodic table and chemical compounds.



were drawn by the "WebArt Designer" attached to the website making software "Homepage Builder" (Justsystem). Musical score was written by the free software "Musescore".

4-2. Performance

Sound source of the music "From 0 to 31" was performed by the Principal Solo Cellist at Hiroshima Symphony Orchestra, Martin Stanzeleit. Cello quintet was made by multiple recording technique. Sound source of the music "Periodic Table in C major" is piano sampling sound incorporated in the "Musescore" software.

5. Significance of expressing science through music

Those who are interested in science would voluntarily read related books, watch TV science show, and go to science museum or scientific lecture meeting. However, if they have no interest in science or mathematics, they would not even come close to such places. Those who are weak in science tend to have images that science is hard to understand and something fearful. In this situation, expressing science through music would shed light on the beauty of science and would broaden science more accessible to ordinary people from different direction rarely attempted so far. Performing our music, for example, as a lobby concert at music hall or cultural center is expected to make it possible to naturally approach to those who are unconcerned with science nor mathematics. It may function as a trigger to have ordinary people become interested in science. We consider that expanding range of people who are interested in science would make soil rich for growing excellent science researchers.

Acknowledgements

We thank Mr. Martin Stanzeleit, Hiroshima Symphony Orchestra who kindly played our music "From 0 to 31". Chihiro Taka also thanks composer Sonoko Arie for her instruction on tonality and harmony.

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