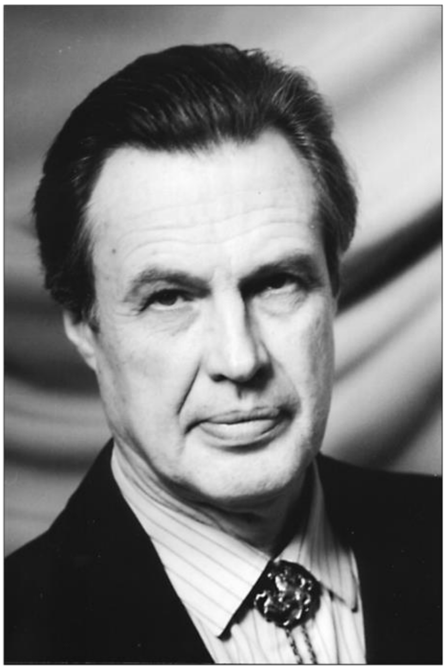
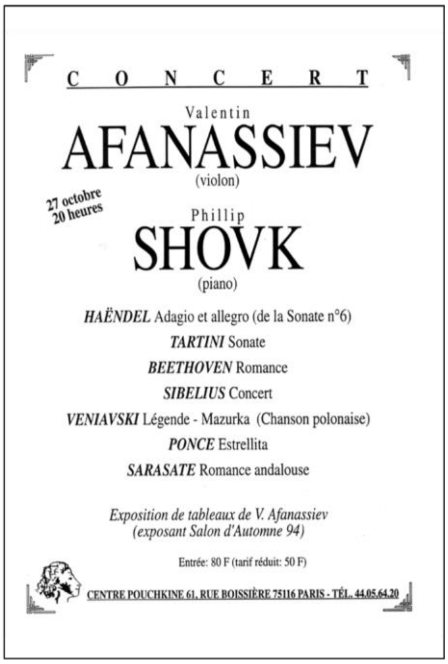
Valentin Afanasiev

Sound-Colour Musical Structure



Valentin Vladimirovich Afanasiev: Musician, artist. Member of the St Petersburg Union of Concert Musicians and the Association of Russian Artists in Paris. Born in 1945, graduated from the violin class of the St Petersburg Conservatoire (1972). Performed as a soloist, in groups and as a concertmaster in Russia and abroad. Gave his first solo concert at the age of thirteen (1957). Contributed to exhibitions of art in Russia, United States, Canada, Germany,
Sweden, France and Italy (since 1974). Owns patents for a number of inventions, including The Means of
Forming a Coloured Image in Russia and Device for Producing Audio-Visual Stimuli in France. Has published widely, including in medical publications of scientific conferences.



C O N C E R T

Valentin

AFANASSIEV

(violon)

27 octobre
20 heures

Phillip

SHOVK

(piano)

HAËNDEL Adagio et allegro (de la Sonate n°6)

TARTINI Sonate

BEETHOVEN Romance

SIBELIUS Concert

VENIAVSKI Légende - Mazurka (Chanson polonaise)

PONCE Estrellita

SARASATE Romance andalouse

Exposition de tableaux de V. Afanassiev
(exposant Salon d'Automne 94)

Entrée: 80 F (tarif réduit: 50 F)

CENTRE POUCHKINE 61, RUE BOISSIÈRE 75116 PARIS - TÉL. 44.05.64.20

Programme of a concert given by Valentin Afanasiev in Paris. 27 October 1994

Valentin Afanasiev

Sound-Colour Musical Structure:

An Elementary Theory of Audio-Visual Stimuli

Russia, Saint-Petersburg
«Russkaya classica», 2004

Cover: Brumeaux (In Mist)
from Valentin Afanasiev's *Scriabiniana* cycle (1997)

ISBN 5-93205-014-4

Some opinions on Valentin Afanasiev s research:

Valentin Afanasievs work addresses the complex problem of the perception of sound and colour signals by the brain. The constructed mathematical model incorporates an algorithm allowing the practical and adequate realisation of a convertible link between a musical phrase and a colour composition. It opens up the possibility of the use of the model in both scientific and applied purposes (manufacturing, medicine, etc.). The importance of this work for the creation of new synthetic forms of musical and fine arts also deserves recognition.

I very much hope that the author, who works successfully both in music and in fine art, is able to realise his extremely interesting concepts as soon as possible.

Y. A. RYZHOV
President of the International University of Engineering, member of the Russian Academy of Sciences

Valentin Afanasievs discovery is of crucial importance for the development of colour-light musical art, as dreamt by so many great musicians and scholars of various periods. New opportunities also arise with regard to the training of musicians, music teachers, artists and computer art experts. Fresh content will be added to the work of musical theatres and orchestras, helping to make serious art more accessible to the general public.

Valentin Afanasievs system of colour-sound relations has no analogues in world practice and is, in every respect, revolutionary. This is the opinion of many international experts.

I very much hope that we will not repeat the same mistakes that we did in relation to cybernetics and genetics, the costs of which we are still paying for to this day.

Professor
VLADISLAV CHERNUSHENKO
Rector of the St Petersburg State Conservatoire, People s Artist of the USSR, winner of state prizes

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Translated from the Russian by Kenneth MacInnes.

Contents

The art of the elegant game of sensations although they are excited from without, this game should possess general contactness can only concern the correlation of the various degrees of mood (tension) of the external feeling to which a sensation relates, i.e. in the broad meaning of the word, it can be divided into an artistic game of the sensations of sound and sensations of sight music and the art of paints.

Immanuel Kant

I have come to the belief that each art aspires towards infinite development in its own field and that such an aspiration finally leads us to a limit of art which it cannot cross, for fear of becoming incomprehensible, strange and ridiculous. I have crossed from this belief to another one that any art which has achieved its own aims should offer a helping hand to another, kindred art.

Richard Wagner

A special research of known associations is required, a quest for parallels in the experiences of colour, not only in vision, but the other senses as well touch, smell, taste and, above all, sound. The perception of colour in the form of sound is by no means a new issue; it has often attracted musicians and is also addressed by physicists. By the will of necessity, painters too have finally approached it.

Wassily Kandinsky

Introduction

All our lives are linked to rhythms and are impossible to imagine without rhythms. Our hearts beat rhythmically. Changes in the rhythms of the heartbeat reflect important changes in the psychological state of the human being.

Another rhythmic process playing an important role in our organism is fluctuations in the brain potentials, recorded in the form of an electroencephalogram (EEG). An entire series of rhythms can be distinguished in the EEG, all of which reflect the functional state of man. These rhythms can be arbitrarily changed by means of an external influence. The simplest means of influence is a flickering light or a variable sound.

Other fluctuating influences, such as a variable magnetic field, can also alter the state of a human being. The effect created by magnetic storms is well known. Irritators with variable parameters can thus alter the state of mind. The state of mind can change in different ways delight, annoyance, aggression, inhibitions, etc. Over the centuries, people have made use of variable sound (music, rhythmic sounds), the light of pictures, coloured ornaments, clothes, etc.

Analysing the parameters of the EEG, researchers of functional influences (phono- and photostimulations) on the brain have discovered that the brain can repeat (assimilate) the frequencies of flashes or sounds. Light and sound fluctuations can provoke epileptic activity or even a convulsive attack.

The neurophysiological mechanisms for perceiving light and sound differ. There is no direct correspondence between sounds and colours. Different regions of the brain rework visual and auditory information, extracting different properties. Certain common principles do, however, exist. This particularly concerns the spatial concept of the temporary structure of a sensory flow music in the broad meaning of the word. In the auditory mode, thisis the alteration of tensions in a sound series. In the visual mode, it is the alteration of tensions in a colour series.

A biological reverse link is used to correct disfunctionings of the brain, with the aim of changing the temporary structure of the EEG. This method is based on the following principle. The cells convey signals to one another with the help of electric impulses. Coming into contact with a neuron, each impulse changes the electric properties of the nerve cell, generating a minor potential. In order to fulfil a certain function, the brain cells work synchronously, like musicians in an orchestra. This synchronous movement creates a melody , which can be heard on the surface of the head, reflected in the form of fluctuations in the bioelectric potential of the brain.

Cases of brain disturbances imply that the orchestra is falling out of tune. The melody of the brain needs to be tuned with the help of a biological reverse link.

Numerous studies have helped to objectivise the influence of music on man. Different works of music influence the EEG waves in different ways. Transposing the EEG as a time series of the potential of the brain into a temporary acoustic series allows the time structure of the EEG to be employed as a biological reverse link.

Various researches have shown that electromagnetic emanations and flexible fields (mechanical vibrations) in a diapason of frequencies ranging from ultra-low to ultra-high act on living organisms in an identical manner. The simultaneous impact of musical consonances and the tonal relations of coloured light is particularly interesting.

The modern musical structure, with a standard value of A of the first octave equal to 440 Hz, represents a gamut (geometric progression) in a diapason of frequencies ranging from 27.5 Hz (A of a sub-counter-octave) to 3,520 Hz (A of the fourth octave).

Continuing this geometric progression and passing ultra-sound frequencies, radio waves and infra-red rays, we encounter a field of visible rays, a nominal thirty-eighth octave, in a diapason of frequencies ranging from ~ 3.92 10^{14} Hz to 7.87 10^{14} Hz, in which A corresponds to the colour blue =6.19 10^{14} Hz.

This fact may be of little significance per se. We do not, psychologically, compare and contrast a definite sound fluctuation with a definite colour. Completely different associations are observed in different people. In music, however, a 1:2 relationship is regarded by everyone as the same note, only in different octaves. There is an analogy here with the perception of the same colour tone in combinations with an achromatic tone, for example brown-redpink.

A musical series is systematised so that the step-by-step increase in the intervals (in the melodic exposition) corresponds to the increase in the tension of the irritator (which is the sounds). The picture changes in an harmonic exposition (simultaneous phonation), where the tension weakens by degree of the increase in the interval from the minor second to the pure quart.

Regarding colour, there is a clear growth in the relative tension in the colour spectrum circle, from any initial colour to its exact opposite.

When combined with the conditions of geometric progression, the above facts lie at the heart of the aesthetic interpretation of the relationships of the fundamental properties of music and painting.

How can the concept of a work of art arise?

The incentive for the creation of a work of art can be either an external factor or an internal experience without any visible external reason. With regard to external factors, we can think of the following example beautiful clouds and majestic mountains. Some things we like better, some things we like less. An artist chooses nature according to his own tastes, intuitively feeling a certain order which, developed by his talent, can turn into a work of art.

An internal experience directed on the creation of a work of art, inside itself, through an internal creative process, also creates an order ready to turn into a work of art.

Art can be thus be regarded as a symbiosis of the irrational and the rational. With the help of the will of the artist-musician, some still incomprehensible internal promptings (das Ding an sich) will be transformed into a work of art (phenomenon) realised in the material of sound or colour.

Something similar can also be seen in mathematics. Alexei Losev claims: Music and mathematics are the one and the same in the sense of the idealness of the sphere to which they both belong. It is worth recalling the legend of the origin of mathematics 2 apples + 2 apples = 4. This is a clear example of the empirical expression of a numerical relationship. Mathematics, however, also becomes an instrument of abstract thinking; its basic laws can be extrapolated onto any subjects. What is more, these subjects can be completely different sounds, colours, geometrical relations, etc.

People learnt to direct sounds a long time ago probably because man is himself capable of reproducing them with his voice. But the concept of music does not contain the word sound , nor is it limited to just sound. We often refer to music in poetry, painting, dance, etc.

From the point of view of acoustics, music is a series of tensions of sound material. There are various different degrees of tensions, ranging from minimal to maximal. These tensions can be shown in the form of a consecutive

movement of sounds from one to another (in a melody) or in a simultaneous sound (intervals and chords).

We observe a similar picture with colour. In the relations between different colours, we also see different degrees of tensions from minimal to maximal.

In Immanuel Kant s interpretations of aesthetic preconditions, art is a projection for the subjective harmony of our capabilities. For the composer, sounds are the object into which he invests (projects) the aesthetically determined movements of his soul. These sounds are recorded in a definite manner in the sheet music. The performer of a work of music deciphers this recording, bringing the experiences of the composer, expressed in definite combinations of sounds, to the listener. This implies that any form of notes (essentially, a system of symbols) contains a definite algorithm, which is manifested during the performance of a work of music.

The internal order to which we have only just referred, serving as the reason for the algorithm manifested in sounds, can also be manifested through colour relations and relations of geometrical orientations. This recalls Immanuel Kant s concept of das Ding an sich, phenomena and the noumenal and phenomenal worlds.

There is an interesting example. Those who are blind from birth find their way around the world with the help of touch and hearing. If it were possible to give them sight, they would have much greater opportunities to perceive. Although the one and the same subject can be perceived in different ways by touch and sight, the sum of these feelings (touch and sight) contributes to more complete information proceeding from the object, increasing it incomparably.

Arts are born and die. The once great art of the national oral epos, for example, virtually disappeared with the invention of book printing. The art of photography and cinema were born, first as black-and-white and then as colour. The art of abstract painting appeared in 1910 a form of the music of colour. Years before this, Vincent van Gogh said that painting would only be able to scale even greater heights when it came as close as possible to music.

Sound music, which we now know and to which have grown accustomed, is, of course, self-sufficient just like the art of black-and-white graphic art. There is generally no need to colour it. There are other excellent examples, like Vincent van Gogh s Prisoners Exercising (after Gustave Dore s engraving) or Johann Sebastian Bach s Chaconne, written by the composer for a violin solo to which accompaniments were subsequently written by Robert Schumann and Felix Mendelssohn. Chaconne is also performed by symphonic orchestra.

Combinations of various forms of the arts are even encountered in the oeuvres of the one and the same master painting and sculpture (Mikhail

Vrubel, Michelangelo, Aristide Maillol) or painting and music (Mikalojus Ciurlionis, Mikhail Matiushin, Paul Klee).

There is a whole body of literature on the creation of art aspiring to join sound and coloured light in something united or rigidly connected, just as space and time are rigidly connected by the Lorentz-Poincare-Einstein theory. Incidentally, categories of space and time were once believed to be independent of each other or “self-sufficient”.

Dialectic necessity thus leads to the appearance of the audio-visual art of music.

We have dreamt of uniting sounds and colour — according to their common laws — for over two hundred and fifty years. Among those who have conducted intensive (to one extent or another) work aimed at bringing about this dream are Newton, Gretry, Rameau, Euler, Goethe, Wagner, Helmholtz, Scriabin, Ostwald, Theremin and Einstein. This is only in the modern age. In ancient times, Aristotle stated that “according to the pleasantness of their correspondences, colours can relate to one another like musical accords and be mutually proportional.”

It is only now, however, that one can fully assert the establishment of correspondences of colour-sound relations. A system has appeared and a new form of art born on its basis. Only at first sight does it seem that its value is only defined by a maximally exact agreement of sound and colour. Every art develops according to its own laws which have, at their heart, something even more profound and, probably, something in common. Passing through the following stages of development — (1) “colour-music”; (2) “visible music”, (3) “audiovisual music” — from stage to stage, accumulating theoretical and practical experience, the real aim of researches and practical decisions, in the field of the art of Music (a complex and monumental system) appears. The value of the complexity of this system consists not only in the fact that the stream of information in the correlations increases by approximately 10% and 90%, but that a dialectic principle (or law) is realised — “quantity crosses over into quality” (it is worth recalling, once again, that the word “music” does not incorporate the concept of “sound” and is not limited to this concept). This is already a completely different form of art, alongside which its forerunners — music and painting (in the sense that we are used to) — are the “evolutionary past”. Something nominally comparable to the impact of a chain reaction appears. There is the influence of not only music (in the original understanding of the world) on the system of colour correlations, but also the influence of the colour relations on the system of sound relations. The principles of musical forms and their elements (motif, phrase, sentence and period), painterly systems and colouristics are manifested in a new way or from an entirely different angle.

Until now, experiments in the field of colour-music were of a subjective nature. The choice of colours for keys was based either on rare occurrences of synopsii (colour sound), or the experimenters were guided by their own understanding of the artistic image or by a momentary mood. At best, things ended with a subjective recording of a tonal sort (key is colour) with these or other colour additions, which were defined by the intuition of the light-artist. Numerous similar attempts gave unsatisfactory results with emotional discrepancies in the perception of the sound and colour series. But the matter lies not only in the colour recording of the tonal, the correspondence of which is virtually impossible at a level of intuitive notions. The laws of music must be distributed equally onto both the sound series and the light-colour series. This is the only possible condition for the correct organisation of sound and colour aimed at achieving an emotional correspondence between sound and colour impressions. The application of internally adequate — by degree of tensions (in this case, it is possible to speak of colour-sound tensions) — intervals, chords and their combinations constantly intensifies the impact on the emotional state. It should be explained at this point that we do not refer to the restriction of freedom or the mechanical substitution of a creator’s personality, but the orderly arrangement of the principles lying within the very essence of a musical harmony and contributing to its boundless expansion of the sphere of creative opportunities of the artist.

The colour-sound theory is quite complex. In short, it can be said that only the correlations of the degrees of colour tensions corresponding to the tensions in the relationships of sounds have been found. In a musical harmony, these are functional relations — tonic, subdominant and dominant.

As colour and sound are different in nature, the system of the relations of colours is represented by three branches — functional inclinations, tonal and melodic. In other words, the one and the same sound can, in a certain sense, be characterised by three different colours, depending on what position the sound occupies:

— in the space of the functional inclinations; — in the space of the key; — in the space of the melody.

All this occurs because the colours of the spectrum (unlike the sound series) are arranged consecutively (gradually) in the sense of frequencies and “kinship”.

We observe a different picture in the relationship of sounds. Frequencies are arranged in proportion to the order of the chromatic gamut, while the degree of maximum kinship of sounds is determined by the interval of the quint. Two colours located next to one another in the spectrum are not a dis-

sonance (contrast). The two neighbouring sounds of the chromatic scale, sounding simultaneously, represent a strong dissonance (a minor second).

In colourology, dissonance is opposite colours.

The geometry of the directions of rays of coloured light also has immense emotional value. The geometrical principles of colour directions can be seen in the three aforementioned positions. In nominal terms, parallel beams of light (consonance) or perpendicularly intersecting ones (dissonance). Each of them is of a certain colour.

The degrees of geometrical tensions are determined by the angular steps of the directions of the beams of light, caused by the corresponding principles of the proposed audio-visual system. The system is based on harmony-functional relations and the principles of dodecaphonics and aleatorics. All this allows any piece of music to be performed with an emotionally adequate accompaniment of light — including, naturally, Alexander Scriabin’s symphonic poem Prom*é*th*é*e (Le Po*è*me du feu).

16/III 1913.

А. Скрябинъ

A. SCRIÀBINE

PROMÉTHÉE
LE POÈME DU FEU

POUR GRAND ORCHESTRE ET PIANO
AVEC ORGUE, CHOEURS
ET CLAVIER À LUMIÈRES

OP. 60

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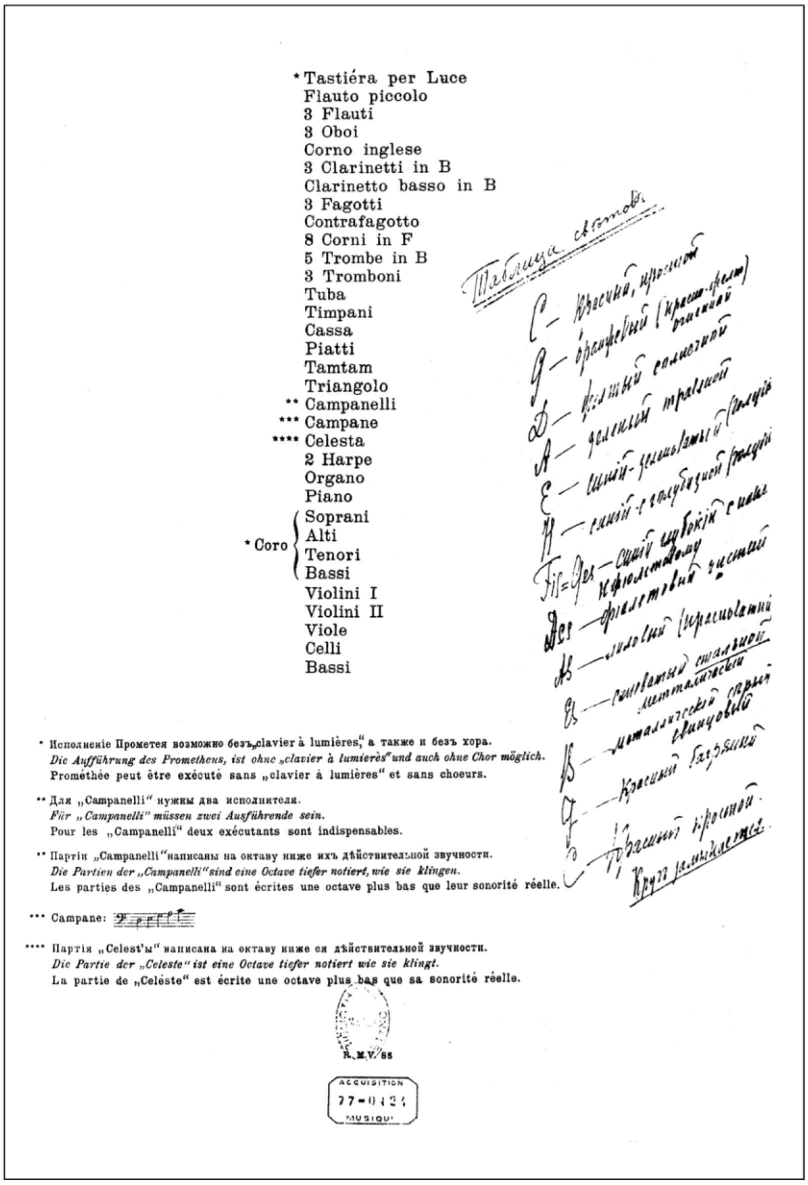
Title page of the score of Prométhée autographed by Alexander Scriabin



* Tastiéra per Luce
Flauto piccolo
3 Flauti
3 Oboi
Corno inglese
3 Clarinetti in B
Clarinetto basso in B
3 Fagotti
Contrafagotto
8 Corni in F
5 Trombe in B
3 Tromboni
Tuba
Timpani
Cassa
Piatti
Tamtam
Triangolo
** Campanelli
*** Campane
**** Celesta
2 Harpe
Organo
Piano
* Coro { Soprani, Alti, Tenori, Bassi }
Violini I
Violini II
Viole
Celli
Bassi

Таблица светов.
C — красный, ярко...
G — оранжевый (красно-ярко...) огненный
D — желтый солнечный
A — зеленый травяной
E — синий-зеленоватый (голубой)
H — синий с голубизной (голубой)
Fis=Ges — синий глубокий с ни... к фиолетовому
Des — фиолетовый чистый
As — лиловый (красноватый)
Es — синеватый стальной металлический
B — металлический серый свинцовый
F — красный багровый
C — красный ярко...
Круг замыкается.

* Исполненіе Прометея возможно безъ „clavier à lumières" а также и безъ хора.
Die Aufführung des Prometheus, ist ohne „clavier à lumierès" und auch ohne Chor möglich.
Prométhée peut être exécuté sans „clavier à lumières" et sans choeurs.

** Для „Campanelli" нужны два исполнителя.
Für „Campanelli" müssen zwei Ausführende sein.
Pour les „Campanelli" deux exécutants sont indispensables.

** Партіи „Campanelli" написаны на октаву ниже ихъ дѣйствительной звучности.
Die Partien der „Campanelli" sind eine Octave tiefer notiert, wie sie klingen.
Les parties des „Campanelli" sont écrites une octave plus bas que leur sonorité réelle.

*** Campane:

**** Партія „Celest'ы" написана на октаву ниже ея дѣйствительной звучности.
Die Partie der „Celeste" ist eine Octave tiefer notiert wie sie klingt.
La partie de „Celéste" est écrite une octave plus bas que sa sonorité réelle.

R.M.V. 85
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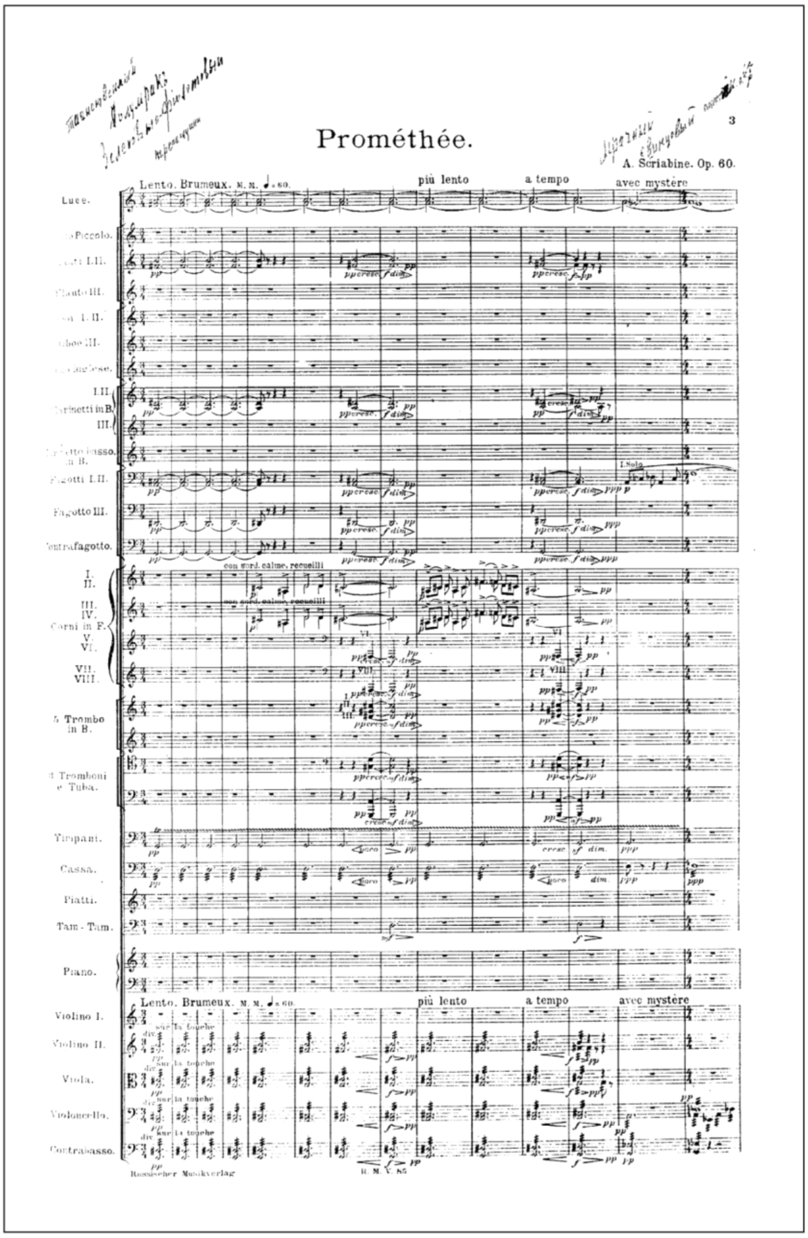
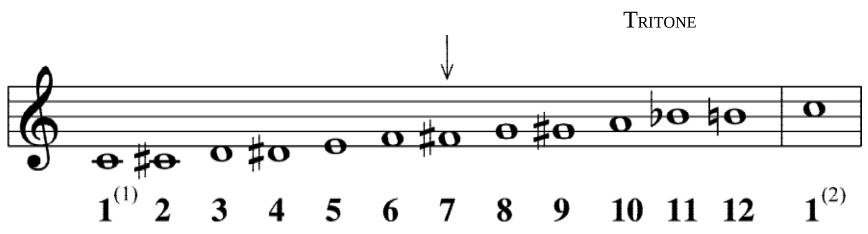
Table of colour-tonal analogies inserted by Alexander Scriabin in the score of Prom*é*th*é*e.
The composer said of these and subsequent instructions concerning colour-sound correspondences:
"I think that when the light symphony eventually comes to pass, it will be possible to correct all this."

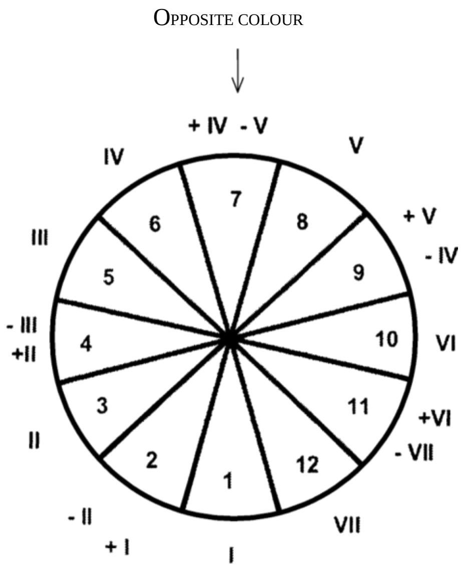


The line of the Luce part on the first page of the score of Prométhée —
a template for the composer's recording of the tonal aspect of a work of light-sound music.

The Space of the Melody

The evolution of musical art has led to the construction of the modern sound system in the form of an octave divided equally into twelve semitones and known as the temperated scale. Any harmony based on this can be reproduced in twelve keys. The consecutive interchange of sounds along the semitones represents a chromatic scale. Comparing this scale to a chromatic (colour) circle appears to show their complete identicalness. Like the colour circle, a chromatic scale effects a gradual (linear) movement ("ascent") along the semitones to the maximum dissonance in their middle (the tritone or opposite colour), as well as a smooth and gradual movement ("descent") to the initial tone or colour, rounding off the cycle.





1 Red
2 Red-orange
3 Orange
4 Orange-yellow
5 Yellow
6 Yellow-green
7 Green
8 Green-blue 9 Blue
10 Blue-violet
11 Violet
12 Violet-red

As practice has shown, there is no direct conformity between sounds and colours. Although the correlation of sound and colour — in the sense of the choice of tonic — is determined by the composer/artist creating the colour- or light-music work, the colour relations should correspond to the sound relations. That is why it is already possible (and necessary) to start building major and minor sequences from any sound or colour, proceeding from the principle of tone, tone, semitone, tone, tone, tone, semitone (major); or tone, semitone, tone, tone, semitone, tone, tone (natural minor). The harmonic minor and major, the melodic minor and (if necessary) any other harmonies are also constructed in accordance with their intrastructural principles.

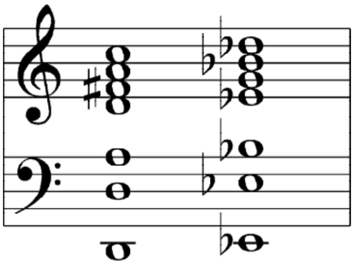
With respect to the consecutive and parallel reproduction of sounds and colours, all the aforementioned is correct in relation to all aspects of linearness in music, including aleatoric opuses.

The "full" identification of the shown relations of the colour circle and the sound sequence ends here. One can say that the melody "reigns, but does not rule."

The Space of the Keys

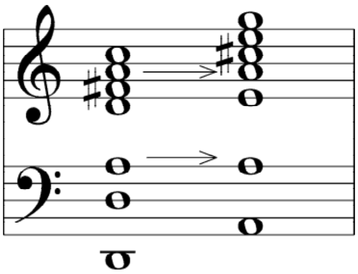
Getting down to an analysis of the cited examples (chromatic circle and chromatic scale) from the point of view of a simultaneous sounding of (harmonic) intervals, we immediately bring out the discrepancy of relations between the neighbouring sounds and the neighbouring colours. The two simultaneously sounding neighbouring sounds (minor second) represent a dissonance, as the effect of beating is manifested, and they are composed of elements (harmonics) far from kinship relations, whereas two neighbouring colours represent the relations of kindred components (elements) and can be regarded and defined as consonance.

For example, the third and fourth sounds in overtone relations represent incompatible combinations:



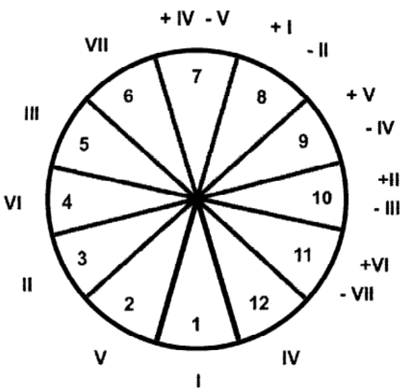
The third and fourth colours — orange and orange-yellow — are both represented as a mixture of red and yellow colours, in maximally close proportional relations.

As far as sounds are concerned, their maximal kinship is determined by the “pure quint” interval:



(The arrows indicate the common components of these sounds the overtones.)

Analysing the chromatic circle and the relations of sounds from the point of view of “kinship”, we get the following interval sequence:



1 Red

2 Red-orange

3 Orange

4 Orange-yellow

5 Yellow

6 Yellow-green

7 Green

8 Green-blue

9 Blue

10 Blue-violet

11 Violet

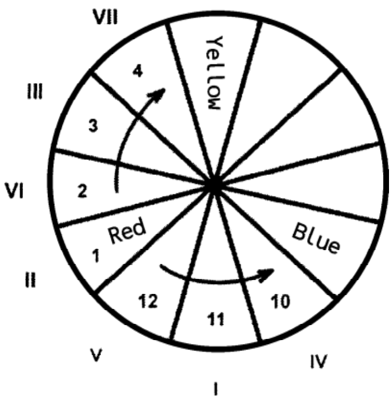
12 Violet-red

This sequence represents the “Pythagorean structure” principle, formed by the consecutive construction of a quint and the reduction of the received sounds by octaval decreasing or increasing to within the bounds of one octaval sound series. IV, I, V, II, VI, III, VII or violet-red, red, red-orange, orange, orange-yellow, yellow, yellow-green, reduced to one octave, represent a seven-step harmony: I, II, III, IV, V, VI, VII or red, orange, yellow, violetred, red-orange, orange-yellow, yellow-green.

Now a little but about the relations of key and harmony.

Key is the height of the sounds of a harmony determined by the position of the main tone (tonic) at a certain step in the sound-series musical system. The concept of harmony only expresses the correlation of steps of the given sound series in height and their functional interrelation. The concrete height of the sounds of a harmony is determined by the concept of key. The unity of both concepts is expressed by the term of harmonic key.

Examining the sequence of colours designated as IV, I, V, II, VI, III, VII in clockwise direction and comparing, for example, the value I with violet 11, we see that a series has formed, all the colours of which contain the colour red, to one extent or another. A colour key, a “harmonic key” range (red is not encountered outside the bounds of this series), has been formed.



A similar picture can be observed when comparing the value I to green 7, where the defining key is a “cold” colour — blue. The clear distinction between keys is thus evident.

Robert Schumann wrote in Characteristics of the Keys (1835): “It cannot be said that a certain feeling, if it should be full expressed, demands to be translated into music by means of this and no other key. One cannot, however, agree with those who assert that everything can be expressed in each key.”

Revolving the colour circle and establishing the correspondences of colour-sound steps necessary for creative resolutions, we determine the “colour-sound” keys necessary from the point of view of kinship. When shifting the colour circle by one sector, we always receive a related colour key in analogy to the relations of the sounds in the seven-step harmony.

The shown harmony, demonstrated on the base of the sound series received by a consecutive construction of the quint intervals, should be formally qualified as major: $I^{(1)}$, II, III, IV, V, VI, VII, $I^{(2)}$, i.e. tone, tone, semitone, tone, tone, tone, semitone.

The parallel minor (maximum degree of kinship) has an identical sound (and, naturally, colour) structure — notwithstanding the different functional value of each sound-colour: $I^{(1)}$, II,-III, IV, V, -VI, -VII, $I^{(2)}$, i.e. tone, semitone, tone, tone, semitone, tone, tone. It is arranged lower by a minor third. The first step of the major becomes the third step of the parallel minor. In this way, the VI major step is represented as the I step of the minor key. All that remains now is to transfer, with another turn of the circle, the colour sector of the initial key from, for example, the 11/I major (violet) position to the 2/I (red-orange) minor position.

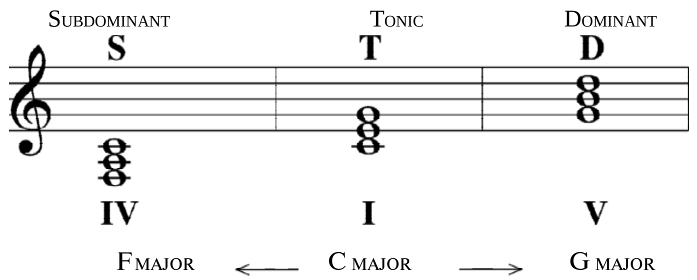
In musicological practice, the major and minor relations are defined as light and shade. The position of the third step, i.e. III in the major and -III in the minor (as well as the lower mediant) is of decisive importance.

Closely studying the result, received as a consequence of the colour displacements in relation to the values of the scale of the major and minor harmonies, naturally representing an identical colour composition, we can see how the functions of the colour steps have changed their states. In the state of minor, the third step -III has received a “cold” colour — blue-green — while the third step in the major III is characterised by a “warm” colour — orange.

The habitual characteristics of a minor and major as expressing “sorrow” and “joy” are nominal in nature. Joyous and sorrowful works can be written in both the minor and the major. The strident dance Yablochko (Apple), for example, is in minor.

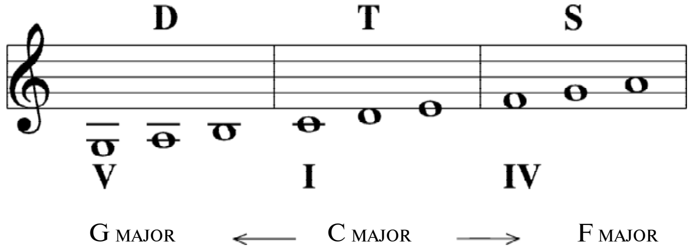
Besides the imperative position of the third step, the internal structure of a major and minor and their opposition are characterised by the relations of the main chords and the relations of the three trichords composing these harmonies.

Take, for example, C major. The chords constructed at the main steps of the harmony I, IV, V contain the attributes of related keys:



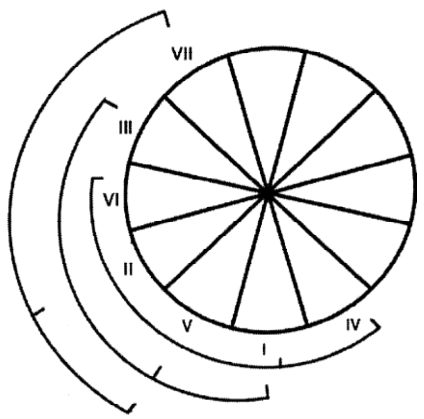
The chords are identical in interval structure — major and minor thirds. The distances between the lower, middle and upper voices are equal to the interval of a quint.

The trichords here consist of uniform intervals — major seconds. The interval between the trichords in relation to the trichord determining the key is a minor second.

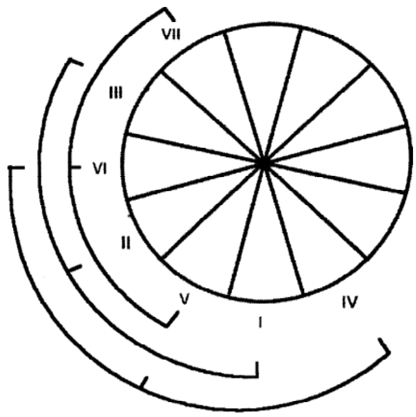


This also applies to the colour series.

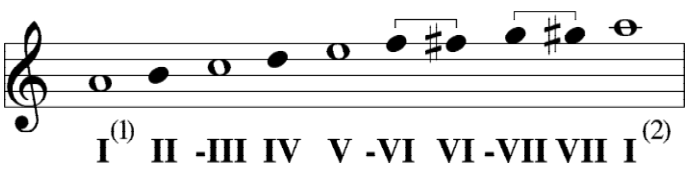
CHORDS:



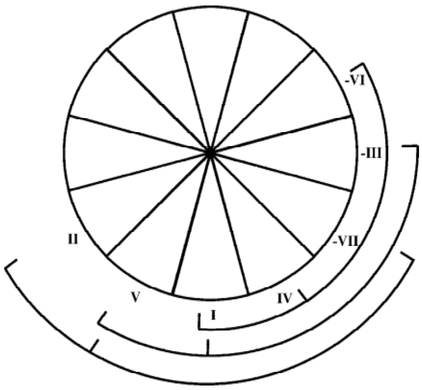
TRICHORDS:



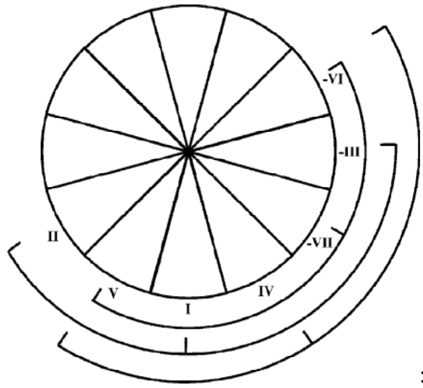
The same reasoning applies to the inner-minor structures. Based on the main steps, the chords here consist of the intervals of the minor and major thirds, while the trichords have a distance between themselves equivalent to a major second. These trichords (except for the one comprising the basis of the harmony) can be deformed in connection with the tinges linked to the principles of the construction of natural, harmonic, melodic minors and the influences of frigia and doria harmonies. All this is reflected in the “full” (combined) minor.



Natural minor, chords:



Natural minor, trichords



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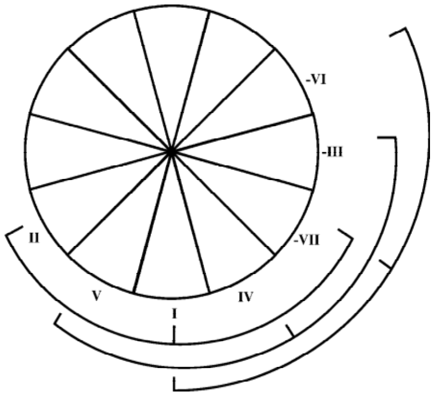
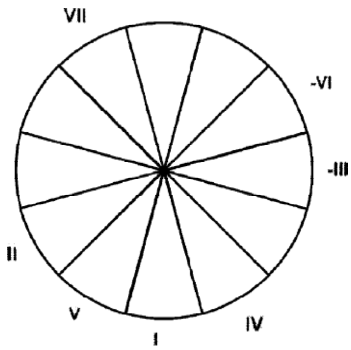
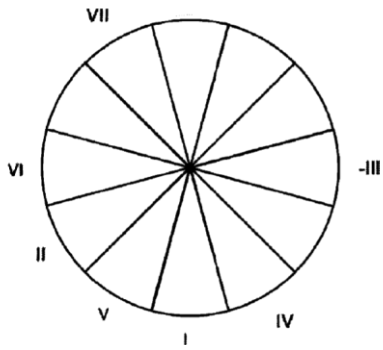
Major trichords in the composition of a parallel minor:



Harmonic minor:

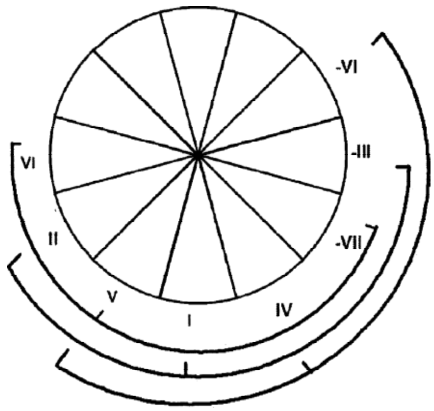


Melodicminor in upward movement:

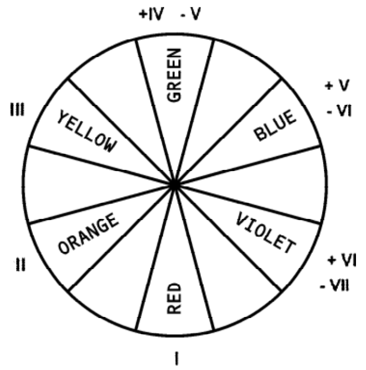


Movement downwards is analogous to the sequence of a natural minor.

The major and minor can also be defined as “hard” and “soft”. Bearing in mind the “softness” of the harmony, uniform trichords can be manifested on the basis of the full (combined) minor:

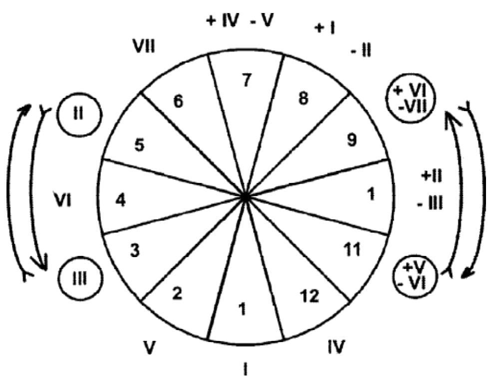


Analysing the colour circle described in the quint sequence, we notice that the relations of the minor second represent a dissonance, as they come close to the relations of opposite colours. The relations of the



major seconds in colour do not, however, look like dissonances (unlike the sound sequences). The whole tone scale constructed here fits into the structure of the chromatic scale shown on page 16:

A slightly altered position of the steps in the colour series would seem to be capable of leading to an elimination of the formed consonancedissonance discrepancies in relation to the basic tone of the harmonic tonal sound series. To this end, it is necessary to change the places of values II and III and, accordingly, +V/-VI and +VI/-VII (guided by logically justified reasons which need not be gone into here; see the later section on the relations of intervals):



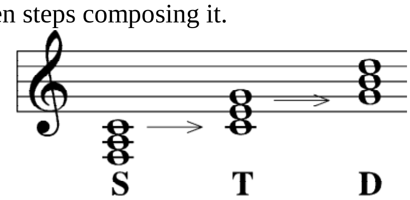
The II and -VII steps have lawfully approached the opposite colour (maximum dissonance), while III and -VI have approached the main colour (colour of tonic I). The result levels out the consecutive manifestation of dissonance, disrupting the tonal harmony of the harmony trichords and the adequacy of the interval relations, while intensifying the predominating value of the tonic chord and gathering its component I, III, V steps in a compact group of close-lying colour sectors. In this situation, the choice of keys (naturally) should continue in line with the principle of kinship in the aforementioned sector-quint correlation.

Every musical structure — pure, natural, Pythagorean, temperated — has its own advantages and disadvantages. By virtue of its nature, colour is capable of combining all the merits of each structure. This is achieved by applying a method based on the principles of inner-harmony functionality. This method helps to resolve the colour problems of the relations between dissonances and consonances, as well as explaining the colour meaning of alteration, defined in the sound relations as a sharpening or weakening of the harmony gravitations.

Although the necessary key colour-range is clearly brought out in this particular circle (based on quints), the functions of the steps comprising the colour harmony — I (tonic), II (upper introductory note), III (upper mediant), IV (subdominant), V (dominant), VI (lower mediant) and VII (lower introductory note) — are, it should be noted, for the time being of a purely formal character.

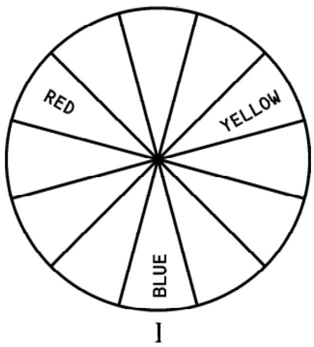
The Space of the Functional Inclinations

In order to correlate the colour resolution to the harmonic, it is necessary to place the functional harmony alongside the principle of supplementary colours. The sounds of a harmony can fulfil three functions — tonic (T), subdominant (S) and dominant (D). When the triads based on the main steps of the harmony — I, IV, V (T, S, D) — are taken together, they contain all seven steps composing it.



(The arrows indicate thecommon sounds for the S—T and T—D relations.)

The main colours at the accepted basis (the one determining the key = I step), such as blue, are supplementary — in this case, yellow and red (according to the accepted system in painting).



Examining this particular colour circle, for example, moving clockwise from blue, it can be seen that three groups of colours have been determined, each of which contains its own main colour (by degree of movement away).

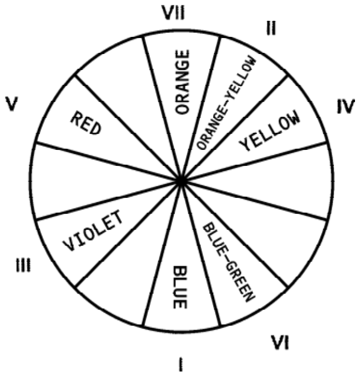
In the group of colours from blue to red, the main colour is dark blue. From red to yellow it is red, and from yellow to blue it is yellow. The group of red is definitely more dissonant here in relation to the group of blue than it is to the group of yellow. The reason is because there is no presence of blue in the group of red, while there is in the group of yellow. The same is observed with the T, S, D functions of the sound harmony. There is no sound of the first step in the dominant group, while there is in the subdominant group (which is why it is less dissonant than the dominant group). When working in a clockwork direction, in relation to blue, the groups of yellow and red can therefore be regarded as, correspondingly, subdominant (S) and dominant (D), while the main colours of these groups — yellow and red — correspond to the IV and V steps.

The most dissonant sound in relation to I step of the harmony is VII (lower introductory tone). In the colour scale, the most dissonant colour is the opposite one, implying that the function of the VII step is fulfilled here by orange.

The following, already weaker dissonance — II step (upper introductory tone) — is in the dominant group; it is furthest removed from the main tone (colour) and, of all the group, is closest to the subdominant (i.e. can be used in chords of subdominant values). Orange-yellow corresponds to these conditions. The III and VI steps are, accordingly, in the tonic and subdominant groups.

The III step (upper mediant) unites T and D, while the VI step (lower mediant) unites S and T. In the major, the upper mediant (III step) lags behind the tonic by a major third, while the lower mediant (VI step) lags by a minor third. In this particular case, the III and VI steps represent violet and bluegreen in the colour scale. Other examples of alteration verify our understanding of these correlations.

We now have a sequence of functionally dependent (analogous to the sound harmony) seven colours in which the tonic (I step) is blue:

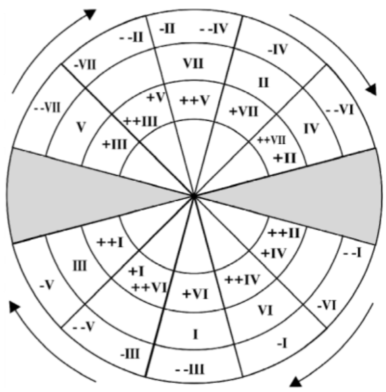


Alteration — the aggravation of dissonance (harmony gravitation) — should be effected by intensifying the contrast. The designation of the altered step should, therefore, indicate the sector of the maximum contrasting (opposite) colour on which the conflict (comprising the meaning of the very idea of alteration) is directed. For example, +I shows the intensification of tension in relation to step II, while -II increases the tension in relation to step I. In

this way, if we have contrast I step of the harmony to blue in the chosen key and the II step to orange-yellow, +I will be identical to blue-violet and the enharmonically equivalent -II will be identical to orange, which visually overcomes the demerits of the temperated structure.

As a whole, the sequence of altered steps coincides with the following colour series:

- I	Blue-green
+ I	Blue-violet
- II	Orange
+ II	Yellow
- III	Blue-violet
+ III	Red
- IV	Orange-yellow
+ IV	Green
- V	Violet
+ V	Red-orange
- VI	Green
+ VI	Blue
- VII	Red-orange
+ VII	Orange-yellow
++ I	Violet
-- I	Green
++ II	Green
-- II	Red-orange
++ III	Red-orange
-- III	Blue
++ IV	Blue-green
-- IV	Orange
++ V	Orange
-- V	Blue-violet
++ VI	Blue-violet
-- VI	Yellow
++ VII	Yellow
-- VII	Red



Each increase (+) or decrease (-) is achieved by displacing the step by one sector. The exceptions are the places of the IV, +IV and V relations, where +IV and -V (this concerns the double alterations) should be moved through a unit of gradation of colour (i.e. through a sector), following the principle of maximum contrast (maximum sharpening of intensity).

The resulting "colour comma" (perpendicular to the I — VII axis) is a consequence of the rigid symmetrical arrangement of the supporting (main) steps/colours I, IV and V, helping to bring out the asymmetry predefined by the relation of the even number of the twelve semitones of the octave and the odd, seven-step harmony (for each step, the opponent, in the singular, is the opposite colour).

In the sound series (diatonic scale), consisting of two equivalent tetrachords, the seventh step (lower introductory tone) demands resolution in tonic. But as the eighth step of the pure (unenclosed) structure does not correspond to the eighth step of the temperated structure, the relations of the lower and upper tonics, expressed in the numerical relations of the frequencies of the fluctuations as one to two (1:2), expands the distance between the tetrachords. This interval is the site of the middle of the zone marked by the “tritone” interval forming the “geometrical” centre of the cyclic sequence between steps I and VIII = I [1].

Tritone

I, II, III, IV, ↓ V, VI, VII, VIII = I [1]

Here is what the colour manifestation of the -V, IV and +IV, V relations look like in the sound variant (in relation to the centre of the zone of the tritone):

Tritone

IV, -V ↓ +IV, V

In other words, -V is “lower” and +IV is “higher”.

The inner-tetrachord chromatic transitions from one step to the next are more uniform than those just described. From all this, it can be seen that the presence of a colour comma with intensity emphasises the prevailing significance of the lower and upper dominants. What is more, when modulating, the uninvolved colours in the comma zone are manifested (by means of a turn of the colour circle) in another key, whereas the next two colours falling into this zone disappear. This clearly intensifies the perception of the inter-tonal distinctions.

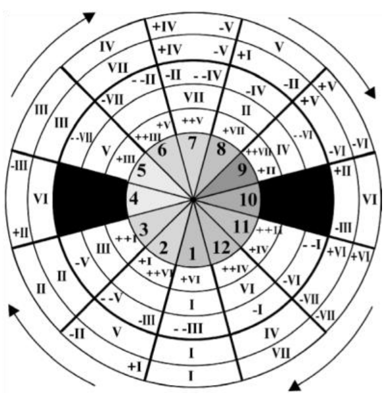
In the depicted scale of designations of the colour-sound steps, the space designating the comma can be shown as an expanded line limiting the value of the colour. It is then clear that, going in a clockwise direction, the diatonic steps of the harmony are arranged equally and consistently. There is a tone after every five sectors and a semitone after every four sectors. There are quints after every two sectors, a major third after every sector, and a minor third after the neighbouring sector.

Guided by definite artistic tasks or other reasons, it is possible to avoid the phenomenon of the colour comma, consistently realising alteration by moving the value of a certain step within the bounds of the nearest sector. This can help to achieve some uniformity, albeit at the expense of considerable easing the conflicting of the +IV, V and -V, IV relations and those arising as a consequence of modulations and tonal deviations.

A Resume and Brief Additions

As a result of all the aforesaid, each of the described three subsystems (melodic, tonal and functional) clearly has opportunities unavailable to the other two.

Only their combined sum represents a full system of colour-sound relations:



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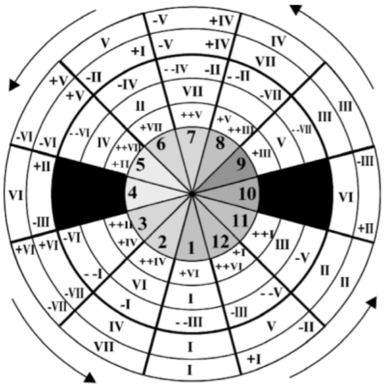
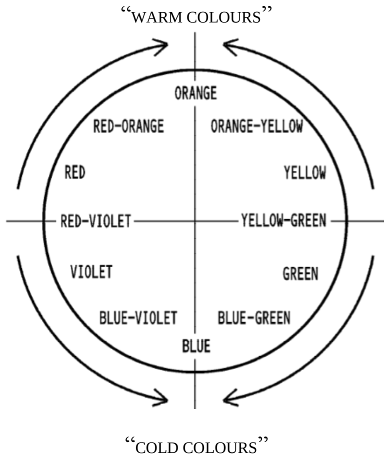
Up until now, the colour circle has been examined in clockwise direction. When looking in the opposite direction, the mirrored colour relations repeat all the inherent laws.

The groups of colours determined by the T, S, D relations naturally change their values:

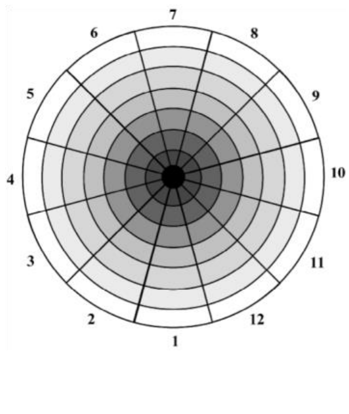


(In the philosophical aspect, it is interesting to observe that the graphic representation of the system of audiovisual stimuli recalls the characteristics of an electromagnetic field.)

When dividing the circle down the red-violet—yellow-green axis, the proportionality of the equal-quantity relations of the "cold" and "warm" colours is easily determined. The maximum divergence is on the "poles". In conditions of a mutual approach to the "equator", this divergence declines and is eventually reduced to zero:



The sound scale applied in music generally consists of seven complete and two incomplete octaves. The extreme octave at the bottom — the sub-counter octave — is usually depicted on the piano by the three top sounds. The extreme octave at the top — the fifth octave — is depicted by one lower sound. Every octave has its own name and special graphic designations of the steps. The same steps of a sound (i.e. the same notes) in different octaves are consonances. They should therefore be conveyed by the one and the same colour. The higher the sound, however, the lower the object with which it is associated. This is clearly linked to the fact that lighter objects have a higher resonance frequency, while heavier, massive objects have a lower resonance frequency. Light tones are perceived as being light and thin, while dark tones are regarded as being dense and the heavy. A gradual increase in the lightness of the colour in correspondence to the increase of the number of the octave is thus required to intensify the adequate emotional impression. It should be noted here that such definitions of colours as, for example, brown or pink are the essence of the modification of the colour tone. Mixing red or orange with black gives various shades of brown; mixing red and white gives pink (black and white are achromatic tones):



The Geometric Principles of Colour Orientations

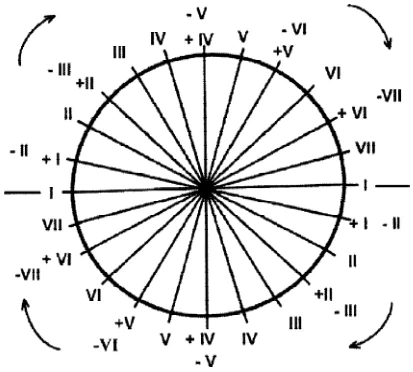
One of the fundamental characteristics of music is movement. Movement is spoken about, in one way or another, in terms of harmony, melody, etc. Such examples are “the chromatic gamut is the consistent movement of sounds across semitones,” “melody is constructed in accordance with the laws of harmony,” “harmony arises in the process of the movement of voices” and
“the sequence of steps (sounds) of a harmony forms its gamut.”

The graphic expression of the movement of colour should be carried out in conformity with the predefined degrees of tensions in the spaces of the melody, key and the functional inclinations.

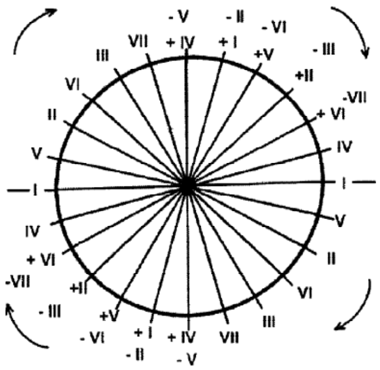
A horizontal is regarded as a psychologically justified starting point (line). The main thing, however, is the relation of the direction taken as the basis and the maximum contradiction to it of the perpendicular.

The chromatic gamut represents a formalised “quintessence” of a melody in which there is an “overflow” from one sound to another.

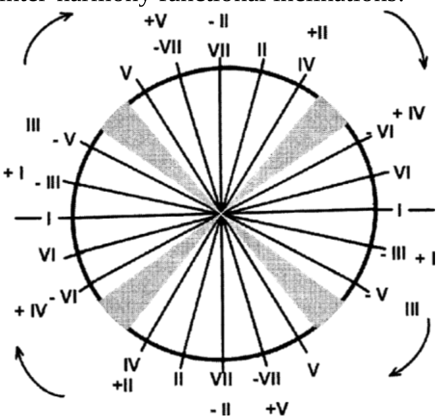
This looks as follows:



The positions of the steps/colours according to the characteristics of kinship relations:

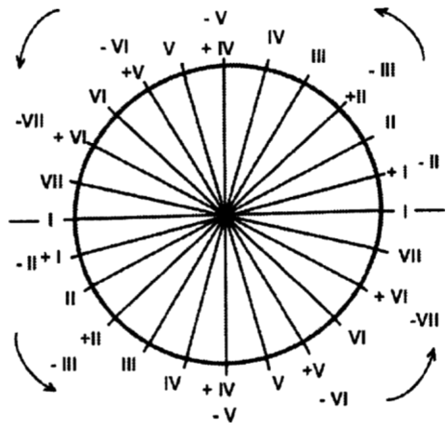


The relations of the inter-harmony functional inclinations:

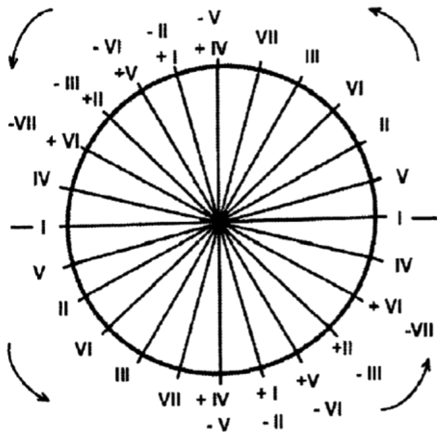


All this in the same order, only in the opposite direction:

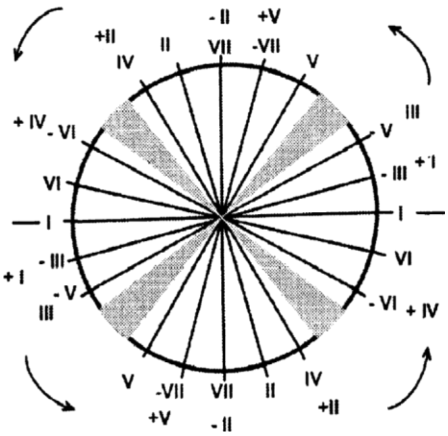
“Melody”



“Key”



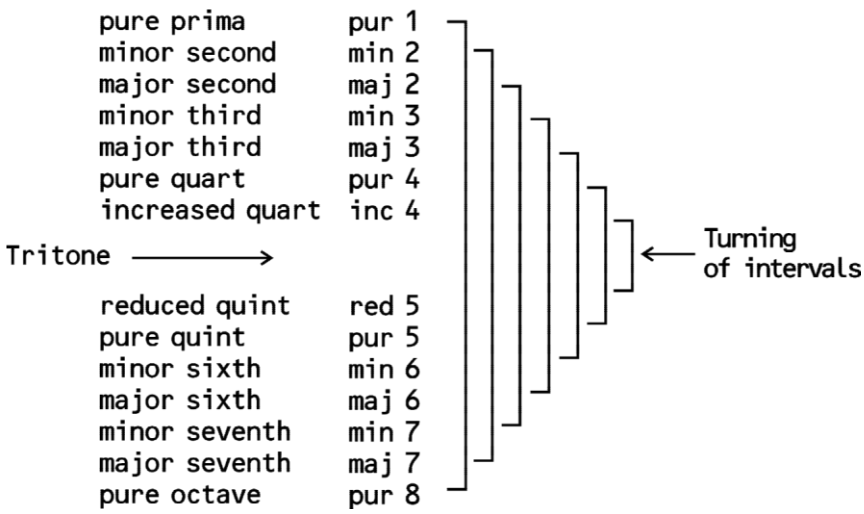
“Functions”



The Characteristics of the Sound-Colour Intervals

Let us consider these characteristics from the position of atonal music, which presupposes the organisation of sound space with the help of interval structures based on interval relations.

The musical scale, divided into twelve semitones, contains intervals:



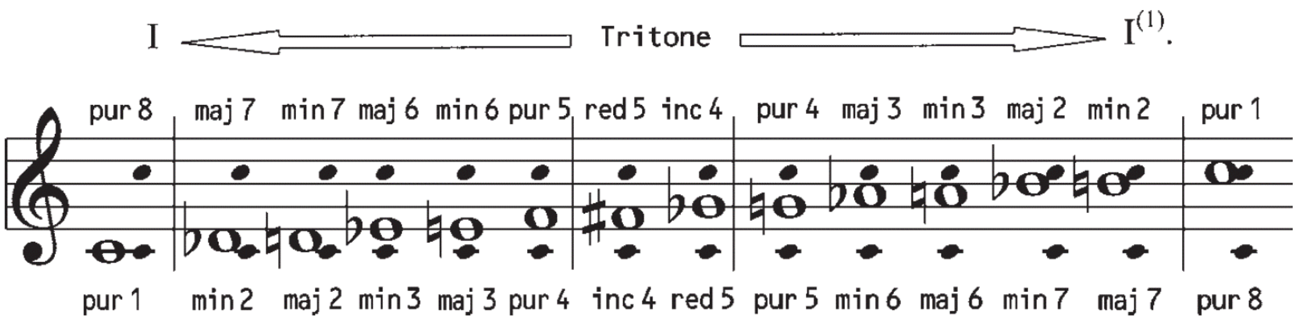
Intervals of more than one octave are compound and regarded as the sum of the octave and the corresponding simple interval.

Depending on the degree of agreement or disagreement of sounding, the intervals are divided into consonances and dissonances.

A dissonance is an accord of a tense character (inc 4, min 2, maj 2) and their turnings (red 5, maj 7, min 7).

The opposite concept is a consonance. Pur 1, pur 8, pur 5 and pur 4 are perfect consonances, while maj 3, min 6, min 3 and maj 6 are imperfect consonances.

Within the framework of the enclosed chromatic gamut (within the bounds of the octave), the mirror symmetry of the arrangement of the intervals, where the basic axis is the I—tritone —$I^{(1)}$ relations.



(The arrows indicate the directions of step-by-step intensification of the tension of the sounding of the harmonic intervals.)

The classification of the intervals in terns of the step-by-step growth of the tensions, naturally following from this scheme, forms the following relations:

(1) In the range of the lower tetrachord with turnings of intervals

I / I = pur 1 --------- pur 8 = I / $I^{(1)}$
I / IV = pur 4 --------- pur 5 = IV / $I^{(1)}$
I / III = maj 3 --------- min 6 = III / $I^{(1)}$
I / -III = min 3 --------- maj 6 = -III / $I^{(1)}$
I / II = maj 2 --------- min 7 = II / $I^{(1)}$
I / -II = min 2 --------- maj 7 = -II / $I^{(1)}$
I / +IV = inc 4 --------- red 5 = +IV / $I^{(1)}$

(2) IN THE RANGE OF THE UPPER TETRACHORD WITH TURNINGS OF INTERVALS

$I^{(1)}$/ $I^{(1)}$ = pur 1 --------- pur 8 = $I^{(1)}$ / I
$I^{(1)}$/ V = pur 4 --------- pur 5 = V / I
$I^{(1)}$/ -VI = maj 3 --------- min 6 = -VI / I
$I^{(1)}$/ VI = min 3 --------- maj 6 = VI / I
$I^{(1)}$/ -VII = maj 2 --------- min 7 = -VII / I
$I^{(1)}$/ VII = min 2 --------- maj 7 = VII / I
$I^{(1)}$/ -V = inc 4 --------- red 5 = -V / I

Each tetrachord represents an independent formation in which the link between the intervals and their turnings is realised via the coefficient of the octave.

The sounds of the interval, taken simultaneously, form an harmonic interval. The sounds of the interval, taken consecutively, form a melodic interval. Every interval is determined by two sizes — quantitative and qualitative.

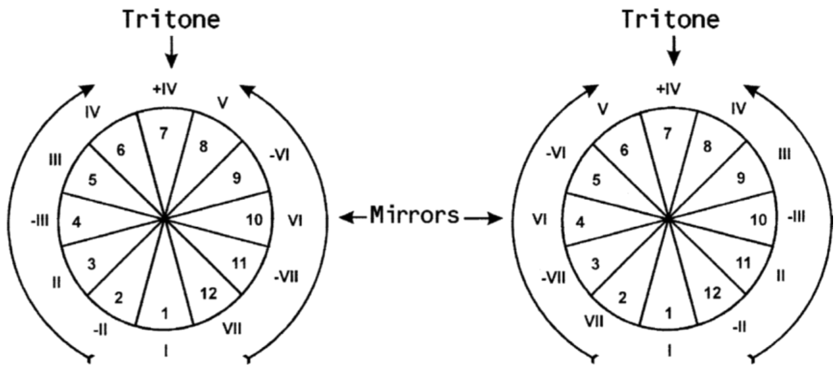
The quantitative is the size expressed by the quantity of steps constituting the interval.

The qualitative is the size expressed by the quantity of tones and semitones constituting the interval.

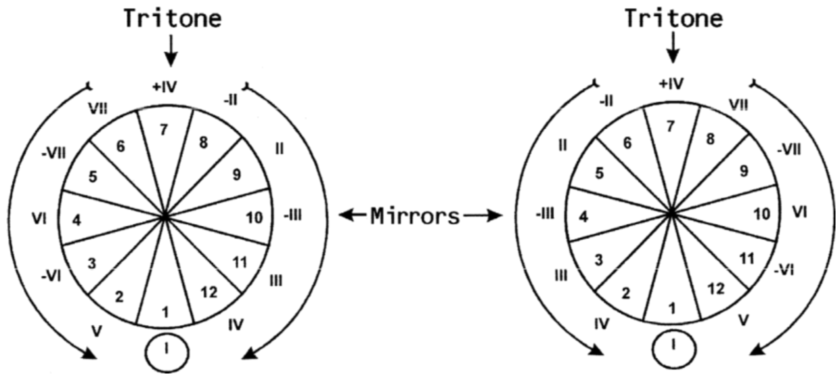
Quantitative sizes characterise the sound-pitch distinctions (melodic intervals) to a greater degree, while the qualitative sizes characterise the relations of kinship (harmonic intervals). An obvious consequence of such factors is the contrasting directions of the step-by-step growth of tensions in the melodic and harmonic intervals. Within the bounds of the tetrachord on the I—tritone and tritone—$I^{(1)}$ axis, the sound series manifests the intensification of the tensions of the melodic intervals by degree of their increase and the intensification of the tensions of the harmonic intervals by degree of their reduction. The lower sound of the interval is called its basis; the upper sound of the interval is called the summit.

Divided into twelve sectors, the colour circle also manifests similar interval laws around the I—tritone axis. The colour tensions grow (in relation to the colour of sector I) by degree of distance from the sector established against value I and by degree of approach to the maximal dissonance (tritone).

In melodic movement, i.e. in the intervals expressing the quantitative relations, the size of the interval "leap" — the distance between the summit and the basis — is of crucial importance. In the variant of the relations of the quantitative sizes of the melodic intervals and the geometry of the orientations, the arrangement of the steps corresponds to the positions of the "space of the melody":



The harmonic intervals are characterised by the degree of intensity of the simultaneous sounding of the basis and summit. The directions of the spread of the values of the melodic and harmonic intervals are opposite. It is therefore natural to construct a colour system of harmonic intervals around the I—tritone axis by means of a consistent comparison of each "melodic" step to the colour of the opposite sector. This is accompanied by a visually justified transition of the values of the melodic intervals into a new quality:

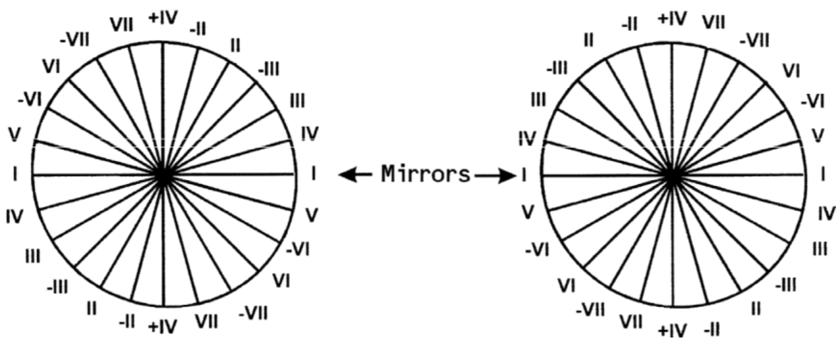


The arrows indicate the opposite directions of the step-by-step spread of the values of the melodic (upwards) and harmonic (downwards) intervals.

Combining the colour relations of the melodic and harmonic intervals, it is necessary to take into account the sequence of the employed systems. Firstly, the "melodic" colour-sound is accepted as the basis for the construction of the interval. By a turn of the colour circle, the sector of colour accepted in this quality is established in value I of the scheme of the harmonic intervals. The required colour is automatically compared to the necessary numerical size in relation to the basis. Then, when crossing over to a system of melodic intervals, the dominating colour-sound of the harmonic interval becomes the basis for the melodic interval, and so forth.

A comparison of the geometrical orientations of the systems follows the same principle.

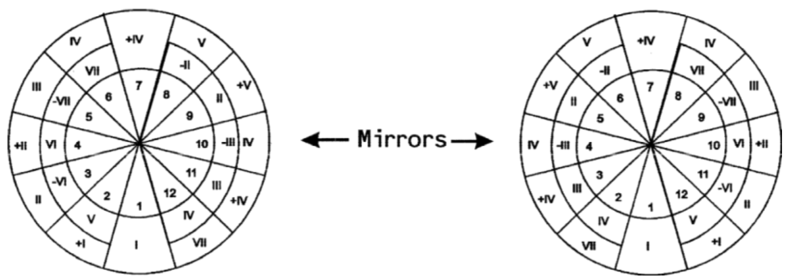
GEOMETRY OF HARMONIC INTERVALS:



(Enharmonic versions are insignificant for a designation of the formal sizes of the intervals.)

In the consecutive construction of the chords (from the lower coloursound), each interval containing a chord is always defined in relation to value I, where the summit of the previous interval naturally becomes the basis of the subsequent interval.

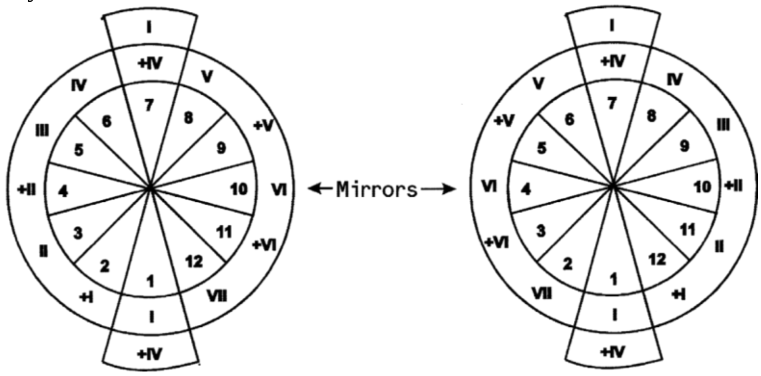
Such a means of defining the colour groups constituting the chord shows the inverse changeability of the values of opposite colours in the relations of the melodic and interval systems:



(The outer rings are the system of the melody, while the inner rings are the system of intervals in relation to the basis I.)

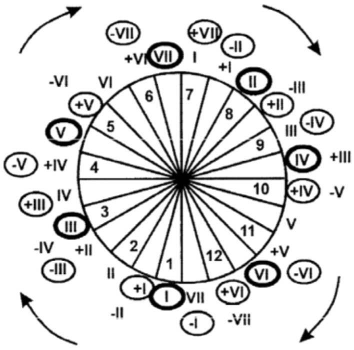
Recollecting the example on page 27 (the section on the space of the keys), we can see how the tendency which had begun to appear there is formalised here in an harmonic system. Two pairs of opposite colours corresponding to the II/-VI and III/-VII relations have now lawfully defined their positions.

The specific nature of the differences in the colour and sound relations require a variation of the creative solutions in order to achieve the maximum adequate effect. In practical application, it is therefore expedient to reduce the colour overload to a minimum. In order to do so, it is enough to change the places of values I and +IV in the system of interval relations. It should be noted that all the values of the other steps of the melody and interval systems retain their colour identity:

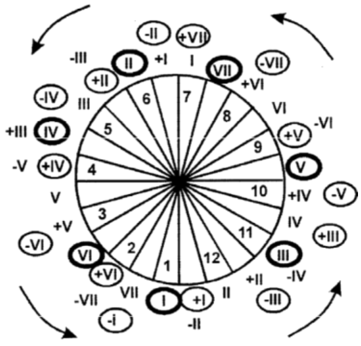


Towards Colour Completeness

Following the psychological principle of colour completeness and artistic practice, manifesting the properties of one colour on the background of the opposite colour to the maximum, it is worth developing the following model:



In clockwise direction



In anti-clockwise direction

— colours of the functions of the main seven steps of the harmony

— pluses (+) and minuses (-) of the same steps

This model simultaneously contains the principles of the construction of both melodic and functional relations. The colour of the “functions” is arranged on the background of the colour characterising the value of a step in the melodic system; with the use of the effect of the inverse changeability of the opposite tones.

A division of the colour circle into twenty-four sectors is required here, as each musical step consists of two opposite colours. Twelve intermediate colours are thus added:

1	red red-red-orange	5	yellow yellow-yellow-green	9	blue blue-blue-violet
2	red-orange red-orange-orange	6	yellow-green yellow-green-green	10	blue-violet blue-violet-violet
3	orange orange-orange-yellow	7	green green-green-blue	11	violet violet-violet-red
4	orange-yellow orange-yellow-yellow	8	green-blue green-blue-blue	12	violet-red violet-red-red

From the Theory of Colour

Artists and scientists have always aspired to bring the diversity of colours observed in nature into a system — to arrange all the colours in a certain order, distinguishing the basic and derivative tones.

The names of the colours — red, blue, etc. — are a verbal expression of the colour tone. All the colour tones are contained in the spectrum of sunlight or in the spectrum of another emanation, which consists of monochromatic emanations with λ from 380 to 780 nanometers. The exception is only purple tones, received by mixing the extreme spectral colours — violet and red.

To reproduce the majority of colours encountered in nature, it is necessary to mix any three colours in certain proportions. These three colours are called the primary colours. There is a multitude of triads of primary colours. The basic requirement which the three primary colours must satisfy is that none of them should be obtained by mixing two others.

A "pure" sensation of colour does not exist for the human eye. We always see colour in a certain environment, on one or another background, in connection with an objective form. The mind also contributes to this sensation. All subjective aspects only change the quality of perception to a certain extent, only displacing it to one side or another.

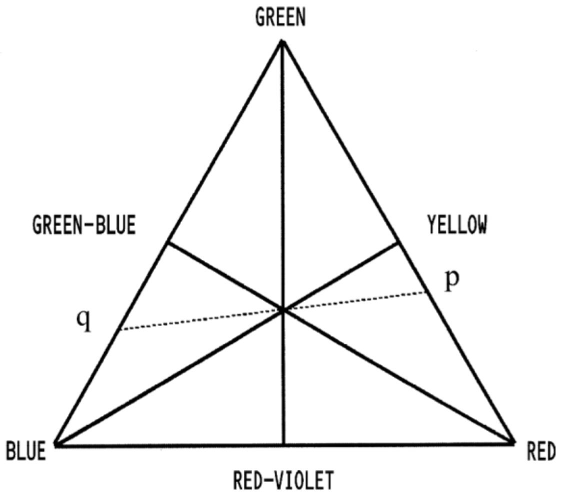
The spectrum served as the basis for systematising the colours in the form of a circle and triangle.

The idea of the graphic expression of a system of colours in the form of a closed figure was suggested by the fact that the ends of a spectrum tend to become enclosed. The dark blue end passes through the violet into purple, while red also approaches purple (like the enclosed nature of the musical gamut).

The arrangement of colours in a triangle is basically the same as their arrangement in a circle, as a triangle can be inserted into a circle. The pure "primary" colours — red, blue and yellow — are arranged at the tops of a triangle. Mixing them in pairs, one obtains "secondary" or mixed colours — orange, green and violet. Mixing can continue even further, ultimately resulting in a colour circle. No matter what related colours are summed up, the result is an intermediate colour corresponding to the components. When bisectors are drawn in the triangle and diameters in the circle, the mutually supplementary colours lie at their opposite ends.

A multitude of colours can be obtained, mixing the three multi-coloured emanations in various proportions. The means of obtaining colours based on the addition of three streams of light of various colours is called additive. The means based on the subtraction of colours is called subtractive.

Red, green and dark-blue are usually the initial colours of the system of additive reproduction, while purple, yellow and light-blue are generally the initial colours of the system of subtractive reproduction. The means of defining the necessary tone is illustrated by the colour triangle. In a triangle, usually an equilateral one, the colours are represented by points. The basic colours — red, green and dark blue (an example of summing) — are located at the tops of the triangle. The colour obtained by mixing two colours in equal quantities is represented by a point standing at an equal distance from them. The supplementary colours — green-blue, purple and yellow — lie in the middle of the sides of the triangle. White, which is obtained by mixing equal quantities of red, green and blue, is represented by a point laying in the centre of the triangle at an equal distance from each corner (black when there is a subtractive formation of colours in the centre).



If two colours are mixed in unequal quantities, for example, adding a units of one colour to b units of another, the mixture can be presented by a point on the line joining them. This point will divide the line of connection in relation of a to b and will lie closer to that colour the more of which is taken.

As green-blue and red, mixed in a relationship of two parts of the former to one part of the latter, give white, white is represented by a point lying twice as far from red than green-blue. This is sometimes expressed by saying that red has twice the painting force of the same intensity of green-blue. Similarly, green has twice the painting force of purple and blue has twice the painting force of yellow.

It can be seen from the triangle that there is a multitude of pairs of supplementary colours. Let us assume that we have drawn the line pq, meeting the sides of the triangle at points p and q and passing through white. The colours corresponding to points p and q, combining together, will clearly give white and will be exactly supplementary. (When mixing pigments, which, from a physical point of view, is subtraction, the pairs of opposite colours give a black achromatic tone.) Orange-yellow corresponds to the point p, while lightblue corresponds to the point q — the intermediate point between green-light blue and dark blue.

Although the presence of mutually supplementary colours has been found in works of painting almost as far back as ancient times, the very phenomenon of the supplementariness of colours was only recently discovered. Mutually supplementary colours could, of course, appear in pictures of any historical period accidentally or as a result of practical experience.

Pairs are usually called mutually supplementary — red and green, blue and orange, yellow and violet, without bearing in mind that each of these “generical” titles includes a large range of colour tones and not every red and green will be mutually supplementary.

In natural-science colourology, the mutually supplementariness of colours is defined as the ability of any one colour to supplement another until the perception of an achromatic tone, i.e. white or grey — as a result of an optical mixing. The lengths of the waves of any two colours which are supplementary are approximately equal to 1.25 (or, to be more exact, lie within the bounds of 1.19 and 1.33).

Supplementary colours are usually arranged in a circle diametrically opposite one another. Instead of supplementary ones, colours closer to contrasting ones can be accepted. The selection can be determined by the fact that the neighbouring tones of the circle are visually perceived as approximately equicontrasting.

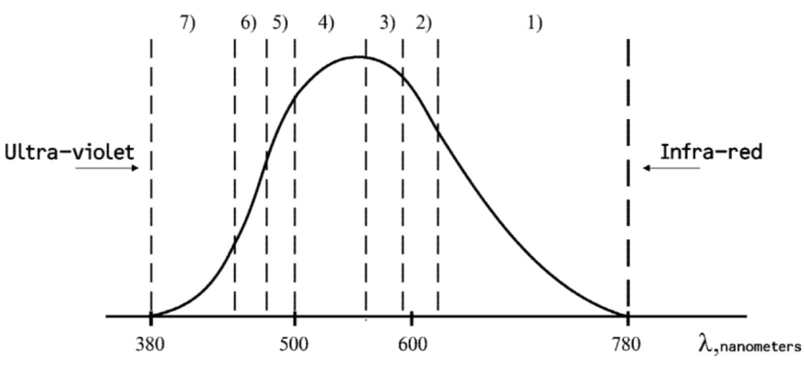
Strictly speaking, the pairs of supplementary colours which give white and grey in a visual mixing are verbally defined as red and light blue, orange and blue, yellow and dark blue, yellow-green and violet, and green and purple.

It should be noted that these pairs of colours are not mutually reversible. For example, the contrasting colour to dark blue will be orange, violet for yellow, etc. It can be seen, however, that colour displacements in one direction or another are insignificant; everything is within the bounds of the maximum kinship. The principles causing these displacements are also clear — the principles of physics, physiology and psychology.

It is therefore important to elucidate the compatibility of these principles within the bounds of this theme.

The lengths of the waves of the emanations received by the decomposition of the white emanation falling into the spectrum have the following values for different colours:

(1) Red..................780-620 nanometers
(2) Orange ....620-590 nanometers
(3) Yellow ....590-560 nanometers
(4) Green ....560-500 nanometers
(5) Light blue...........500-480 nanometers
(6) Dark blue............480-450 nanometers
(7) Violet ....450-380 nanometers



FUNCTION OF RELATIVE LIGHT EFFECTIVENESS

(SHOWING THE NOMINAL BORDERS OF VARIOUS COLOURS)

The continuous change in colour corresponds to the gradual change in the length of the wave. The division of the visible area of the spectrum into seven parts is, therefore, nominal. The fact is that on several sections of the spectrum, the change in the colour with a change in the length of the wave is insignificant. The nominal highlighting of the aforementioned sections is explained by the fact that the most noticeable changes in the colours take place on their borders. The sequence of these spectral colours can be broken into both smaller and larger number of sections, for example, four (blue, green, yellow and red). It is also possible to add sections of orange-red, yellow-orange, green-yellow, etc. to the indicated colours.

The eyes analyses the resulting sensation of the colour both qualitatively (in terms of chromaticity) and quantitatively, recording the brightness of the emanation falling on it.

The sensation of colour depends not only on the physical characteristics of emanation (power, spectral structure), but also on the properties of the eye. When the sensation of colour arises, it is necessary to take into account the physiology of this sensation, i.e. the construction of the visual analyser and the principles of its work during the action of emanation. The eye receives the sensation of colour only when the conic elements of the retina operate.

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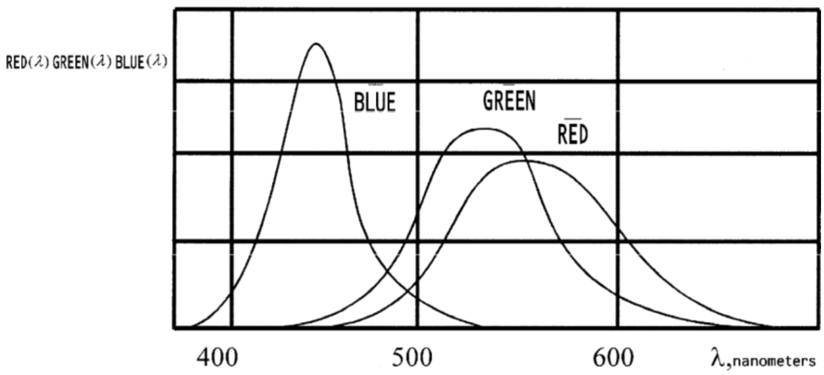
The reticular environment has three versions of conic elements — groups of cones reacting to emanations with waves of lengths 380—550 nanometers, 500-600 nanometers and 600-780 nanometers. All three types of cones work under conditions of relatively high lightness.

The "fingers" work at low levels of brightness. They are all identical in terms of spectral sensitivity. The action of the emanations on them gives rise to sensations differing only in value. At low levels of brightness, the eye distinguishes subjects not by colour, but by lightness.

Each of the three groups of cones has the greatest sensitivity in the long, medium- and short-wave sections of the spectrum, i.e. they possess their own spectral sensitivity. The sensation of a definite colour arises during the action of emanation on cones of primarily one type. For groups of cones with the greatest sensitivity in the long-wave area of the spectrum, this is the sensation of red. In the medium-wave section it is green. In the short-wave section it is blue. The eye consists of three receivers and so the aggregate of the cones of each type are called red-, green- and blue-sensing receivers or red-green-blue receivers. The streams of emanation falling on the retina have different spectral structures, and the levels of stimulation of the three colour receivers of the eye are different owing to the varying spectral sensitivity. The correlations of the levels of stimulation of the red-green-blue receivers creates the perception of the colour of the emanation perceived by the eye. To appraise the colour action of the emanation, we employ the concept of the spectral sensitivity of the three receivers of the eye which, like the functions of spectral sensitivity of any receiver, together with the energetic sizes $\Theta e\lambda(\lambda)$ of the emanations falling on them, allows the levels of stimulation of the red-green-blue receivers describing colour as a measure of the action of emanation on the eye to be calculated.



CURVES OF THE RELATIVE SPECTRAL SENSITIVITY
OF THE RED-GREEN-BLUE RECEIVERS OF THE EYE

As the curves of the relative spectral sensitivity of the red-green-blue receivers define the levels of stimulation of the basic receivers, they are also called the curves of the basic stimulations, while red, green and blue, the sensations of which can arise under the action of emanation on each of these receivers separately, are called the basic physiological colours. It can be seen from the curves in the drawing that each colour-sensing receiver of the eye reacts to homogeneous emanations in a wide range of the visible section of the spectrum, while their spectral sensitivity has a sharply expressed maximum.

If homogeneous emanations of λ = 400 nanometers and λ = 410 nanometers act on the eye, there is a sensation of blue, as these emanations act mainly on the blue-sensing receiver. But the sensitivity of the blue-receiver to an emanation of λ = 400 nanometers is less than to an emanation of λ = 410 nanometers. It therefore follows that if the force of these emanations are identical, the sensation of a brighter blue will correspond to the second emanation, as the eye quantitatively reacts to the falling emanation. Under conditions of the simultaneous action of emanation on two or three receivers of the eye, a separate perception of red, green and blue of the basic stimulations is absent. There is the perception of a uniform colour, the chromaticity of which is defined by the correlation of the values of the three main stimulations, while the brightness is defined by their sum.

Under conditions of the one and the same value of the sums of the three basic stimulations, i.e. one brightness, they can have a multitude of relations. Under conditions of the one and the same correlation, they can have a multitude of sums. Colours that are different in chromaticity can thus have identical brightnesses, while colours with the one and the same chromaticity can have a multitude of different brightnesses. This means that brightness and chromaticity are characteristics of colour independent on one another.

If there is no predominance of one of the basic stimulations, the result is the appearance of sensations, the chromaticity of which are different from red, green and blue. For example, emanations with lengths of waves from 560 to 580 nanometers act more or less equally on the red- and green- receivers. Their colours are yellow. Emanation with lengths of waves from 480 to 510 nanometers act mainly on green- and blue-receivers and have a light-blue colour. The emanations of the long- and short-wave ends of the spectrum, acting simultaneously and primarily on the red- and blue-receivers, evoke the sensation of purple. The sensation of white corresponds to a definite correlation of the simultaneous stimulation of all three receivers. An absence of stimulation creates the sensation of black.

A Mathematical Model of Light-Sound Relations

Sir Isaac Newton broke sunlight down into seven colour components, noticing that the frequencies of the borders of the colours of the solar spectrum are correlated, like the frequencies of the symmetric frigia gamut of a pure structure:

$$\frac{\nu}{\nu_{RED}} : \quad 1 \qquad \frac{9}{8} \qquad \frac{6}{5} \qquad \frac{4}{3} \qquad \frac{3}{2} \qquad \frac{5}{3} \qquad \frac{16}{9} \qquad 2$$

RED ORANGE YELLOW GREEN LIGHT BLUE DARK BLUE VIOLET

$$\underbrace{T \quad T/2 \quad T} \qquad T \qquad \underbrace{T \quad T/2 \quad T}$$

In this way, besides the dispersion of light, Newton also discovered an analogy between colour and music, leading to the development of the coloursound art.

Any sound of the musical gamut, divided into twelve semitones, occupies a position within the bounds of a definite zone an area within the bounds of which the given sound or interval can have different quantitative expressions, while retaining its quality and name. For example, the quality and name of the interval remain constant within certain bounds when there are different frequency relations between the sounds of this interval (zone of the major second, minor third, etc.). The sound of A on the first octave is perceived as unchanged at frequencies of 435, 437, 440, 443, etc. with permissible deviations up to a quarter of tone (plus and minus an eighth of a tone). The free intonation of music by performers on instruments with partially recorded structure (violin, etc.) and singers is based on the zone nature of hearing. The zone phenomenon is also observed in the field of tempo and rhythm (time zones), timbre and dynamics.

From this point of view, the colour spectrum perceived by the eye represents an aggregate of zones, the central values of which we define as the maximal manifestations of what are called red, orange, yellow, green, light blue, dark blue and violet.

Let us first examine the uniform-temperated twelve-step chromatic gamut with the simplest structure:

doh re mi fa so la ti doh^{1}

$$1 = 2^{\frac{0}{12}} \quad 2^{\frac{1}{12}} \quad 2^{\frac{2}{12}} \quad 2^{\frac{3}{12}} \quad 2^{\frac{4}{12}} \quad 2^{\frac{5}{12}} \quad 2^{\frac{6}{12}} = \sqrt{2} \quad 2^{\frac{7}{12}} \quad 2^{\frac{8}{12}} \quad 2^{\frac{9}{12}} \quad 2^{\frac{10}{12}} \quad 2^{\frac{11}{12}} \quad 2^{\frac{12}{12}} = 2$$

$$b_0 \quad b_1 \quad b_2 \quad b_3 \quad b_4 \quad b_5 \quad \mathbf{b_6} \quad b_7 \quad b_8 \quad b_9 \quad b_{10} \quad b_{11} \quad b_{12} \qquad (1)$$

It can easily be seen that steps in the uniform-temperated gamut form a geometrical progression with a denominator of $q = \sqrt[12]{2}$.

Then
$$\frac{b_{k+1}}{b_k} = \frac{b_k}{b_{k-1}} = \sqrt[12]{2},$$

or
$$b_k = \sqrt{b_{k-1} \cdot b_{k+1}} \quad (k = 1, 2, \ldots, 11) \quad (2)$$

Consequently, each internal step of gamut (1) is the average geometrical of their neighbours. Let us call this local geometrical symmetry with coefficient of symmetry (relations of the members included in the proportion) $\sqrt[12]{2}$.

Gamut (1) also has global geometrical symmetry, i.e. the works of members equidistant from the ends are equal to the square of the average member b_6:

$$1 \cdot 2 = 2^{\frac{1}{12}} \cdot 2^{\frac{11}{12}} = 2^{\frac{2}{12}} \cdot 2^{\frac{10}{12}} = \ldots = 2^{\frac{5}{12}} \cdot 2^{\frac{7}{12}} = (\sqrt{2})^2,$$

or
$$b_n \cdot b_{12-n} = b_6^2 = (\sqrt{2})^2 \quad (n = 0,1,2,\ldots,5),$$

from which we get

$$\frac{b_{12-n}}{b_6} = \frac{b_6}{b_n},$$

or
$$b_6 = \sqrt{b_n \cdot b_{12-n}} = \sqrt{2} \quad (n = 0, 1, 2, \ldots, 5) \quad (3)$$

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The seventh step (1) $b_6 = \sqrt{2}$, the tritone, equal to an increased quart or a decreased quint, is thus the average geometrical of any pair of steps equidistant from the ends. We shall call tritone $b_6 = \sqrt{2}$ the centre of the global geometrical symmetry of the gamut.

The global geometrical symmetry connects the interval and its turning through the interval coefficient of the octave.

It is evident from equalities (1-3) that under any shifts, the structure of the uniform-temperated gamut is not broken, i.e. the uniform-temperated gamut permits modulations in any key.

We now divide the visible area of the spectrum within the bounds of $\nu_0 = 3.92.10^{14}$ Hz and $\nu_{12} = 7.84.10^{14}$ Hz into twelve parts forming a geometric progression with the denominator $q = \sqrt[12]{2}$.

Then
$$\frac{\nu_{k+1}}{\nu_k} = \frac{\nu_k}{\nu_{k-1}} = \sqrt[12]{2} \quad (k = 0,1,2,\ldots,12) \quad (4)$$

Employing formula (4), we get the geometrical progression $\{\nu_n\}$, where

$\nu_0 = 3.92 \cdot 10^{14}$
$\nu_1 = 4.15 \cdot 10^{14}$
$\nu_2 = 4.40 \cdot 10^{14}$
$\nu_3 = 4.66 \cdot 10^{14}$
$\nu_4 = 4.93 \cdot 10^{14}$
$\nu_5 = 5.23 \cdot 10^{14}$
$\nu_6 = 5.54 \cdot 10^{14}$
$\nu_7 = 5.87 \cdot 10^{14}$
$\nu_8 = 6.22 \cdot 10^{14}$
$\nu_9 = 6.59 \cdot 10^{14}$
$\nu_{10} = 6.98 \cdot 10^{14}$
$\nu_{11} = 7.40 \cdot 10^{14}$
$\nu_{12} = 7.84 \cdot 10^{14}$

We thus get a spectrum broken up in an analogous manner to the uniform-temperated sound gamut, with correlation of the members of the series = 10^{14}, where ν_k is the frequency of light fluctuation and b_k is the frequency of the corresponding sound fluctuation.

Each sound frequency b_k is matched with the corresponding area of the spectrum, defined by the integrals: for k = 0 and k = 12

$$J_o = J_{12} = \int_{\nu_0}^{\nu_1} \Theta(\nu) d\nu + \int_{\nu_{11}}^{\nu_{12}} \Theta(\nu) d\nu, \text{ and for } k = 1,2,\ldots 11 \;\; J_k = \int_{\nu_{k-1}}^{\nu_{k+1}} \Theta(\nu) d\nu,$$

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where $\Theta(\nu)$ is the function of the relative light efficiency.

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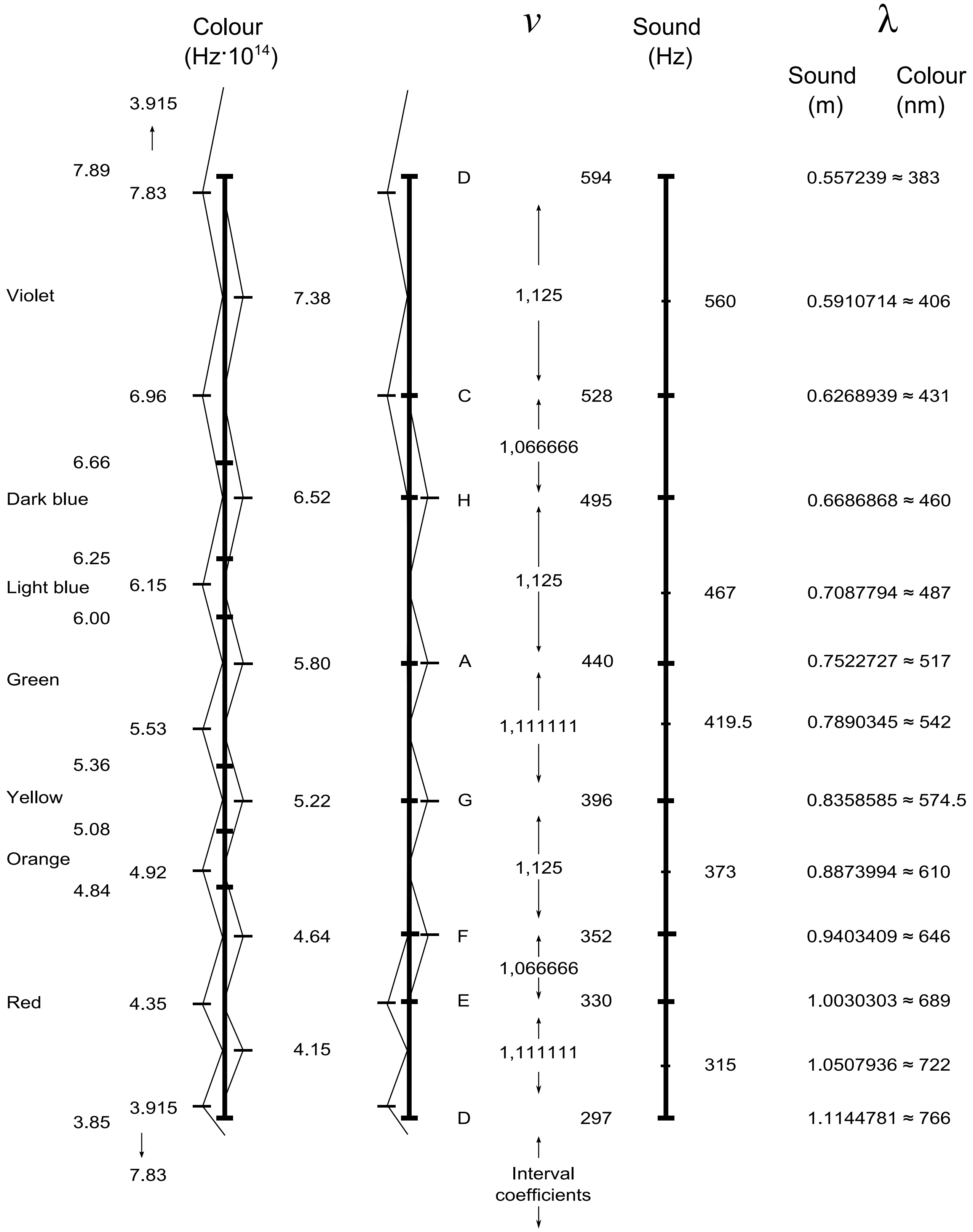
The results can be tabulated:

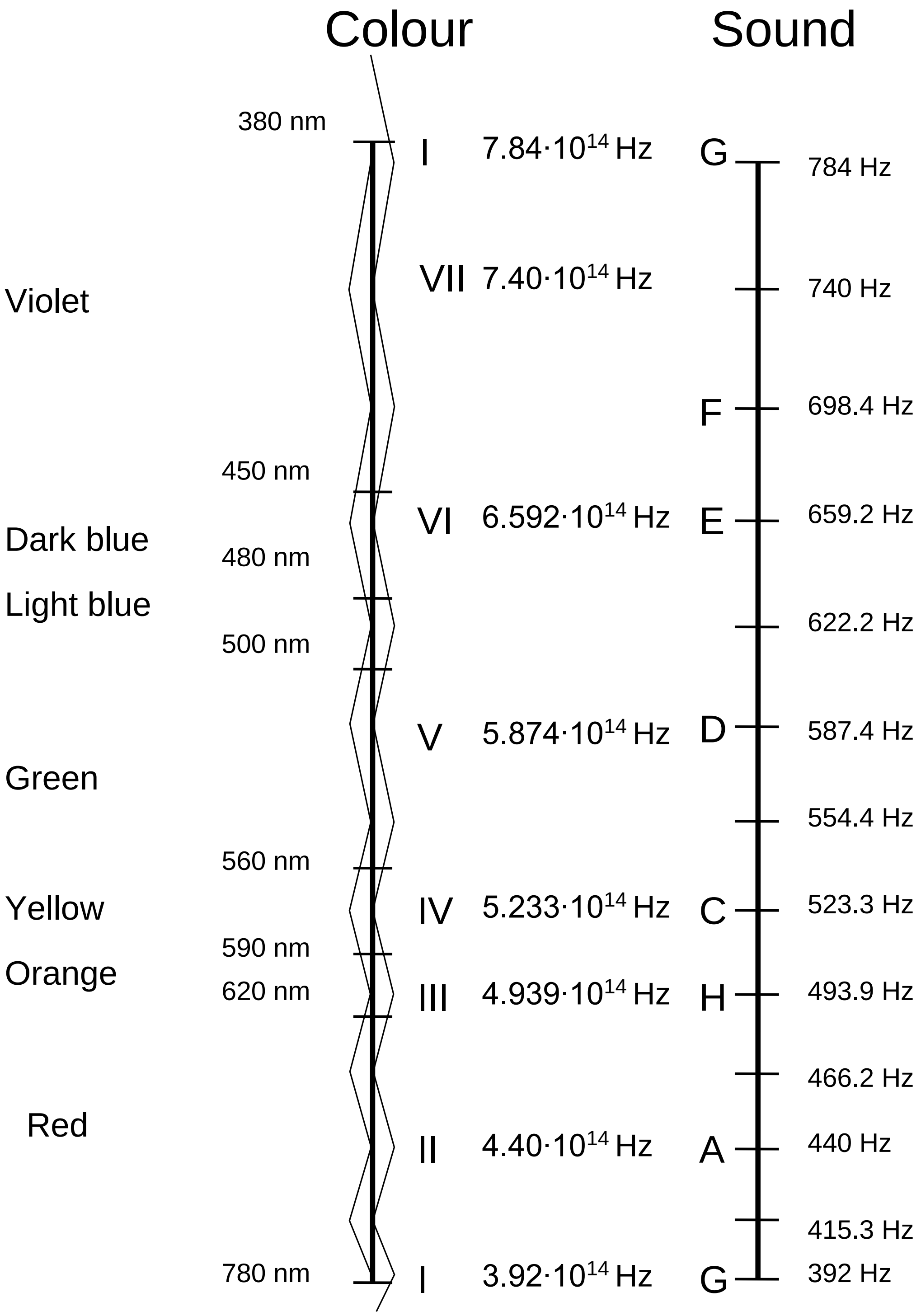
Frequency of sound fluctuation b_k, Hz	Area of the spectrum determined by the integral J_k
$b_0 = 392$	$J_0 = \int_{3.92\cdot10^{14}}^{4.153\cdot10^{14}} \Theta(v)dv + \int_{7.40\cdot10^{14}}^{7.84\cdot10^{14}} \Theta(v)dv$
$b_1 = 415{,}3$	$J_1 = \int_{3.92\cdot10^{14}}^{4.40\cdot10^{14}} \Theta(v)dv$
$b_2 = 440$	$J_2 = \int_{4.153\cdot10^{14}}^{4.662\cdot10^{14}} \Theta(v)dv$
$b_3 = 466{,}2$	$J_3 = \int_{4.40\cdot10^{14}}^{4.939\cdot10^{14}} \Theta(v)dv$
$b_4 = 493{,}3$	$J_4 = \int_{4.662\cdot10^{14}}^{5.233\cdot10^{14}} \Theta(v)dv$
$b_5 = 523{,}3$	$J_5 = \int_{4.939\cdot10^{14}}^{5.544\cdot10^{14}} \Theta(v)dv$
$b_6 = 554{,}4$	$J_6 = \int_{5.233\cdot10^{14}}^{5.874\cdot10^{14}} \Theta(v)dv$
$b_7 = 587{,}7$	$J_7 = \int_{5.544\cdot10^{14}}^{6.222\cdot10^{14}} \Theta(v)dv$
$b_8 = 622{,}2$	$J_8 = \int_{5.874\cdot10^{14}}^{6.592\cdot10^{14}} \Theta(v)dv$
$b_9 = 659{,}2$	$J_9 = \int_{6.222\cdot10^{14}}^{6.984\cdot10^{14}} \Theta(v)dv$
$b_{10} = 698{,}4$	$J_{10} = \int_{6.592\cdot10^{14}}^{7.40\cdot10^{14}} \Theta(v)dv$
$b_{11} = 740$	$J_{11} = \int_{6.984\cdot10^{14}}^{7.84\cdot10^{14}} \Theta(v)dv$
$b_{12} = 784$	$J_{12} = \int_{7.40\cdot10^{14}}^{7.84\cdot10^{14}} \Theta(v)dv + \int_{3.92\cdot10^{14}}^{4.153\cdot10^{14}} \Theta(v)dv$

For the frequency v_k the area of the spectrum is thus defined by the borders from v_{k-1} to v_{k+1}.

CORRELATIONS OF THE FREQUENCIES AND LENGTHSOF WAVES:
NATURAL ORDER



TEMPERATED ORDER



The order of the sections of the spectrum, given in the tables of the correlations of frequencies and lengths of waves, illustrates the principle ofzoned colour distribution. The sufficient uniformity of the colour gradations, caused by the perceptive requirement, is easily achieved by visual correction.

Now for the construction of the sound and colour melodic and harmonic intervals.

If we select a fluctuation with frequency b_o or □$_o$ as the basis of the melodic interval, the summit of the corresponding interval can be found on the basis of the following table:

Interval	For a sound (Hz)	For colour (Hz)
minor 2	$b_1=q.b_o$	$\nu_1=q.\nu_o$
major 2	$b_2=q_2.b_o$	$\nu_2=q_2.\nu_o$
minor 3	$b_3=q_3.b_o$	$\nu_3=q_3.\nu_o$
major 3	$b_4=q_4.b_o$	$\nu_4=q_4.\nu_o$
pure 4	$b_5=q_5.b_o$	$\nu_5=q_5.\nu_o$
tritone	$b_6=q_6.b_o$	$\nu_6=q_6.\nu_o$

To generally define the summit of an interval, the frequency of its basis should be multiplied by the coefficient C_k, which is constant for the given interval.

Thus:

$b_k = C_k\ b_o$

$\nu_k = C_k\ \nu_o$

In sounds, the frequency relations of the melodic and harmonic intervals are adequate.

To define the summit of the colour harmonic interval, the frequency value of the summit of the corresponding melodic interval should be divided or multiplied by $\sqrt{2}$:

$$\nu_k = \frac{C_k \cdot \nu_0}{\sqrt{2}} \qquad \text{or} \qquad \nu_k = \sqrt{2} \cdot C_k \cdot \nu_0$$

(excluding the tritone interval, which is identical in both the melodic and harmonic interpretations).

All of the above can be seen in the following tables of the basic coefficients of the colour-sound tensions:

SPACE OF THE MELODY (VARIOUS TIME INTERVALS)

Intervals	Sound	Colour
minor 2	q	q
tritone	$\sqrt{2}$	$\sqrt{2}$
frequency 5	$\sqrt{2}q$	$\sqrt{2}q$

SPACE OF THEKEYS (KINSHIP)

Intervals	Sound	Colour
minor 2	q	$\sqrt{2}q$
tritone	$\sqrt{2}$	$\sqrt{2}$
frequency 5	$\sqrt{2}q$	q

Space of the harmonic (simultaneous) intervals

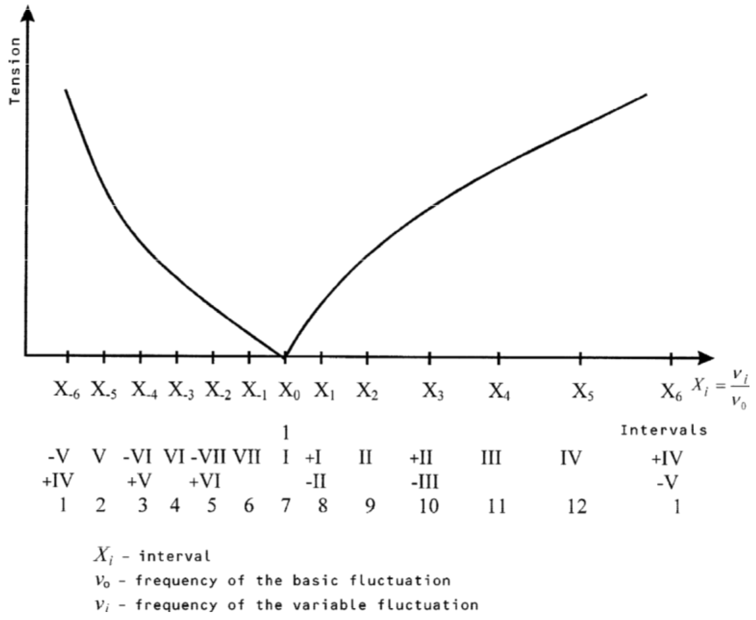
Intervals	Sound	Colour
minor 2	q	$\sqrt{2}q$
tritone	$\sqrt{2}$	$\sqrt{2}$
frequency 5	$\sqrt{2}q$	q

Space of the functional inclinations

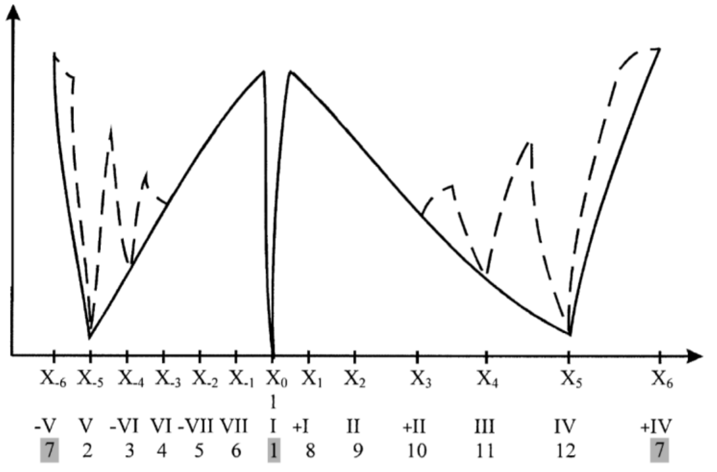
Intervals	Sound	Colour
Chromatic semitone	q	q
S/D alteration	q	q^2
Diatonic semitone	q	$\sqrt{2}$

The following diagrams demonstrate the correspondence of the sound and colour steps in conditions of an identical character of the change of the interval tensions.

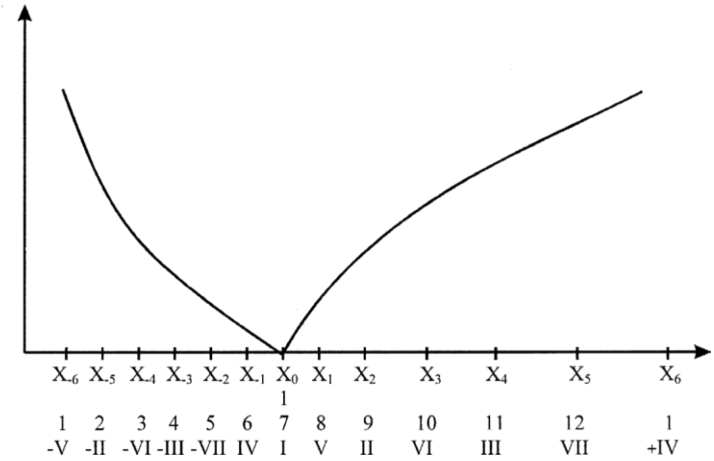
Melodic intervals



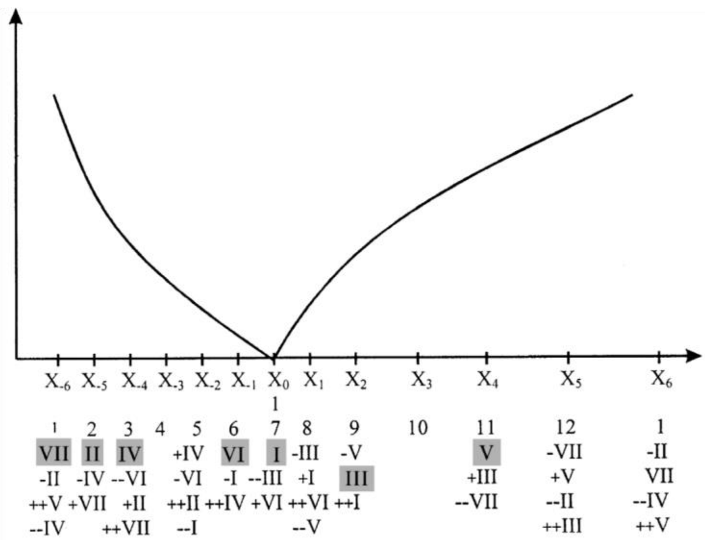
Harmonic intervals



Kinship relations



Intra-harmony (functional) relations



It is now time to pay attention to the specifics of the colour enharmony, which is well illustrated by the cardinal aspiration towards colour completeness:

n+6	VII ≡ -II	→	I n
n+6	+I ≡ -III	→	II n
n+6	+II ≡ IV	→	III n
n+6	III ≡ -V	→	IV n
n+6	+IV ≡ -VI	→	V n
n+6	+V ≡ -VII	→	VI n
n+6	+VI ≡ I	→	VII n

The arrows indicate the supporting steps; n is the number of the colour.

To get a various-stepped character, the changes of lightness in an interval range of the size of the steps should be defined with the help of a geometrical progression — analogous to the steps of the sound musical series. If, for example, the range of the change of lightness is equal to n and the number of steps is twelve, the denominator of geometrical progression q is calculated by the formula $q = \sqrt[12]{n}$.

The link between sound and light is precisely determined by the mutual correspondence to the Weber-Fechner psychophysical law. Man perceives not the absolute, but the relative growth in the power of the irritator (light, sound, load on the skin, etc.), i.e. $\frac{dR}{R}$, where R is the power of the irritator and dR is the growth in the power of the irritator. The increment in the intensity of sensation dE is proportional to the relative increment of the force of irritation $\frac{dR}{R}$:

$$dE = a\frac{dR}{R} \quad (1)$$

where a is the coefficient of proportionality.

This differential equation defines the link between the intensity of sensation E and the power of irritation R acting on a sense organ:

$$E = a(\ln R - \ln R_0), \quad (2)$$

or

$$R = R_0 e^{E/a} \quad (3)$$

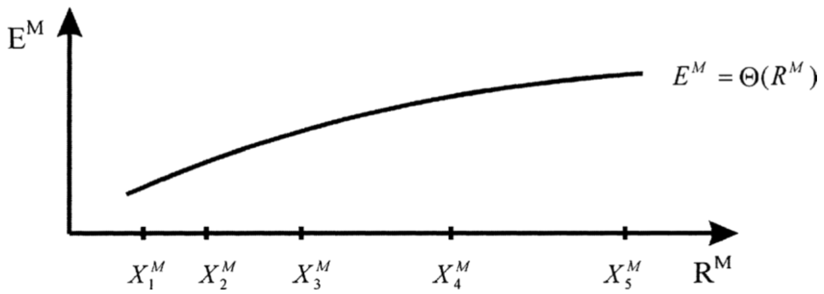
where R_0 is the power of initial irritation.

Formulae (1-3) are the mathematical expression of the basic psychophysical law — the Weber-Fechner psychophysical law. According to this law, in order to make the intensity of sensations E grow in arithmetic progression, the power of irritation R causing them should grow in geometrical progression.

When listening to intervals in the order minor 2, major 2, minor 3, major 3, pure 4 (the volume of a tetrachord), the following is clearly defined: the intensity of the sensation of tense sounding grows by the degree of the increase in the melodic interval.

By degree of the increase of the harmonic interval, this intensity of sensation, on the contrary, decreases.

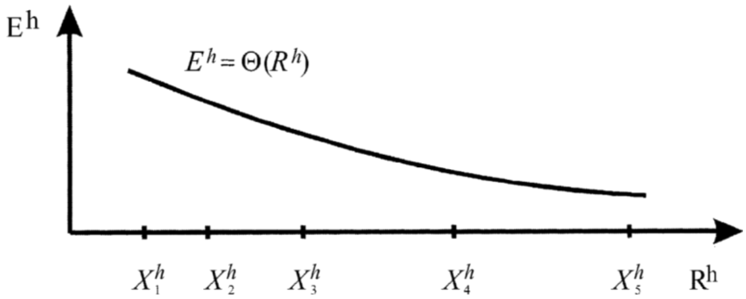
MELODIC INTERVALS:



where R^m is the size of the irritator (melodic)

E^m is the intensity of sensations

HARMONIC INTERVALS



R^h is the size of the irritator (harmonic)

E^h is the intensity of sensations

In the case of melodic intervals, the function on the given section is increasing. In the case of harmonic intervals, the function is decreasing. It follows that

$$\frac{dE^M}{dR^M} > 0 \quad , \text{ and } \quad \frac{dE^h}{dR^h} < 0$$

In both cases, the various-stepped colour series shows: $\frac{dE}{dR} > 0$

The required effect is achieved by the transformation of the colour melodic interval into an harmonic interval via the coefficient of a tritone.

We know that any colour can be obtained by mixing definite components of each of the three main colours, for example, green, red and blue. Colour X is created by a mix of quantity a of colour A, quantity b of colour B and quantity c of colour C:

X = aA + bB + cC

If components a, b and c are proportionally changed in this equation, the result will be a light of the same tint, but a different richness.

An analogue can be drawn here with the richness of sound, which is achieved by mixing harmonics (overtones) in the necessary proportion, thus creating sounds of various quality (timbre).

The decomposition of the sound fluctuation into a Fourier series can be presented as follows:

$$\begin{aligned} f(t) = a_0 \; &+ a_1 \cos \omega t + b_1 \sin \omega t + \\ &+ a_2 \cos 2\,\omega t + b_2 \sin 2\,\omega t + \\ &+ a_3 \cos 3\,\omega t + b_3 \sin 3\,\omega t + \\ &+ \ldots \end{aligned}$$

where components a and b are the determining factors in the timbre characteristics of the given sound fluctuation.

Lightness and loudness can be regarded as the comparative energetic characteristics of light and sound, as the former are defined, correspondingly, by the size of the light energy and the size of the pressure falling on a unit of the area.

The Quarter Tone System

This system is based on the division of the octave into twenty-four equal intervals in 1/4 tones with a denominator of geometrical progression: $q = \sqrt[24]{2}$

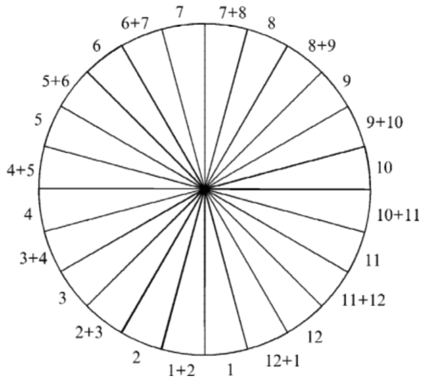
Accepting an intensity of the melodic interval of the tonic equal to one and of the tritone equal to twelve, we break the scale of tensions into twelve equal parts. We therefore get twenty-five points with the following coordinates on the plane in a rectangular system of coordinates in the interval from X = 0.707 to X = 1.414:

M_1 (0,707;12)	M_{13}(1;0)	M_{14} (1,029; 1)
M_2 (0,728;11)		M_{15} (1,059; 2)
M_3 (0,749;10)		M_{16} (1,091; 3)
M_4 (0,771; 9)		M_{17} (1,122; 4)
M_5 (0,794; 8)		M_{18} (1,155; 5)
M_6 (0,817; 7)		M_{19} (1,189; 6)
M_7 (0,841; 6)		M_{20} (1,224; 7)
M_8 (0,866; 5)		M_{21} (1,260; 8)
M_9 (0,891; 4)		M_{22} (1,297; 9)
M_{10}(0,917; 3)		M_{23} (1,335; 10)
M_{11}(0,944; 2)		M_{24} (1,374; 11)
M_{12}(0,972; 1)		M_{25} (1,414; 12)

The dependence of the tensions on the size of the melodic interval can be given by the equation of the parabola y = axI + bx + c, which is expressed by the empirical formulae:

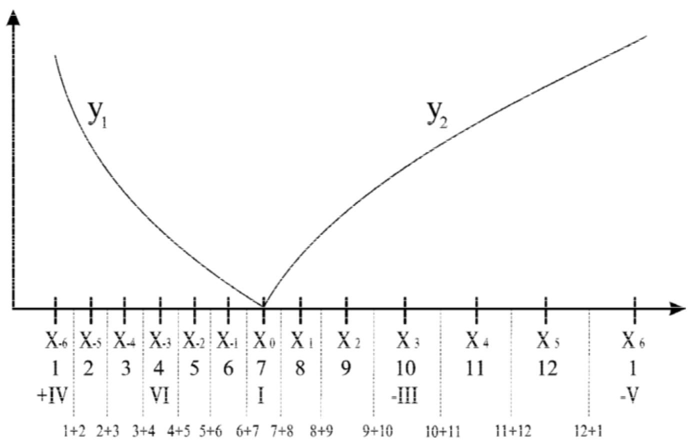
$y_1=25x^2 - 86x+61$, $(0{,}707 \le x \le 1)$ and $y_2=-12x^2+57x-45$, $(1 \le x \le 1{,}414)$.

The intensity of the harmonic intervals determined by the ear can be concretised by the colour relations in the same system of coordinates as the melodic intervals.

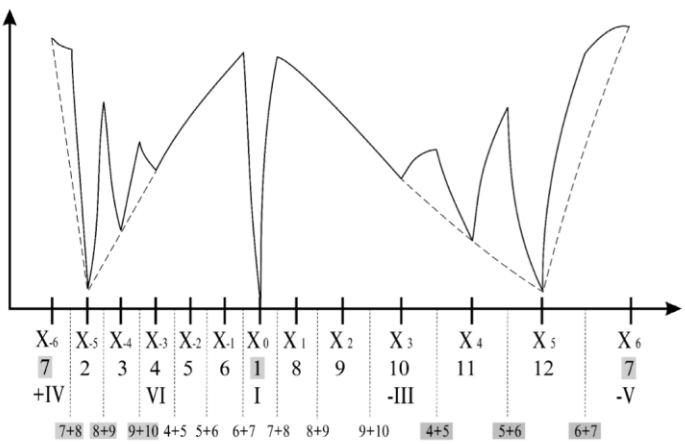


NUMBERS OF COLOUR:

VARIOUS TIME INTERVALS:



SIMULTANEOUS INTERVALS:



It can be noted in passing that the latter example traces the logic of the establishment of the semitone system (shown by the dotted line) — the basis for the historical development of European musical art.

Conclusion

When adjacent sections of the field of vision are of various colour, a mutual inductive change in the sensation of their chromaticity is known to occur. The colour contrast on the test object of grey is also discernable when there is an inductive change of lightness. If we quickly transfer our gaze onto a surface of white after a long examination of a surface painted red, the given surface will seem blue-green, and not white. In correspondence with the inductive lightness contrast, one might assume that a colour induced by a background would be supplementary to the inducing colour. Research shows, however, that the induced colour differs, albeit insignificantly, from the supplementary to the inducing colour along the colour tone by 10-40 nanometers in the direction of the smaller lengths of waves for dark-blue and in the direction of the larger lengths of waves for light-blue and yellow-orange emanations.

If a small patch of grey is placed on a red background, it will look light blue-green. If the background has a green-yellow hue, the grey patch will seem violet. Green located between yellow and blue, for example, will behave differently to the colour red in the same location.

The behaviour of colours thus depends on situations and their location. The behaviour of sounds also depends on the situation and location. Music is more than just the beauty of sound. A piece of music is always defined by the logics of the relations of the degrees of kinship — melodic, harmonic and intra-harmonic — where the same sounds can be manifested in completely different manners. All this diversity can, nevertheless, be reduced to a consistent sound series, forming a musical structure. This musical structure (in a range of approximately seven octaves) comprises and is capable of manifesting everything that has just been characterised, within the limits of any of the octaves to each of the familiar gamut. This opportunity is defined by the octave identicalness.

The suggested system of audio-visual stimuli follows these principles, permitting an identical manifestation of the logics of the relations typical of the musical structure. What is more:

1. The difference in the colours of the spectrum is explained by the different lengths of the wave of light, just the same as the difference in the pitches of the sounds in an octave is explained by the different lengths of the sound waves.
2. The logics of functional transitions in T-S-D relations corresponds tothe effect of the sensation of intensive gravitation, similar to the phenomenon of colour induction corresponding to the aesthetic principle of colour completeness.
3. The phenomenon of supplementary colours in a spectrum indicatesthe psychophysical basis of the adequate perception of interval relations. This is also underlined by the sum of the integrals $\int_{(n)} + \int_{(n+6)}$ = standard units of effectiveness (see the figure on page 46).

Although the neurophysiological mechanisms of the perception of colour and sound are different, the common principles of the processing of information allow the relations of the interval tensions of sounds in acoustical modality to be correlated to the relations of the interval tensions of colours in visual modality. The application of audio-visual stimuli can, with maximum effectiveness, help to form an emotional state defined by the algorithm of a piece of music.

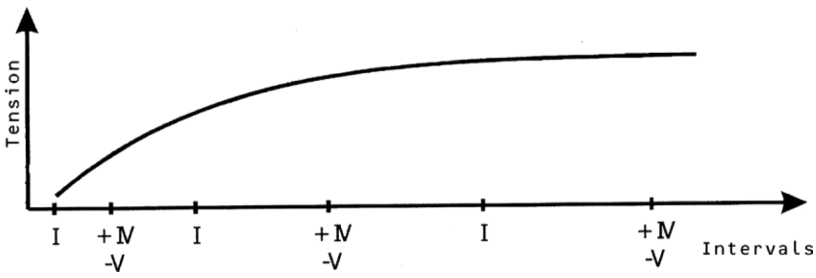
Uniting in an adequate manifestation of the algorithms of the musical structure, the qualitative differences of sound and light also influence the process of musical thinking, defined by the characteristics of the visual process. In relation to the logics of the parallel lightening of the colour tones, the impact of the gradations of white enjoys a certain self-sufficiency.

In colour-sound practice, it is necessary to take into account the specifics of the spatial manifestation of the least structural elements of musical forms — motif, phrase, clause and period. Their colour-light construction should be realised, for example, in the same way as typographical print setting, when each following sign manifesting itself does not close or cancel the previous one. A repeat exposition of a theme or fragment in another colour key or the justified variation of comparisons colour-sound spaces are possible.

The practice should be taken into consideration by the logics defined by the following factors.

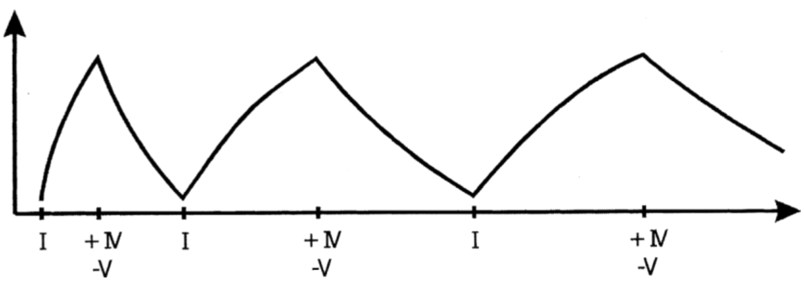
1. The space of the functional inclinations in all cases records the colouridentity of the introductory tones standing a half-tone “lower” or “higher” than the tonic.
2. The values of brightness (achromatic tones) and the values of the lightness of the colour tones are established in correspondence to the limits of the given sound-height range (monochrome movement is also expedient under timbre-light associations).

For example:

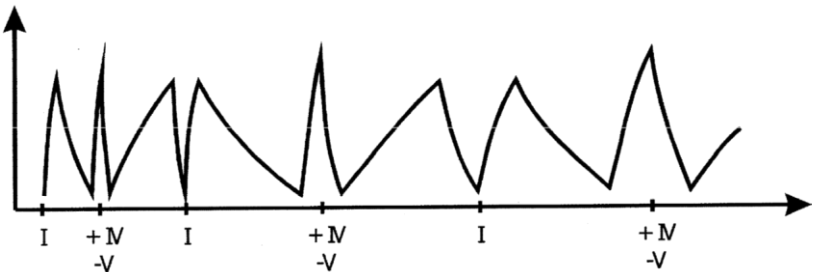


3. Octave periodicity of colour tones and sounds:

In the melodic aspect



In the harmonic aspect



Modern musical instruments (for example, synthesizers) are easily commuted with lighting appliances, allowing the use of musical notation as colour-light symbols. When engaging in tonal reconstructions, it is expedient to follow the algorithm of the line in the Luce part, as suggested by Scriabin. Each of the instruments reproduces the colour-light combinations in correspondence with the tuning defined by the features of one or another coloursound space.

Work is currently proceeding on the attempt to implement the aforementioned system. Under the guidance of the author, Boris Bokatovich, a post-graduate student of the Department of Computer Systems and Networks at the St Petersburg University of Aerocosmic Instruments, has created a computer programme experimentally confirming the tenets of the theory of audio-visual stimuli.

In conditions of the simple rationalisation of modern technical resources, the colour-light relations will be transformed naturally into sound relations. This will allow any visible subject to be heard, including, for example, the harmony of the spectra of electromagnetic emanations of various chemical elements.

Finally, in a “musical-philosophical” key, Wassily Kandinsky’s “painterly-philosophical” concept is logical manifested: “In each epoch, the style of personality and time forms many exact forms which, despite what appear to be major differences, are so strongly and organically akin to one another that they can be regarded as the one form; its

internal sound is, ultimately, the one main sound. These two elements are subjective. The whole epoch wants to reflect itself and artistically express its own life. Just like the artist wants to express himself and only depicts forms mentally kindred to him. Gradually, however, the style of the epoch is formed, i.e. to a certain extent, the external subjective form. In comparison with this, the purely and eternally artistic is an objective element, which becomes clear with the help of the subjective.”

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