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On Colour

Optical aspects of colour in visual arts

The Variability of Light

WHAT IS LIGHT

The term “light” often assumes various, modified meanings; the word is also used figuratively in physics although physics only studies the objective aspect of natural phenomena rather than the reflection thereof in our consciousness, thus merely examining the objective essence of light – luminous energy. In reality, and in its inherent meaning, light is something we experience; we realise light trough perception by our visual system. Without vision, there would be no light for us just like there is no light for us in the radiations outside the sensitivity range of our eyes (e.g. ultraviolet or X-rays). Light is contained in our consciousness and, therefore, it is primarily a psychological phenomenon in this sense. It acts here as a sensation, a feeling while the physical aspect thereof is just a stimulus, impulse or the objective essence thereof. The term “perception” is sometimes used; however, the word is almost always determined in a more comprehensive context, e.g. when taking in an object with all of the features thereof. The perception in this case would be, *inter alia*, the colour.

THE THREE METAMORPHOSES OF LIGHT

Light around us is demonstrated by its innumerable transformations. It is heterogeneous if coming from various sources; it changes when passing through various environments or being reflected by the surfaces thereof. The abundance of the manifold luminous phenomena discloses three specific features of their variability:

E.g. cloudless sky appears to be blue, a lawn green, evening glow red. This difference which is presented with particular distinctiveness within the rainbow light arrangement, the spectrum or sunbow, is called the colour of light.

We also distinguish differences in light changes on the light vs. dark scale. For instance, snow radiates its whiteness while the dark colour emphasises tree trunks and branches against the snowy environment. The lawn areas appear lighter in sunshine and darker in shady spots. Even individual colours have different levels of lightness when compared to one another, e.g. dandelion flowers shine more against the green grass while the blue of a cornflower appears darker amongst the yellowish leaves of ripening wheat. The individual tones of a colour, or various colours differ from one another by their lightness.

Both the features, colour and lightness thereof, are still insufficient to characterise the appearance of the individual light changes. These are also demonstrated in the varying degrees of distinctiveness of the colour itself. For instance, lively, distinctive yellow adorns the flowers of many plants, while the area of freshly bared fir wood or a hay leaf only gives off a faint yellowish glow. Red lends skin colour a touch of light pink while it burns powerfully in poppy flowers or in the sunset glow. The strength of colour involved in various degrees in the sensation of light is called the colour saturation.

Therefore, variability of light occurs in three dimensions where each of the individual changes is determined by three features (or variables):

1. Colour – the individual changes thereof are classified by the spectrum. This is complemented by the colours of purple (magenta) and white.

2. Lightness – is the intensity of the perception of light, manifested in the light to dark ratios.

3. Saturation – is the intensity of a certain colour manifestation in the light perception regardless of its lightness.

DEPENDANCE OF LIGHT PERCEPTION ON THE OBJECTIVE CHARACTERISTIC THEREOF

The arrangement of our eyesight does not allow the same light stimulus or luminous energy value to generate the same perception of light, i.e. the same colour, lightness and saturation. Some properties of eyesight make this relationship rather complex. The adapting characteristics of our eyesight make us respond to different light stimuli with identical sensations. For example, the paper of a book page reflects light of different intensities on a cloudy day and on a sunny day, or it reflects a yellowish light in the yellow light of a lamp – and yet, it still appears white.

It is particularly typical that our eyesight reports light relations with as little modification as possible, although the objective values thereof change. Therefore, colour, if incorporated in a constant colour environment, retains a rather stable character of its phenomenon even under varying styles of lighting.

The relationship between a light stimulus and its perception might vary even with regards the same stimulus not always generating the same light perceptions. A representative example is given by Leonardo da Vinci in his book on painting. He refers to the moonlight which, during the day, does not show as radiant as at night, although the light remains the same. The examples demonstrate that a certain sensation of light, i.e. a colour, lightness and saturation, cannot be always expressed by the same objective value under differing circumstances.

COLOUR VARIABILITY AND ARRANGEMENT

The spectrum, the rainbow, involves a natural scale of individual colours, with just the magenta (reddish purple) range missing – they result from a combination of red and purple lights, and white is absent, too, as it is the result of a special spectral composition.

The sequence of colours in the spectrum: The first colour is red, followed by orange, yellow, yellowish-green, green, blue-green, blue, blue-violet, and the last colour is violet (table I). However, that is but a rough list of the order; in reality, the transformation from one colour to another is smooth, with no sudden changes and differences. The sequence should be completed with magenta colours constituting the transition between red and violet. If these are put between the two colours, the ends of the spectrum colour ranges will be connected, creating a continuous, closed colour wheel.

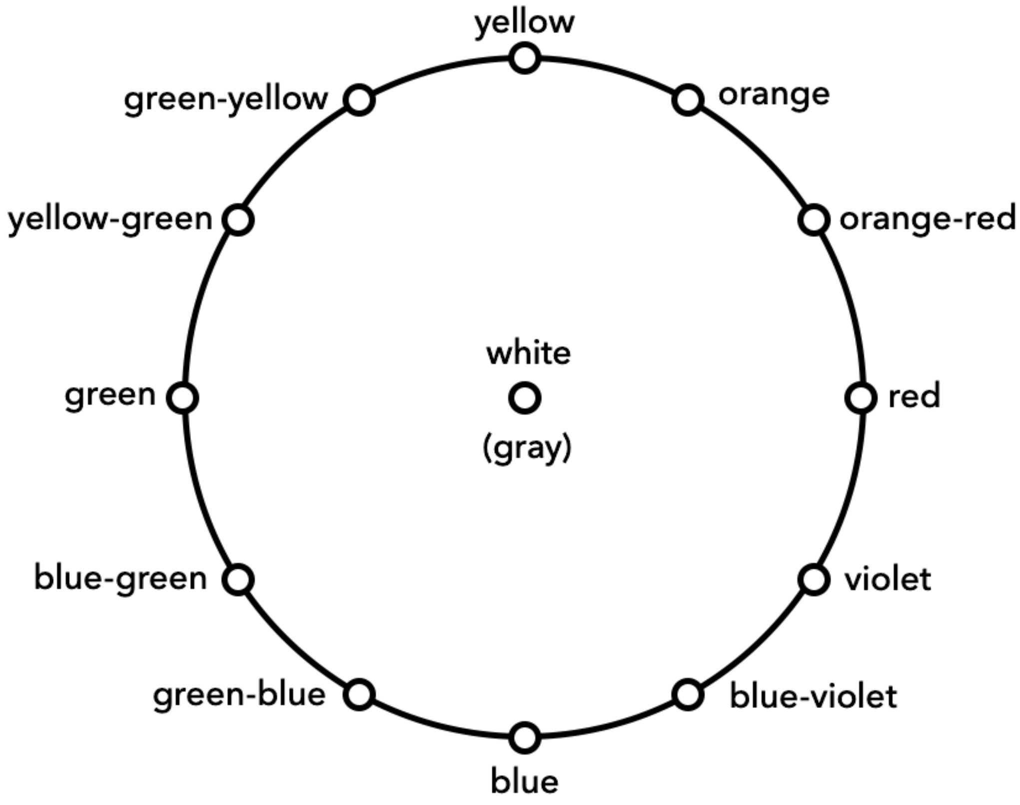

Fig. 1 The Colour Wheel arrangement

This method arranges colours along the wheel, placing them along the perimeter one by one according to their order in the spectrum, and closing the wheel with magenta. The colours which resemble each other most are located next to each other, e.g. red and reddish-orange; the more different they are, the further away they are located. The most different colours are located furthest from each other, i.e. on the opposite sides of the circle. So, blue is located opposite yellow on the wheel, cyan is opposite orange and the opposite pole of green is red. The colours of these pairs differ extremely not only by their appearance but also by many other opposite properties – therefore, they are called opposite colours. If lights of such colours are combined or merged in appropriate proportions to create a single light, they generate white light, complementing each other in the process and, therefore, they are called complementary.

The order of the colours along the perimeter of the wheel does not permit a suitable position for white. It would mean not only a break in the smooth transitions in the natural order of colours; it would also fail to capture the specific properties of white not possessed by the other colours. If, for instance, a white area is lit with a light of a certain colour, it reflects its colour with no modification. White paper does not change the colour of a drawing, watercolour painting, print or colour photograph.

This inactive, neutral behaviour of white towards the remaining colours as well as its other properties dictate that white be put separately in the centre of the colour wheel.

The colour schedule in the circular arrangement (fig. 1) has twelve members, not listing magenta which is linked to the section between red and violet.

Example: let us divide the wheel into quarters with two lines, perpendicular to each other, i.e. a horizontal and a vertical line, both running through the centre of the circle. Let us put yellow (light cadmium) at the top pole of the circle while the bottom pole is taken by blue (cobalt). Green (viridian) will be placed on the left end of the horizontal diameter of the circle and red (alizarin crimson) on the right end. The task is proposing the other members in the wheel to take the positions between these colours in order to create a circle of eight colours evenly distributed with even differences from one another. This means that e.g. a yellowish green should be mixed to appear between yellow and green and constitute the most precise appearance of the middle colour inserted between the two. Therefore, it may tend neither to green nor to yellow. Let us complete the circle in the remaining quarters applying the same method. Analogously, the method lends itself to application on another level, doubling the number of colours along the perimeter and achieving finer distinctions. The distribution also very roughly defines the positions of complementary colours as they should be located opposite each other (table I).

REFRACTION OF LIGHT

The term “colour” is used similarly to the various meanings of the term “light”. In a certain context, it applies to e.g. the sensation of colour, while at other times, it means the colouring agents, e.g. the colours of the palette. In the physical interpretation, colours mean the individual colour lights of the spectrum referred to by the relevant wavelength or frequency (vibrations per second).

In reality, the colours we encounter are the results of the various compositions of spectral lights. Not even such lights alone when obtained by means of the dispersion prism are quite simple, i.e.

non-composite single wavelength lights. They are usually termed pure spectral lights or pure colours even though they are also the result of composition, albeit within a very narrow range.

A slot placed in front of the spectral prism lets through not just a single ray but a number of rays constituting a passing light beam. Upon leaving the prism, each of the rays generates a spectrum and as the individual rays line up beneath each other within the width of the slot, so do their overlapping spectra (fig. 2). The tallest one, ray A, has the highest spectrum (A´); the bottom ray B has the lowest spectrum B´ while the spectra of the intermediate rays appear in-between. The resulting spectrum is formed by the overlaps and, therefore, does not only have single-wavelength lights in its individual spots; the prevailing light is of the closest neighbouring wavelengths.

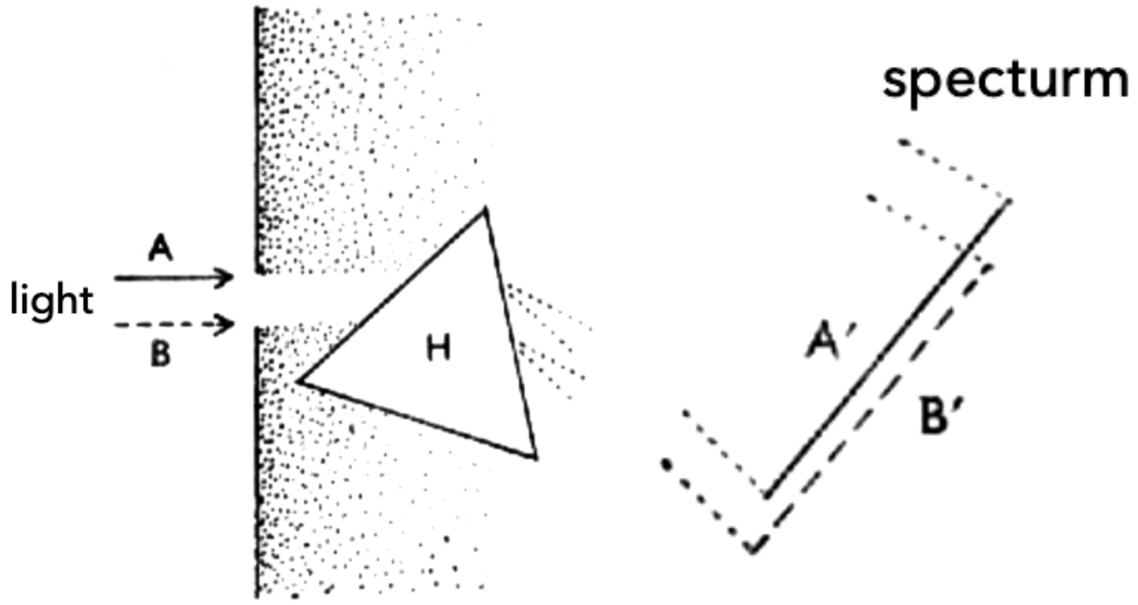

Fig. 2 Light diffraction by prism

PAINT SPECTRA

The spectral composition of paints, e.g. painter’s palette paints, can be assessed in a very simple manner. The light reflected thereby and dispersed by a prism is projected directly in the eye. Put a narrow strip of the paint on a large black mat on the table, parallel to the position of your eyes, or paint the mat directly with the paint in question. Hold the dispersive prism close to your eyes and turn it around its axis, slowly, to find the position which provides the image of the dispersed light for the eye (fig. 3). In this case, the paint strip replaces the slit for light in the prism. This will show us e.g. that saturated yellow paints reflect a range of colour lights from approximately half of the spectrum, from red to green. Similarly, deep blue paints reflect the range of another half of the spectrum, from green to violet (table II). Since the strip usually reflects a smaller quantity of added white light depending on the level of colour saturation, a weak reflection of the remaining parts of the spectrum is usually displayed as well.

If a white strip is put on the black mat, you will see the full range of spectral colours when you look in the prism.

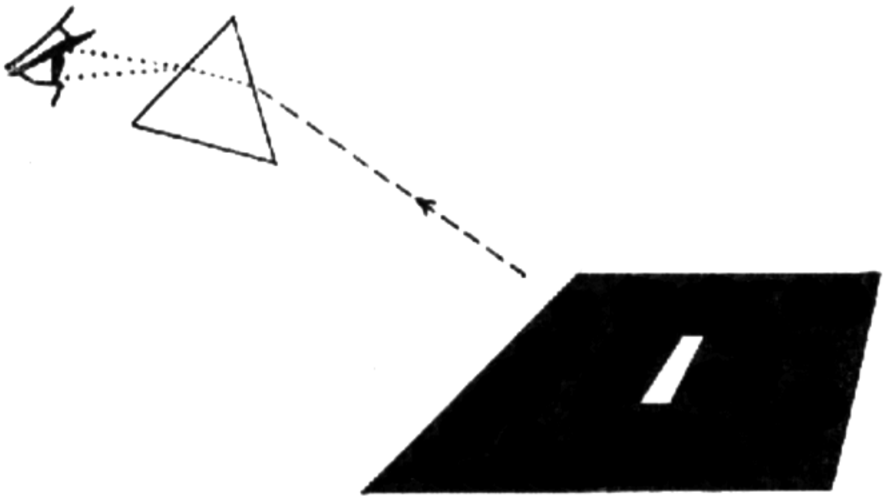

Fig. 3 Light diffracted by the prism projected into the eye

NEGATIVE SPECTRUM

A different, special spectrum (called negative) is shown by a black strip on an area of white. The rays reflected from the white mat along the lengthwise edges of the strip, are dispersed in the image thereof as emitted by the prism to the eye in a way combining red and violet light. This method of dispersion yields an image of a spectrum of equally excellent colours as the standard spectrum, although of opposite composition. It starts with turquoise, has magenta in the middle and ends with yellowish green. It lacks green just like the standard spectrum lacks magenta. The colours are lined together to the natural order thereof as in the former spectrum mentioned above (table II).

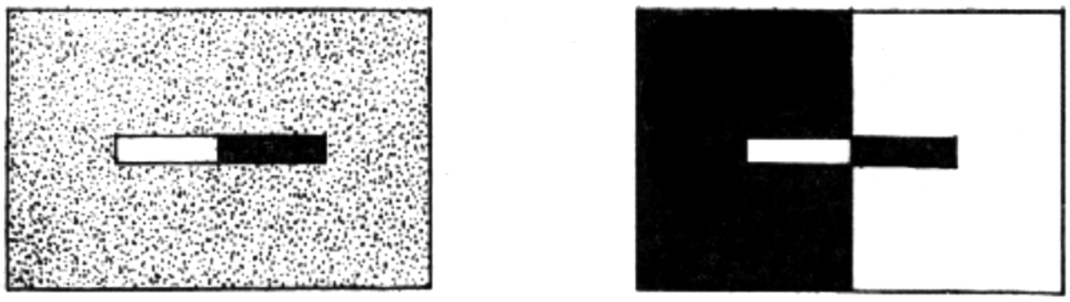

Fig. 4 White and black strips for simultaneous observation of regular and complementary spectrum

Both spectra, the standard as well as the negative, can be observed simultaneously: put both strips – white and black, of identical width – on a grey mat next to each other. Or follow the other method as suggested by fig. 4. The prism shows the eye the colour combination of both spectra in the close continuity thereof. There is a sharp separation of the two images, and the opposite complementary colours of the other spectrum face the colours of the standard spectrum.

Using slits of light and shadow of identical width, and projecting both spectra through the prism to the projection area to make them overlap perfectly (e.g. by redirecting one to the other by means of a mirror), the result will be white light. Therefore, the other spectrum is called the complementary or negative spectrum.

The observation of a spectrum projected directly into the eye, particularly if strips of excess width are used, might involve a case of a strip of white in the middle of the standard spectrum instead of green, dividing the spectrum into two parts. In the complementary spectrum, there might be a black strip instead of magenta. In such cases, extend the distance between the eye with the prism and the strips until the two separate parts of the spectrum are connected.

COLOUR MIXING

Classification of simple, or primary, colours on one part and mixed, or composite colours on the other hand is only sensible for colours serving as colourants, particularly paints. This classification, as well as the term for a secondary colour, i.e. a colour blend of two colours, or tertiary colour obtained by blending three colours, merely plays an auxiliary role of facilitating an overview of the mixing methods. For example, various kinds of green are mixed from the primary colours of blue and yellow. However, no green is obtained when the spectral lights of yellow and blue are combined in one spectral light. Besides, saturated paints, even the primary ones, are never physically simple – they are of a broad composition and, therefore, they are mixes. Each of the colours on the perimeter of the colour wheel can be obtained by putting together certain different spectral lights. For instance yellow is formed by combining orange and yellowish green lights.

The aforementioned classification of colours as simple and composed ones is even less sensible when our sensations thereof are taken into consideration. It would contradict the psychological opinion that considers colour a simple perception phenomenon rather than a combination of sensations. Therefore, so-called component theories determining colour as the resultant of several definite components, are largely refused as well.

SHADING OF WHITE

The highest, lightest level on the colour brightness range is white while the lowest level is black. The distinctive lightness levels of the remaining colours lie within this range, i.e. between these two extremes. Therefore, white dominates all colours through its lightness, black dominates due to its darkness.

There is a continuous sequence of greys between white and black – from the lightest to medium-light to dark which already borders on black. It is a simple direct transition which can be expressed by a straight line segment. Choosing a vertical line, black is placed at the bottom extreme and white at the top. In this linear arrangement (fig. 5), lightness increases smoothly and evenly in the upwards direction. The entire transition can be evenly divided into a certain number of degrees, with more pronounced differences, i.e. with rough divisions, or with slight differences which are more numerous and as fine as needed.

Fig. 5 The scale of white to black shades

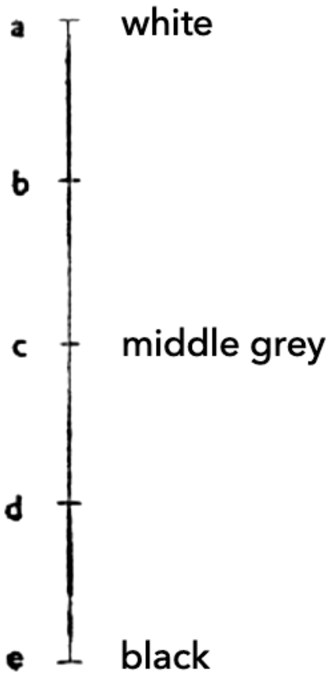

Fig. 6 Five-value greyscale

Example: mixing white and black poster paint, divide the white to black transition to an even sequence of five degrees (fig. 6). Solution: Start with mixing the middle degree, i.e. grey (c) which forms the medium-light point between white (a) and black (e). The suggestion of blue caused by the properties of coloured substance mixing can be eliminated by the addition of a minute quantity of yellowish ochre. Apply the paints on grey paper, in separate strips placed at even distances and in the natural order, white–grey–black. Then, make an assessment of whether the grey was estimated correctly, i.e. make sure it is neither too dark (closer to black) nor too light (closer to white) and adjust the grey accordingly (fig. 7).

The subsequent intermediate levels (b, d) are determined in the same manner. Apply all five stripes to the paper and assess their evenness.

The line will not look the same when applied to paper of a lightness level different from the paper on which it was designed and mixed. A lighter-coloured paper, particularly white, will render the dark degrees even darker by contrast while the contrast of a darker or black paper will lighten up the light degrees. The five-step line is already capable of delivering very distinctive visual expressions and can be used in visual arts.

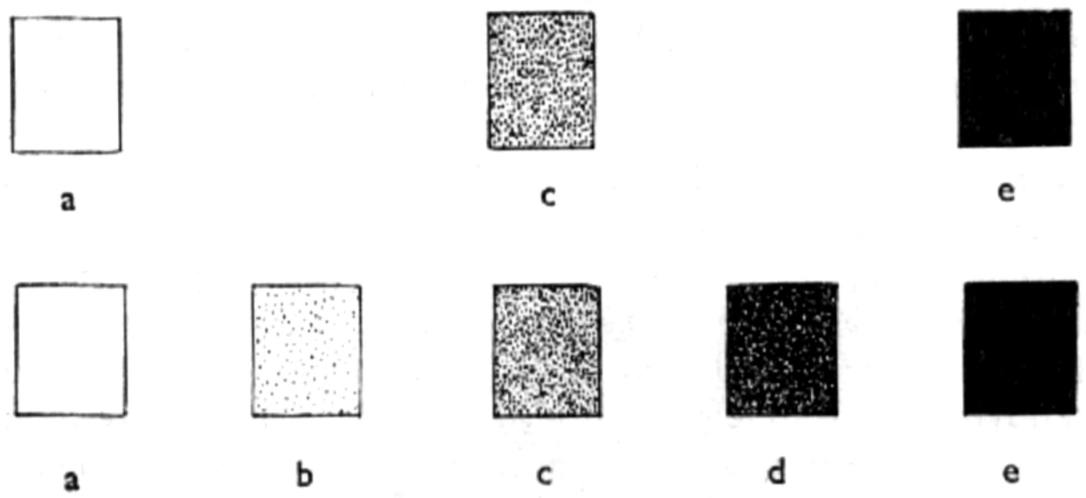

Fig. 7 Greyscale shades divided into three and five values

Greys are made when white is deprived of its lightness whether by adding black to white, or by shading a white area etc. In the white-to-black direction, this is a darkening process while the opposite direction, from black to white, is lightening. This is a way white is shaded and various degrees of whiteness, or tones, are created. The darkest one, the sensation of black, stands out under light rather than when surrounded by dimness; its distinctiveness depends in a complex manner not only on the physical essence, e.g. the lowest reflectiveness of light possible, but also, in various ways, on the properties of visual perception. At night or in complete darkness, e.g. in full black out, there is no sensation of complete blackness but rather of flickering dark grey.

The white-to-black scale has a significant range of application in multiple visual representation techniques, photography, press, charcoal drawing etc. The extreme white-black difference is exploited in various graphic techniques, especially wherever particular clarity is needed, in technical drawings, typography etc.

SHADING GREEN

The greyscale is of a special significance in the shading of other colours. Particularly in painting practice, a huge quantity of tints, shades and tones can be obtained when colours are mixed on the palette with white, grey or black.

However, the colour shading follows a more complex course than in the case of white. Let us elaborate in more detail on the variability of green in terms of lightness. We choose green because the process of mixing tones of green is least disturbed by the properties of poster paints which frequently and noticeably modify the colour in the process. Again, let us use poster paints for mixing purposes.

If white or light grey is gradually added to the green, a number of tints or tones of the green can be obtained which will appear to have various degrees of lightness based on the quantity of white or light grey added. Therefore, this is a process of modifying colour lightness which we have called lightening. Contrastingly, the gradual adding of black or dark grey to the green will yield darker and darker individual shades thereof. In relation to the preceding method, this is the opposite process from the perspective of lightness modification, and is called darkening.

LIGHTNESS ASSESSMENT OF THE COLOUR SHADED

Let us assess the lightness of the poster green paint itself as used for the sake of shading. If a sample of the paint coating were to be put on white paper, it would appear to be something dark on a white area. Contrastingly, on a black or dark grey surface, it would appear as a lighter patch. A negligible or no difference at all would be noticed if the sample were put on a medium grey area. Both the colours, green and medium-light grey, are of identical or almost identical lightness, and the medium grey expresses the lightness value of the green colour assessed (table IIIA, B).

Such matching of colour lightness is of significance in the practical colour composition design. In black and white photography, the essential requirement is the representation of an image in the greyscale with lightness ratios approximately identical to the colour lightness properties of the object photographed.

LIGHTNESS LEVELS OF THE SHADED COLOUR

The arrangement of the entire range of tones gives a clearer idea of the overall course of the variability in lightness of our choice of colour – green. It is a triangle in which the grayscale acts as the hypotenuse. Green is at one vertex and must lie perpendicular to the hypotenuse at the position of same-lightness level grey.

The link between the vertex, i.e. green, and white or a light grey is a line of increasing lightness which is practically obtained by adding white or light grey to green. Similarly, the link between green and black or dark grey forms a line of increasing darkness mixed of green and black or dark grey.

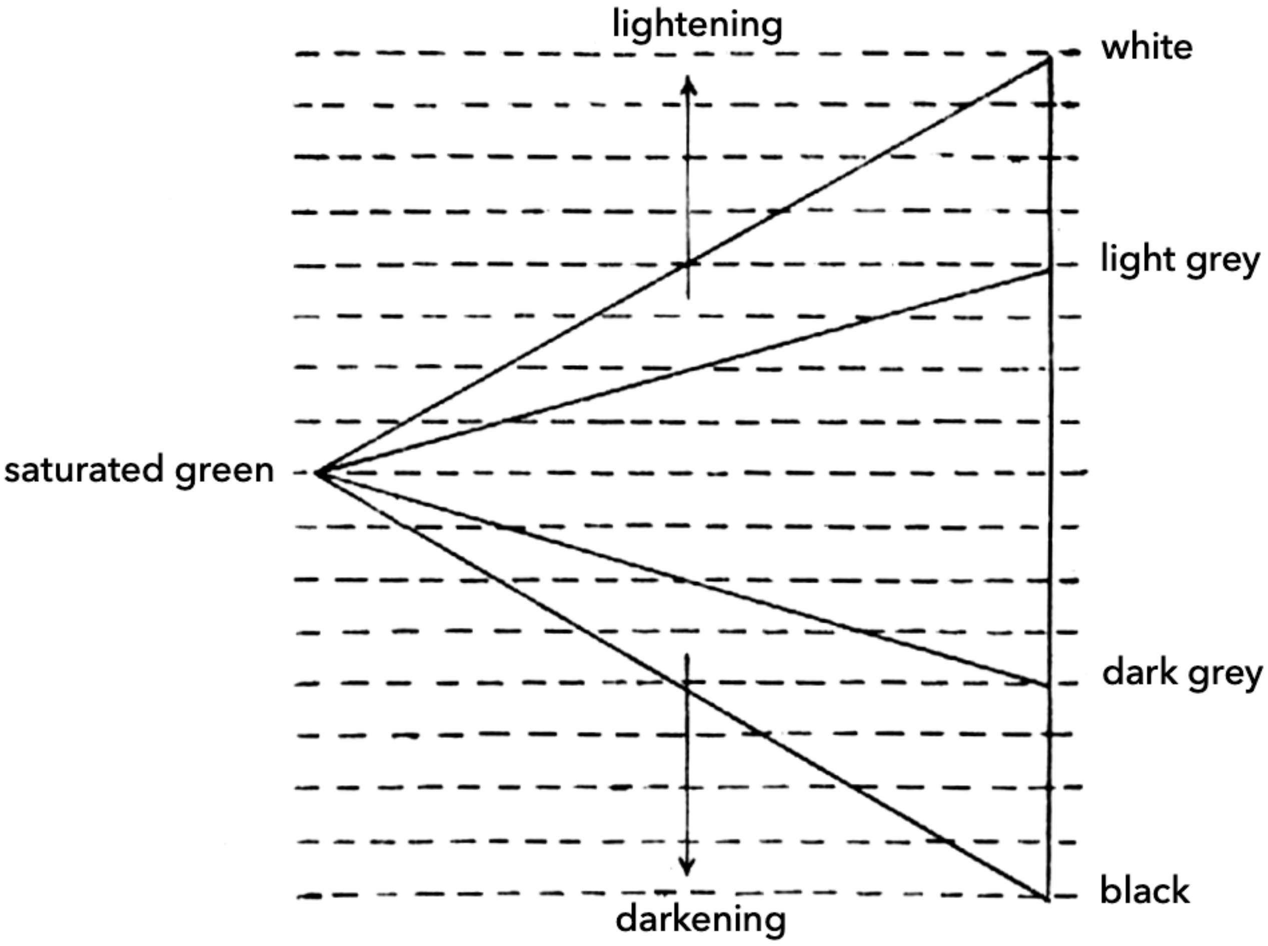

Fig. 8 Course of colour lightness in the triangle and the colour hue system

The triangle is thus a 2D form which groups all lightness transformations of the selected colour (green, in our case) in its natural context. The changes in lightness run along the vertical axis: lightness increases evenly in the upwards direction while darkness increases in the opposite direction, downwards. Upwards movement within the triangle, whether diagonal or vertical, means lightening while downwards movement means darkening (fig. 8).

SEQUENCE OF SAME-LEVEL LIGHTNESS SHADES

Within the triangle, movement in a direction perpendicular to the hypotenuse, i.e. to the grayscale, gives a special result. Such lines consist of tones which have identical levels of brightness. For example, in the top part of the triangle, the K–L link (fig. 9) means very light tones, where all of them maintain the same level of lightness; similarly the M–N line at the bottom involves an identical level of darkening in its deeply dark shades. The longest sequence of this type is the one perpendicular to the hypotenuse reaching the apex.

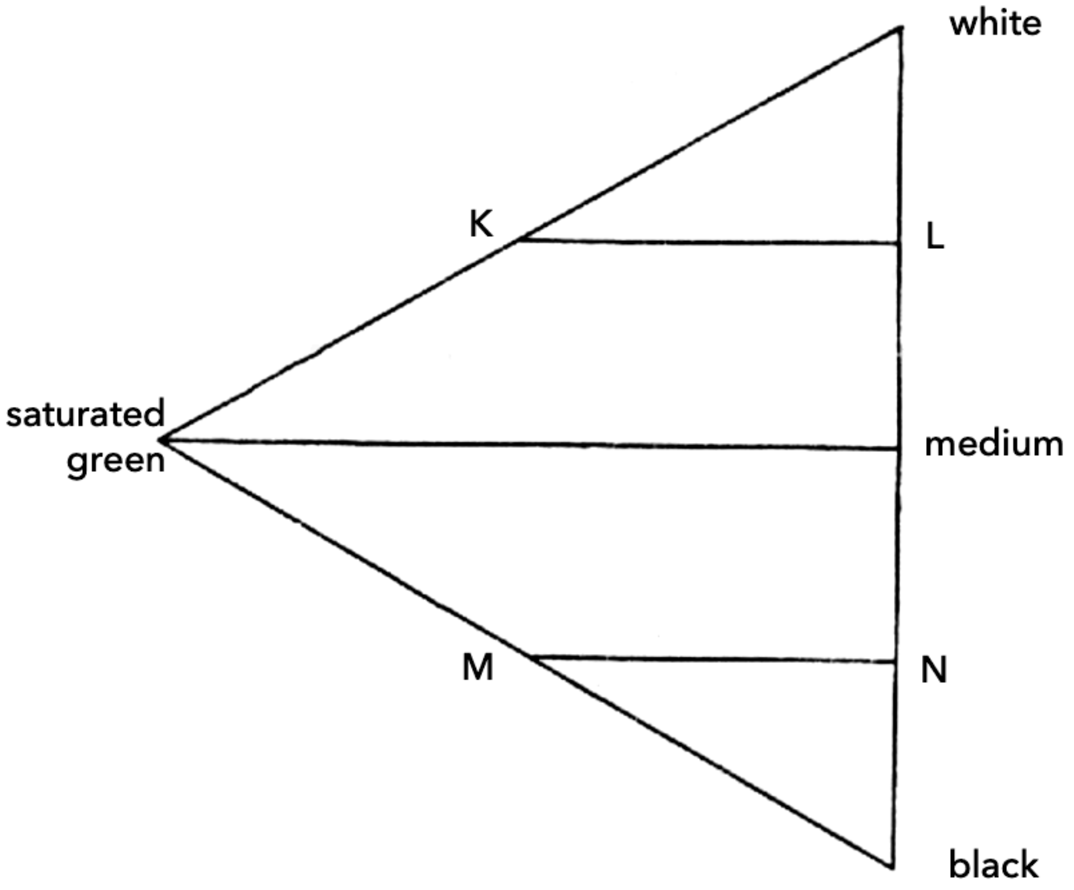

Fig. 9 Sequences of hues of constant lightness

DEPENDENCE OF COLOUR LIGHTNESS ON OBJECTIVE LIGHT VALUES

Although the brightness characteristics of colour depend on the intensity of light input, i.e. on the objective lightness values, this is a very complex kind of dependence. The eye's ability to greatly adapt to various luminous intensities is involved here. So, for instance, we see a black board in the classroom as black both on a cloudy winter day and on a sunny summer day when the blackboard actually reflects more light than a sheet of white paper on a dull day in winter.

However, there is yet another dependence in the relationship between a photostimulus and the sensation of light. For the feeling of increasing brightness to rise in even steps (a, b, c), i.e. in an arithmetic growth sequence, the photostimulus values (A, B, C) must grow in multiples, i.e. in a geometric sequence. The relationship between the stimulus and the perception is expressed by the logarithmic curve (fig. 10). This is a law of psychophysics, called Weber-Fechner law according to its originators. In perception, its validity is most approximate for low and medium light intensities. In the colour composition approach, this law is of a special importance particularly in the handling of light atmospheres in visual representation. Let us elaborate on the law with a simple example:

There is a rotating axis in the centre of a circular opening in a deep box inlaid with silky black velvet. Segments of coloured circles are attached to the axis; when made to rotate quickly, the segments generate circles of their colour, darkened, in combination with the black. Now, we should design the size of combined segments for five evenly darkened shades (a, b, c, d, e). Let us choose the limit angle sizes, namely the highest, i.e. full circle, a = 360 °, and the lowest, e = 180°, and put the intermediate segments (b, c, d) between the two. The steps will be determined based on a geometric sequence, i.e. with rounded angle sizes (fig. 11) of a = 360°, b = 302°, c = 254°, d = 214° and e = 180°. The rotation will yield five concentric rings of increasing darkness from the centre outwards to the edge of the circle.

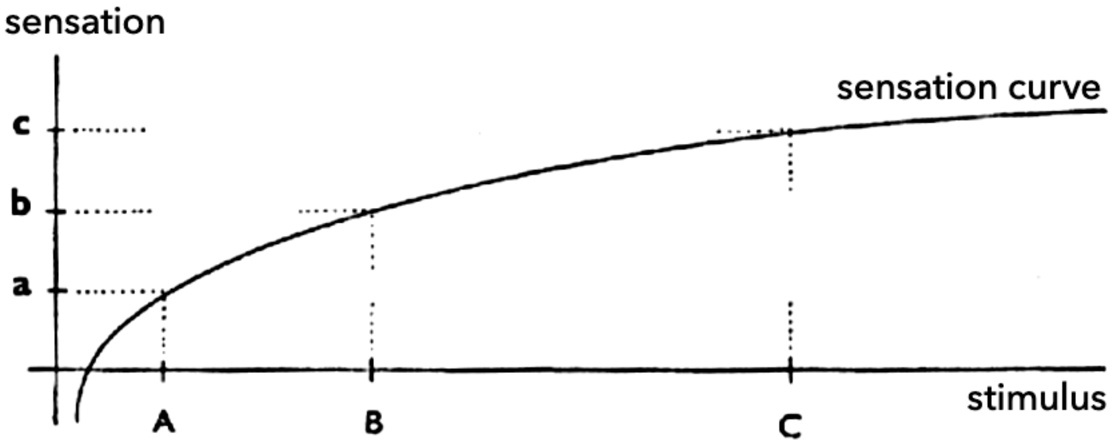

Fig. 10 Weber-Fechner law. The relationship between the increase of magnitude of a stimulus and the perception thereof

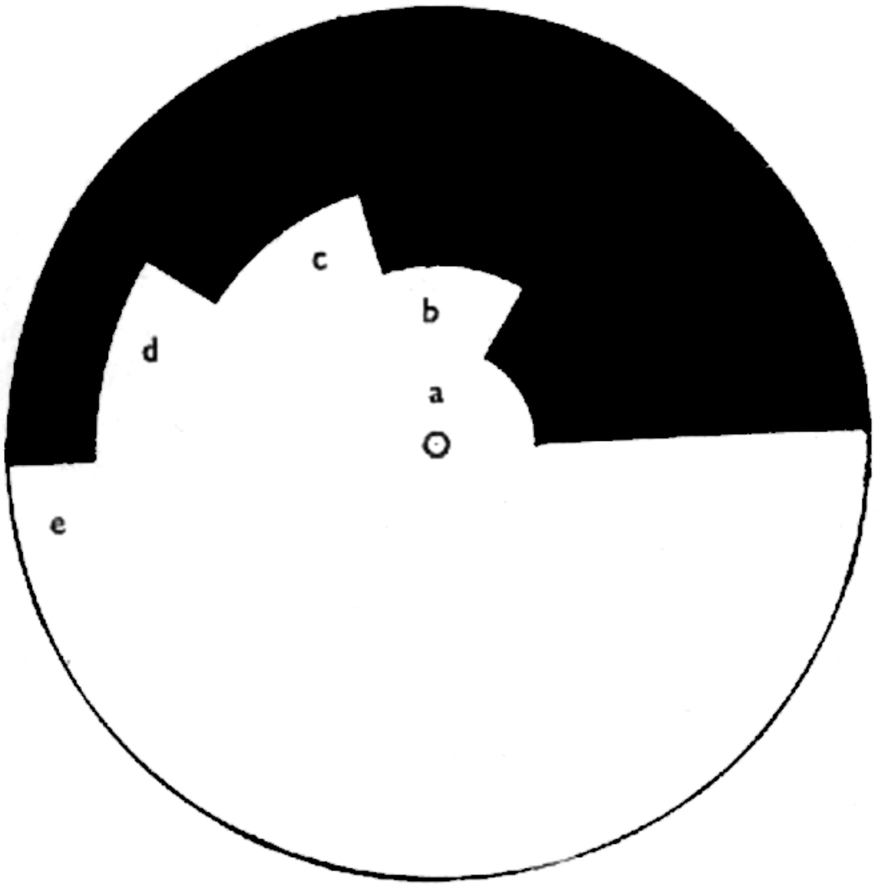

Fig. 11 Adjustment of rotating wedges for even darkening of colour

To a great extent, the lightness of colours changes with the influence of contrast. Even some special properties of visual perception may affect the evaluation of lightness. Ideas and experience already acquired are at play here, and we tend to process the colour of things based on what we know about it rather than how we see it. For instance, white walls of a room are realised as white while the cloudy sky of non-quantifiably higher luminous intensity appears to be grey, when we look out the window.

The variability of light even occurs within the spectrum to a certain degree; there is not just the colour transformation but also the changes to colour lightness. The lightest colours are yellow, the darkest blue, similarly to the distinguishing of saturated colour paints e.g. on the painter's palette.

VARIABILITY OF COLOUR SATURATION

An apt representation of the course of saturation changes in a specific colour is the same triangle we have already seen above, representing the lightness changes. Let us take the example of the same green we have already used to demonstrate the toning processes. Notice the scale formed by a line perpendicular to the hypotenuse and intersecting the apex, i.e. the line connecting saturated green and grey of the same brightness level. The individual steps on this line may be obtained e.g. by mixing the two paints, green and grey of the corresponding lightness, to a certain ratio. Increasing quantities of grey are gradually blended with the green. Such mixing yields specific colour grading. The individual grades achieved in this manner will not only be green but they will also maintain the same level of lightness, i.e. they will be balanced in terms of both colour and lightness. The only difference will be the lesser effect of green in the grades containing more grey; where there is less grey, the green will be more saturated. In this line, the most saturated green is in the apex of the triangle while the grey is the zero degree of saturation thereof.

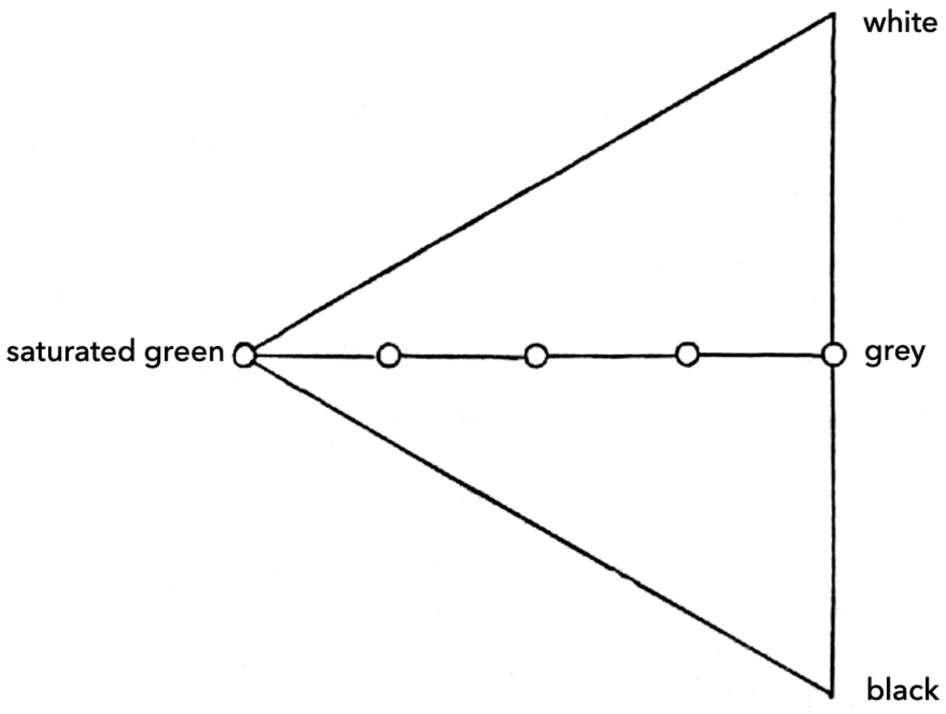

Fig. 12 Five-level saturation scale with constant lightness of hue

Example: Let us divide this line of equal lightness tones evenly into five grades (fig. 12). First, mix the grey so that it is neither darker nor lighter than the green applied. Assess strips of paint coatings next to one another as a test (tables IIIA, B). Subsequently, follow the same procedure as in the preceding exercises. First, propose the medium grade between green and grey, i.e. the medium saturation, and then the remaining intermediate grades. If this sequence were to be used for painting purposes, we would be surprised by its lack of distinctiveness and by its softness. The following explanation will point out some of its special properties, significant for the various practical uses and absent in any colour composition of unbalanced lightness.

COLOUR SATURATION CHARACTERISTICS UPON LIGHTENING AND DARKENING

Just as saturation decreases if grey of identical lightness is added, it also decreases when lightened up by adding white or light grey, or darkened by adding dark grey or black. The mixed tones are not only less saturated but, compared to the saturated colour they were derived from, also lighter or darker depending on the shading method employed. The procedures of shading affect lightness at the same time as saturation.

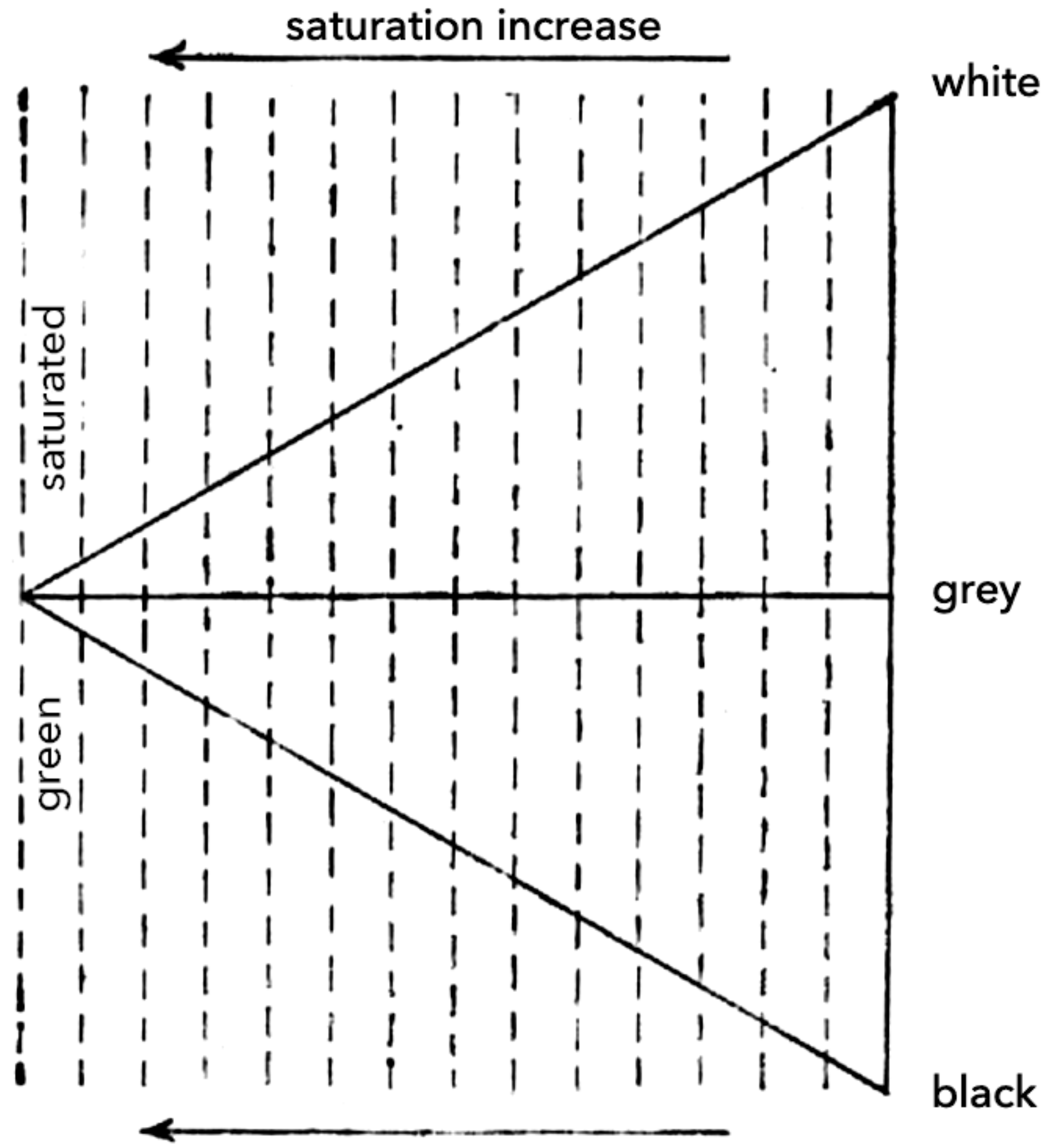

Fig. 13 Course of colour saturation increase in the triangular representation

Therefore, in the triangular arrangement of colour tones, the hypotenuse is the line of zero saturation. Saturation increases evenly in the direction perpendicular to the hypotenuse. For example, the more saturated the original paint used for the creation of the individual tones, the further away it is from the hypotenuse. If the saturation increase in the triangle were divided into steps, such steps would be arranged in vertical segments parallel to the hypotenuse as shown in figure 13. In each individual segment, going from the hypotenuse, saturation would be one grade higher although it would remain unchanged along the vertical dimension.

A special composition of tones is created with the steps located within the triangle along one of the lines parallel to the hypotenuse. The tones only differ from one another by their lightness while the saturation level remains the same for all of them. Therefore, this is a special set of tones held together by a saturation balance.

SCALE OF TONES OF IDENTICAL SATURATION

Let us design the scale with five grades of even distribution (fig. 14).

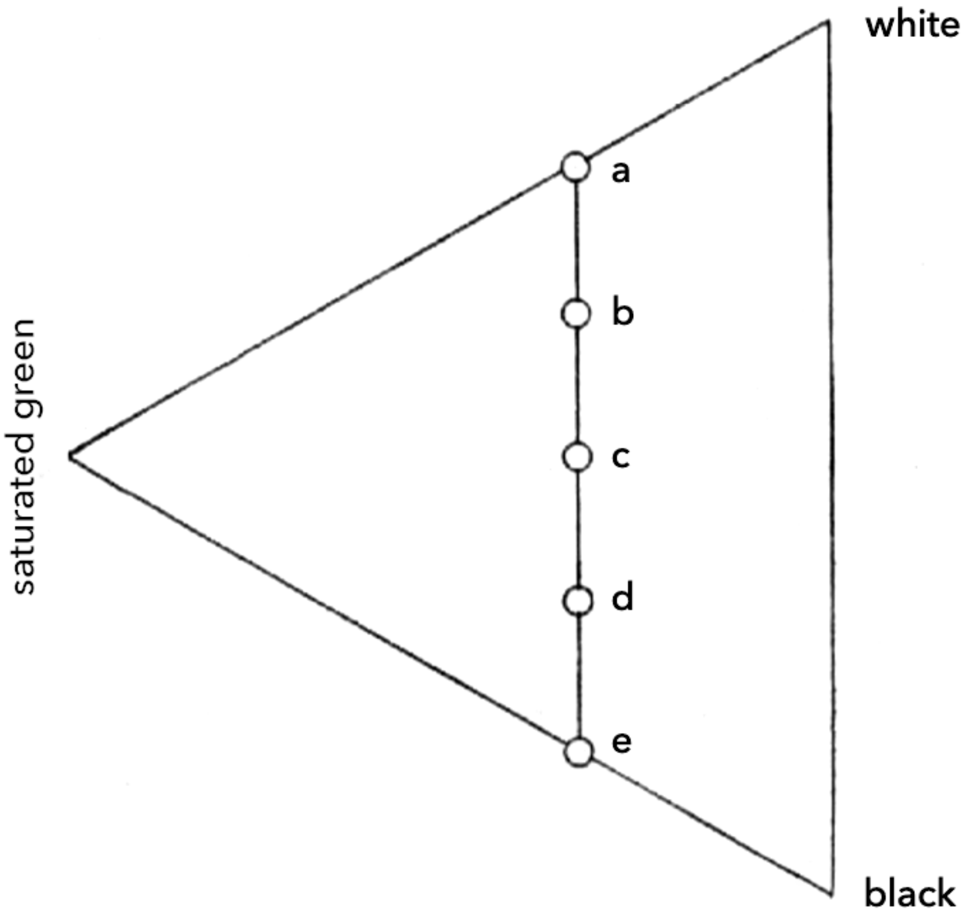

Fig. 14 Five-level scale of shade with constant colour saturation

First, mix a tint (a) lightened by an addition of white and a shade (b) darkened by the addition of black to the saturated colour. Apply a coat of the tones next to each other and test whether you managed to create tones of identical colour saturation level. With a little practice, estimation is no problem and this exercise is particularly effective for refinement of colour saturation relationships. Light degree (a) may not demonstrate a higher level of saturation or, in our case, greenness, than the dark degree (e) which would look greyish, if put next to the light tone. And vice versa, the dark degree may not demonstrate more of a greenness than the light one. Mixing the extremes will allow us to arrive at the intermediate levels (b c, d) (fig. 14). When black is added, the saturation level of the darkened shade usually looks too suppressed in relation to the lightened tint. If we do not wish to balance the accord to such low level of saturation and if our palette contains saturated dark greens, these should be used to enliven the darkened shade and the addition shall help us to adjust the darkened shade to the lightened tint in terms of both colour and saturation.

COLOUR SATURATION RATIOS IN THE COLOUR WHEEL

The gradation of saturation in individual colours also occurs in the circular representation thereof. Lower and lower saturation levels appear on smaller and smaller concentric circles (fig. 15). The centre of the circle, i.e. the position of white or neutral grey, has zero colour saturation.

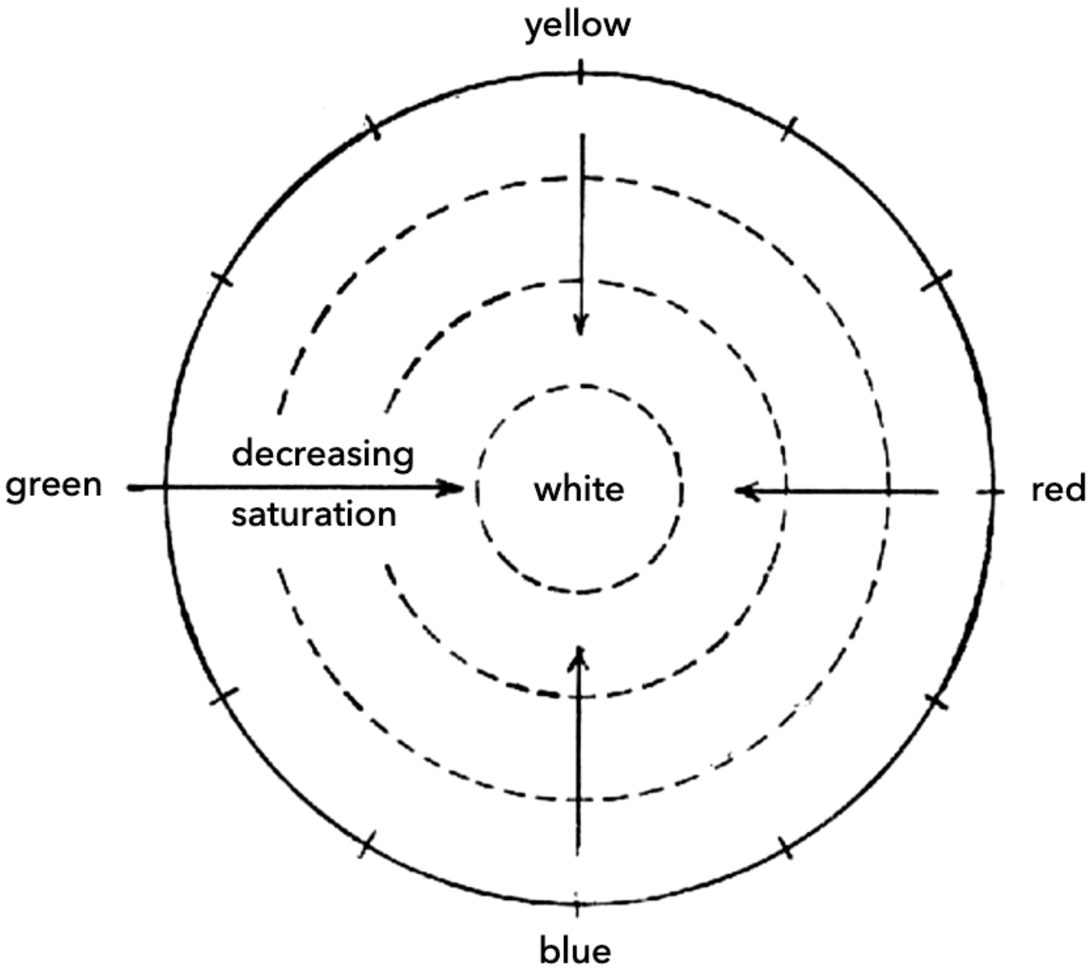

Fig. 15 Saturation-related colour transformation in the colour wheel

DEPENDENCE OF COLOUR SATURATION ON PHYSICAL PROPERTIES OF LIGHT

Physically, the level of colour saturation depends both on the ratios of spectral composition of light and on its intensity. When white light is added to coloured light, its colour saturation diminishes; this also applies to the mixing of paints when white or grey paint is added to the saturated colour. The light colour saturation also diminishes with a decrease in intensity; in the process of paint mixing, this occurs when black or dark grey is added. This is also noticed e.g. in a monochromatic object which does not appear to show as much saturation of colour in shadows as in light.

The spectrum achieves a high saturation level through a very narrow colour radiation composition. The sensation of a saturated colour is also caused by the extended composition of spectral radiations, e.g. deep yellow which reflects approximately one half of full spectrum radiation. The colour saturation of light can also be reduced through adding the complementary light, e.g. adding green light to red light.

Just like lightness, colour saturation is affected by contrast to a great extent. The sensation of colour saturation also depends on the time during which the colour itself is perceived. Any longer exposure, particularly in case of a saturated colour, tires our eyesight out and makes us subsequently perceive it as if with a lesser saturation. If such tired eyesight is offered a complementary colour in the next moment, this is perceived as a colour with more saturation. Just like the lightness ratios, the saturation ratios have a complex dependence on the objective part as well as on the nature of perception.

Sometimes, the term “colour saturation” is replaced by “purity of colour”. The meaning of the latter, however, is not as definite or clearly defined. From the point of view of physics, only spectral colours are pure, although even saturated colours resulting from a broader spectral composition demonstrate excellent purity. If colour purity is viewed from the perspective of colour as a perception only, the term “purity” has a broader meaning than defining the colours which appear most saturated as the purest colour sensations. Even less saturated colours can seem to possess excellent purity, e.g. the pink or other colouration of a transparent glass, the bluish hue of aquamarine etc. These are colours of modest saturation, and yet they cannot be called any less pure.

ADDITION OF LIGHTS OF COMPLEMENTARY COLOURS

If a white surface in a dark space is simultaneously lit by complementary lights then, with certain intensity ratios of such lights, the surface will appear white. Both lights combine (add up) here to generate white light; they complement each other to this result and, therefore, they are called complementary colours. To achieve the white result of the combination, the lights must be in a

complementary balance, i.e. they must keep a certain ratio of intensities or saturations. If, for example, green light prevails in terms of either intensity or saturation, the result would be greenish; with excess red, the result would be pinkish. A perfect complementarity of lights is also sensitive to the right mixing ratio, otherwise the result of the mix will not be white. If, for instance, blue-green light is used instead of green, this would mix with red light to give a bluish light. Contrastingly, a yellowish green light would mix with the same red light to create a yellowish result.

The circular colour model puts complementary colours in the opposite positions along the perimeter of the wheel. The direct link between them, which forms a diameter of the circle, has white in the middle as the neutral result of their mixing. From this neutral centre, the saturation of both complementary colours increases towards the ends of the diameter, and the highest saturation level is achieved on the perimeter. The diameter of the circle thus consists of a continuous line of colour grades of the transition between the two colours. A simplified scale (of five grades) of the addition is demonstrated by table IIa.

POINTILLIST COMBINATION OF COMPLEMENTARY COLOURS

Complementary colours cannot be determined by mixing coloured paints; however, there are some painters' methods of determining them, particularly the method of pointillist painting where tiny areas of two complementary colours are placed close together, in turns, until the entire surface is filled therewith. This is easily achieved e.g. by the mosaic arrangement where squares of red alternate with squares of green, as on a chess mat, or even more simply just by narrow colour stripes. From a distance, the tiny squares or stripes can no longer be distinguished and the two colours merge into a single hue. The resulting colour of the combination shows how well we managed not only to estimate the complementary colours but also the mutual ratios thereof to achieve the complementary balance. If the result of the combination has a neutral grey colour, the estimation was correct and delivered a complementary balance. However, if the area appeared rosy, it would mean red was prevailing and we would have to either decrease its saturation (by adding grey) or slightly expand the green stripes. The procedure in case of a greenish grey of the combination result would be analogous in the opposite direction – we would increase the area of red, or decrease the saturation of green.

This determination of complementary colours might involve situations where the colour ratio of the complementary pair is not well defined, analogously to the mixing of complementary lights. The resulting grey would be yellowish or brownish; in such a case, the green we choose should be a bit bluish or the red more purplish. If the resulting grey has a bluish hue, the green should be pushed towards yellowish green and red to orangey red.

ASSESSMENT OF COLOUR COMPLEMENTARITY BY MEANS OF ROTATING SECTIONS

Complementary colours may be made to merge also by alternating their images on the same spot in the retina at speed. While the image of the first colour is still lingering in the eye, the other colour comes in and the eyesight fails to notice the difference, creating the impression of a single colour. This occurs e.g. in cases of a fast rotation of a wheel divided into two sections with complementary colours.

To that purpose, cover two paper circles with one of the colours each. Adjust the centres to allow affixing to the axis of rotation, and cut the circles along the normal vector. Slide the two wheels onto each other along the cuts, as depicted in the following image (fig. 16). This method allows any angle proportion, and thus the entire transition scale for the two colours and the balance situation, i.e. the grey result of the merge in particular, to be created by gradual insertion of the sections. This could also specify the mutual complementary relationship of colours in the circular model which has been proposed as an example of a rough scale in the paragraph on colour variability.

POINTILLIST PAINTING METHOD AND ADDITION OF COLOUR LIGHTS

The comparison of the three methods of determining complementary colours raises an important question. The first method, i.e. lighting a surface with the two complementary lights at the same time gives a white result while the pointillist and rotating circle sections methods only deliver a grey result (table II).

In the former case, the two lights merge in the same surface, which means that each point of the surface also reflects both colours, resulting in a sum thereof. In the second, pointillist method, the two colours remain separate in the area regardless of how far away we get from them – even though in case of longer distances, the eye can no longer recognise them as separate colours, and the area appears to be monochromatic. Therefore, the result cannot be a sum as in the first case – just an average. If one of the colours reflects e.g. 40% of light and the other 60%, the average of the light reflected by spots of identical dimensions will amount to a total of (40+60)÷2, i.e. 50%; namely just a grey result.

It is important to know that the pointillist and mosaic style of painting will never result in a sum of lights, always in just a middle value. The same applies to the assessment of complementary colours on the rotating wheel. Here, the individual colours are separated both in terms of area and time during the rotation.

Experiments have been performed with a rotating wheel divided by sections in colours following the colour sequence of the spectrum. Even then, the result could not have been white due to the reasons just mentioned. Therefore, the explanation that the colours used are not as pure as spectral colours is not valid.

ARRANGEMENT OF COMPLEMENTARY COLOUR PAIRS

Each colour from a complementary pair constitutes a triangular arrangement with its variations. Both triangles share a single hypotenuse, i.e. the vertical sequence of white to black. The opposite nature of complementary colours means that their triangles are positioned opposite each other and lean against the hypotenuse. **In a pair of complementary colours of identical saturation, e.g. green and red**, the two triangles constitute a symmetrical form. The black-to-white vertical line then acts as the axis thereof (fig. 17a).

For the remaining colour pairs where the saturation of the colours is not identical, the arrangement obtained is irregular. The form of the blue and yellow complementary colour pair is the least regular. Saturated blue is the darkest of the other saturated colours while yellow is the lightest. What it means for their triangular arrangements is that each of the colours must be located opposite the grey of the hypotenuse which is defined by the same value of lightness. Therefore, the two triangles are irregular, just like the representation of their combination (fig. 17 b).

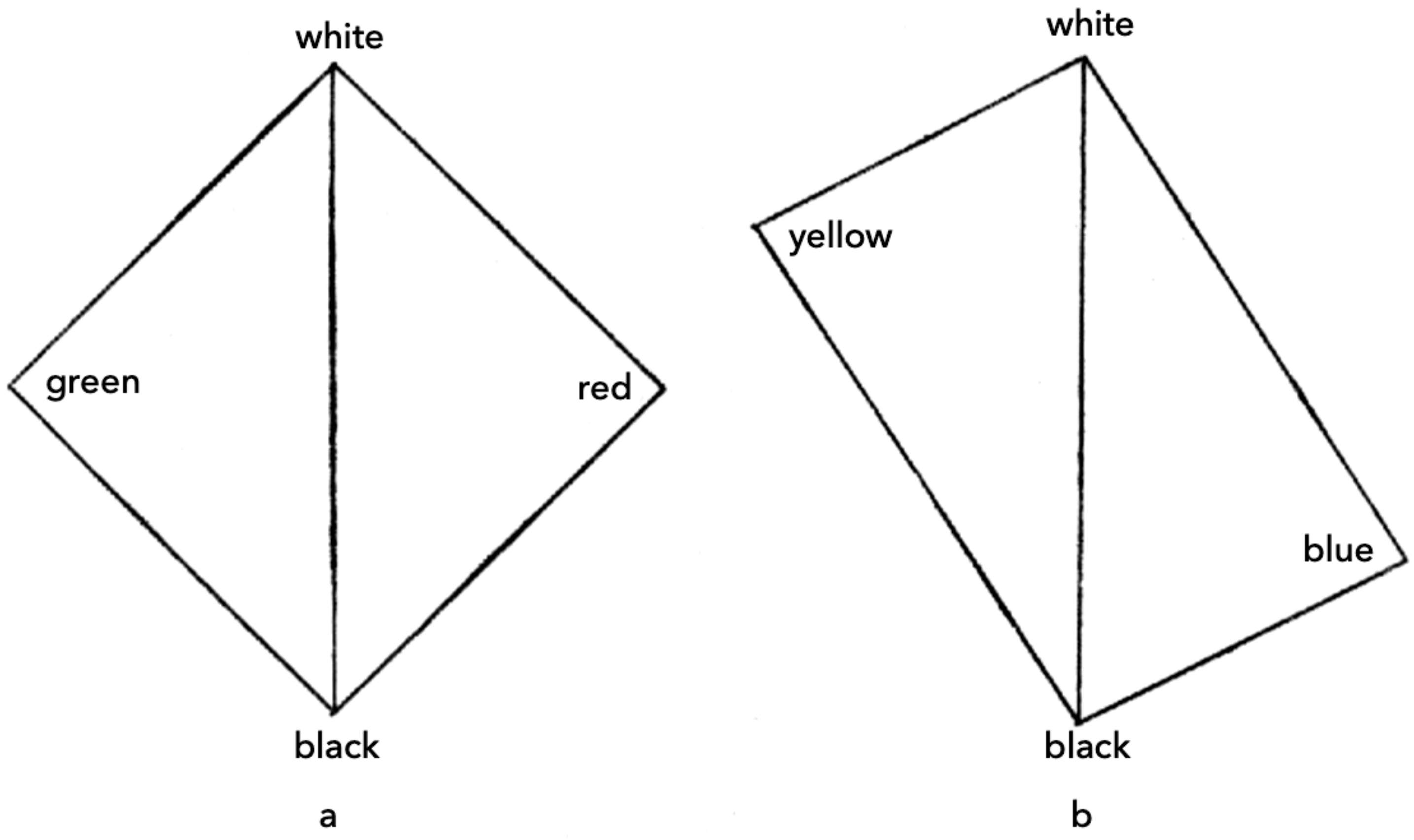

Fig. 17 Grouping of triangles with complementary colour arrangements

OVERALL LIGHT VARIABILITY MODEL

In the17th century, Isaac Newton, an important English researcher, placed colours evenly over an equilateral triangle in order to express the laws of colour mixing. Besides 2D systems, the progress in time has brought 3D systems: various forms of 3D representations, like a tetrahedron, a hemisphere, a cone etc. Further progress in the 3D solutions puts colour hues in a regular base-to-base bi-cone, as designed by **W. Ostwald**, a German scientist.

Recent times have brought a colour model based on the physical properties of light. The system was devised by CIE – International Commission on Illumination (Commission Internationale de l'Eclairage) which determines the hues by coordinates based on the wavelengths of the individual spectral components of light. However, this arrangement is the least fitting for the purposes of assessing colour relationships from various visual art perspectives.

After World War I, **A. Kirschmann**, a German scientist, published his design of colour variability arrangement in an improved bi-conical form. The base is not perpendicular to the shared axis of both cones but runs on an angle. This model considers the correct distribution of individual colours even with respect to their lightness value. Kirschmann builds his model on the sensory values of light, i.e. on what the colour essentially is, and on the natural relationships resulting from the visual perception properties. Therefore, the bi-cone is closest to the most appropriate system which would perfectly capture the relationships and laws of light variability.

A. Munsell, an American scientist, used the same starting point in his colour arrangement model.

COLOUR MODEL: BI-CONE WITH INCLINING BASE

So far, we have only looked at a partial arrangement of light variability: just the hue and saturation changes in the light wheel, just the lightness value and saturation characteristics of a single hue in the triangle. This means each of the systems explored only two variables and, therefore, a 2D form (wheel and triangle) were sufficient. However, total light variability occurs in three directions; the individual positions are distinguished by the hue, lightness value and saturation. Therefore, the best overall expression is only possible in 3D. The colour wheel and triangles of individual colour hues are used as the basis for the 3D modelling.

Each of the colours arranged along the colour wheel forms a triangle when arranged by hue. All of the triangles share the same hypotenuse, i.e. the black-to-white vertical line. All of them lean against the vertical line and create a circle around it, forming a base-to-base bi-conical form with the black-to-white line as the backbone (fig. 18). The shape is characterised by the typical inclination of the shared base of the two cones. The triangles of individual colours are not identical; the position of the apex changes step-by-step along the sequence, i.e. the position of the saturated colour spots where the lightness value must be identical with the grey of the same lightness, located on the axis of the bi-cone. As the lightest, yellow colours occupy the highest positions along the shared base perimeter, saturated blues (as the darkest colours) are situated lowest and the remaining colours are distributed within the range defined by the two.

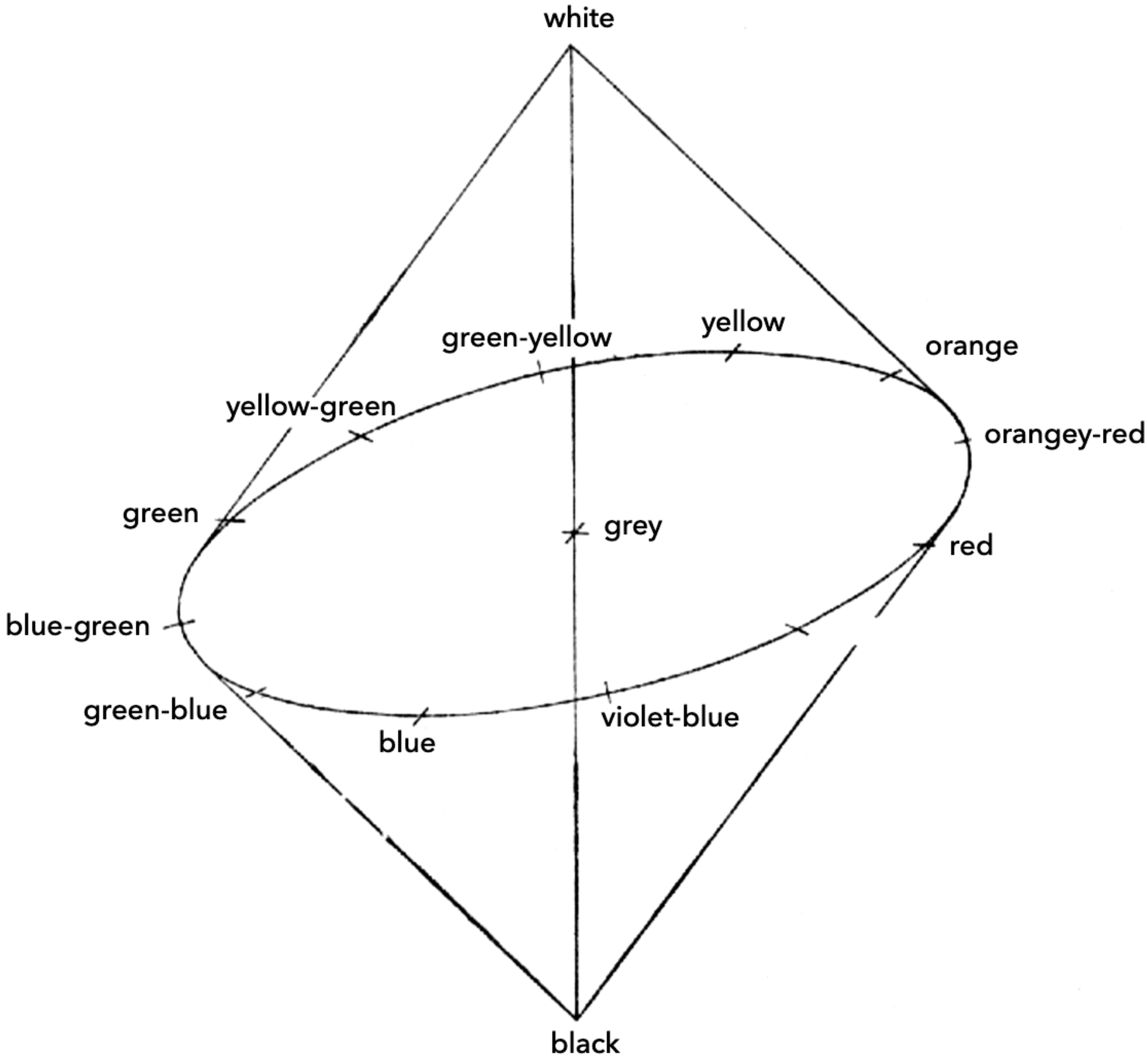

Fig. 18 Lightness variability bi-cone

The saturated colours in the sequence of arrangement along the colour wheel are distributed along the perimeter of the shared base of the two cones. The saturation gradually diminishes towards the axis; the value on the axis itself is zero. From the lowest lightness level, i.e. from the black at the apex of the bottom cone, lightness increases evenly upwards. A horizontal section of the cone, i.e. a section perpendicular to the axis, contains colours of the same lightness value where the degree corresponds with the height where the section was taken. A vertical section through the axis will create two triangles of complementary colour arrangements. Movement within the cone, along a line running parallel to the axis, means hues of a single colour and saturation value which only differ from one another as to the lightness value. Movement along a horizontal line crossing the axis of the cone contains the hues of a single colour and lightness value with saturation decreasing towards the axis. If extended beyond the axis, the line continues and follows increasing saturation in the complementary colour.

BI-CONE FORMATION CHARACTERISTICS

Science uses various methods in its attempts to assess interrelationships of the individual sensory values of light within its variability exactly. For instance, the changes of colour saturation upon lightening or darkening of hue are measured, the number of the smallest differences in hue upon colour transition in the circular arrangement is examined, the lightness characteristics of hues are measured etc. Such measurements are taken by empirically quantitative methods, i.e. by the most precise determination of the value possible, as much as the complex nature of perception allows. The measurements give us a more precise idea of the light variability course, thus providing improved conditions for a more precise modelling of the arrangement thereof.

The bi-cone as construed is the ideal model for the purpose at hand. Its form roughly corresponds with the colour variability range as achieved by artist's paints. Therefore, it suffices when used to imagine colour relationships in such restricted range of light variability. However, if we aim to capture the absolute scope of variability, particularly in terms of strong light perceptions, e.g. sources of light, high shine etc., in the bi-conical arrangement, the form of the bi-cone must change accordingly. The author of the model, A. Kirschmann, was aware of this fact. He points out that only once the individual courses and relationships within all light changes have been duly measured, the shape of the bi-cone can be modelled with more precision. As soon as he published his bi-cone, he stated it was not known how its envelopes are formed (unless they are collapsed), and the angle of inclination of the cone base was unknown as well. There was also the question of whether the tips of the cones were blunt or not.

COLOUR TERMINOLOGY

In the field of visual art, the colour terminology remains an open issue. Over time, a number of names have accumulated here, many of which are excessive or even detractive to a clear idea of the colour phenomenon. Terminology should not be overloaded by a multitude of terms, some of which are even understood differently; it should be as simple and as pertinent as possible. If variability of light follows three directions, then logically, three names should suffice to define the individual changes with the maximum precision possible. So far, we have used the terms colour, lightness and saturation. However, the first out of the three, i.e. the colour, is a problem. We are used to assigning it a broader, less clear meaning. Therefore, other terms like colour quality, type, tone and aspect are used. Particularly in visual art, we lack an established term which would be satisfactory. This book uses the term "colour" on its own, with no other specification. We try to manage with just this term alone, and leave the issue of potential other definition open. Some other terms, used rather frequently in artistic practice, have been handled in the preceding explanations.

Colour. This term is not always used in the same sense; sometimes, it is used to express a broader, more general meaning while at other times, its meaning is restricted. E.g. we can talk of dark blue and light blue colours even though they are just hues of a single colour, blue. We would not call a scrap of e.g. light orange fabric the same colour as a dark orange fabric. Some colour hues even have their very own names, not specifying the colour they are based on; these are called "colours" particularly often, e.g. brown, grey, black, olive, pink etc.

However, colour is assessed in another manner, too — watching a chair of orange beech wood, we would say there is just one colour although there are lights and shadows amounting to a difference in the orange identical to that of the two aforementioned fabrics. So, we no longer speak of two colours; we rather say that the shaded parts of the object have a darker hue of the colour found in the lit parts thereof. According to this other assessment method, the fabric samples should be called the same colour, although different hues. Having accepted the term "colour" in this latter, restricted meaning, the need for another term would not be as urgent.

"Coloured" as a term. We do not lend this term a simple, logical meaning. For instance, we do distinguish a colour photograph from a black-and-white one, although both black and white are called "colours". At the same time, the term "black-and-white" sounds as if there was nothing but black and white; the grey transition is lost. Besides, there is photography solely in the shades of blue, green, red etc., as obtained particularly through colour toning.

White light is also distinguished from coloured lights. Even here, we deny white the character of "colour", although it is called a colour otherwise.

Colour quality. The term has been used in scientific terminology for a long time, particularly in psychology. It defines what a colour is like, regardless of its lightness or saturation. For instance, grey is a colour of white quality, olive is a colour of yellow-green quality, brown of orange quality etc.

Colour purity. Spectral colours are termed "pure" even if they are nothing but a narrow wave composition just approximating the physical purity of a single-wavelength light. They are not easy even in the sensory evaluation of purity. If the intensity of their light gradually decreases, they lose their distinctive colour luminance until they fade out. This renders the important earlier definition of colour saturation which defines saturation as the ratio of pure coloured light and white light added thereto quite insufficient. For example, if a colour is shaded, it loses saturation without having any white light added to it.

The component theory defines the individual colour hues by their content of pure colour, white and black. The phenomenon of the hue depends on the mutual ratios of the three components. However, solely white or solely black can be added to the pure colour. The pure colour itself, containing no white or black, corresponds to the highest saturation level and, therefore, is sometimes called "full". With respect to this theory, let us recall that light contains no black at all as black is the absence of light.

The term "pure colour" becomes even more complicated within the context of common evaluation of colours, as well as in the artistic practice. Numerous lightened and darkened hues appear pure, for instance the rosehip flower calls out with pure pink. Particularly transparent materials, e.g. noble glass, demonstrate distinctive purity even with negligible saturation levels. Contrastingly, many tones and, particularly, those noticeably grey, give less of an impression, or no impression of purity at all, and are usually called desaturated.

There are some ways of representation in painting which require the colour expression of a picture to be in "pure tones" in general. The term "purity" is also associated with neutral colours and tones thereof. We can encounter the expression "pure white", "pure black", "deep black" or even "pure grey" if it has no tendency towards any other colour. Therefore, the term "purity of colour" in visual art has a broader meaning, difficult to fit into a simpler rule.

Tone. In the colour-related terminology, this word carries various meanings. Sometimes, it is used in a sense similar to the preceding term, i.e. quality of colour, defining what a colour is like. As such, it has been adopted by the International Commission on Illumination (CIE) as the term for individual colours. According to that, a colour may have a yellow, red, green tone etc. Recently, there have been attempts to give the aforementioned meaning to "tone" also in visual art. However, it is more frequent – and more fitting, actually – in relation to another meaning, namely that of tinting, lightening and darkening of a colour. The term is used in this manner particularly in Western countries.

Sound tones and, similarly, the individual spectrum radiations correspond to certain wave frequencies which carry the sound or light. This similarity has probably been the most important reason for introducing the term "tone" also to the terminology of individual colour differences. Here, however, it causes difficulties. Magenta colours only occur when spectral lights of very different wavelengths are combined. Therefore, they defy definition by a single frequency in the way the individual spectral colours are marked – unless the frequency of the complementary (green) spectral light is used. However, this is not possible for white which also results from a spectral combination; therefore, the colour is often called "toneless", as opposed to the other, "tone colours". This addition to the terminology makes it even more complicated.

Bright colour. The name is introduced in an effort to distinguish colours located along the perimeter of the circular model from the so-called desaturated colours located in the centre of the wheel. This is a term violating the sense of the word per se and introducing confusion in the terminology. Only a combination of colours can be bright; not a single colour in itself. A lawn or meadow with no flowers is not bright; it is just green and only if flowers blossom in the midst, the area flourishes with brightness.

White and the grayscale differ from the other colours and their liveliness. The more the other colours differ from grey, i.e. the more saturated they are, the livelier they are as well. Colour photographs render images in lively colours in contrast to black-and-white photographs. Therefore, this book uses the term "lively colours" as opposed to the neutral colour, i.e. white with its shades of grey, and black.

In this sense, psychological literature sometimes uses the term "coloured light" and "colourless light" meaning white light.

Desaturated colour. This is actually a less saturated colour and this term is a better way of showing how the colour tone changes. The "toned colour" probably comes from the process of mixing two different colours on a palette where e.g. a little bit of red is combined with green, thus diminishing or "toning" its saturation. There is usually another change, too, concerning the hue as well as saturation. The result is commonly not the original green but, more often, a yellowish green – the more orange the red was, the more yellow the green will be. So the term "toning" refers not only to the change in tint/shade but the transformation of colour.

Nuance. This refers to a delicate difference in colour, e.g. vermillion is often made with fine variations of crimson or slightly orange – these are the nuances.

Colour values have the same meaning as colour tones. For example, greys are values of white.

LIGHT AND OUR SURROUNDINGS

The nature of light is wave-like and particulate. The wavelengths of individual spectral lights decrease gradually with the sequence of lights in the spectrum; therefore, red light has the longest wavelength (0.0007 mm) while violet has the shortest (0.0004 mm). The minute wavelengths of light and the immense velocity of a light beam crossing the vacuum translate into the huge frequency of the waves. Red lights do 400,000 billion oscillations while violet almost double that amount.

In sound waves, the double frequency is called an octave. The waves of a similar nature, like light waves, form a number of such octaves. From the long waves of radio broadcasting to very short waves of the gamma radiation, there are about fifty and the numbers go on towards even shorter waves. These fifty octaves also include the part of an octave constituted by light radiation. In other words, although light energy only takes a relatively very small proportion of the great range of similar energies it is able to illuminate the world around us with such a multitude of colours and hues.

On both ends, the spectrum continues with waves not perceived by our eyesight. On the red side, these are the so-called infrared rays while on the violet side, there are the ultraviolet rays. What would our surroundings look like if our eyesight, during its evolution, had chosen a group other than the light radiation for the visible range? For example, in X-rays a person would look like a transparent or translucent mass with a slightly darker detail of the skeleton, or of the dark metallic objects carried by the person.

The colour components of light travel at the same speed in the vacuum. This is proved by the light of the rising sun; if some spectral rays travelled at a higher speed, the sun would first glow with that particular colour.

Some light phenomena cannot be explained by wave processes but only by the particle nature of light. The opinion that light is a stream of minute particles was formulated in ancient days already, and various versions thereof were used to explain the essence of light in the Modern Times, too. For a time, the wave theory prevailed but recently it has been revalidated and the dual character of light, both the waves and the particles, has been purposefully combined in a single theory. According to that, energy is not distributed smoothly over light waves; it exists in particles or quanta called photons by Albert Einstein.

Regardless of where light comes into our eyes from, it originates from a substance, whether from the substance of the source where it is formed by burning, heating up, electric discharge, fluorescence, or from a substance which reflects it or lets it through. We cannot see light on its path through space, save for cases where it travels through environment of insufficient transparency, foggy or dusty environment. Therefore, only the Moon and the stars shine through the night while the space amongst them, saturated with streams of light energy radiated by thousands and thousands of stars, remains dark.

As a surface exposed to light reflects the light back into space, it becomes the secondary source. This is most obvious at night when the sun-lit Moon illuminates the landscape. Various surfaces reflect light in various manners, with differing intensity and various spectral compositions. The things around us appear in various colours, and we are used to considering the colours thereof to be a property of their surface or material. However, are materials actually coloured? Why do they seem different e.g. in moonlight and in sunlight? Strictly speaking, materials are not coloured; not even the light energy they reflect is coloured. Only the sensation of perception by the eye is the colour. To simplify the following explanations, let us grant materials the possession of colour.

THE LAW OF LIGHT REFLECTION

Light has some remarkable properties. Although it appears to be something ultimately delicate and unmeasurable, upon arrival to the surface of the environment it behaves in a way similar to elastic materials. It is reflected from the surfaces according to the same laws as elastic objects. This fact constituted the most important reason behind the particle theory of light. It meant that the stream of minute particles constituting the light flow was reflected from the material surface; this was the simplest explanation for light reflection.

The angle of light reflection from the reflecting surface is measured from a line running perpendicular to the surface at the point of incidence of the ray of light (fig. 19). The size is determined by the well-known physics formula – the angle of incidence equals the angle of reflection. Both the incident and the reflected rays are on the same plane perpendicular to the reflective surface.

Another one of light's properties is its ability to pass through materials, even such hard materials as e.g. glass or diamonds. The surface of the material does not reflect all of the light; some light continues to travel right into the material. The quantity of the light reflected and light entering the material depends on the nature of the material, angle of incidence, difference between the materials, i.e. the material from which light enters the other material, as well as on the wavelength of the light.

Light travels through different materials at different speeds. For instance in water, it slows down approximately by one quarter of its speed in vacuum (where it travels at maximum speed); in glass, light travels at roughly two thirds of its speed in vacuum. At the same time, the direction of the ray is deflected – we call this refraction upon the interface of two different environments. The refraction is based on the nature of the material light passes through; this is called the optical density of the material.

Just like light reflection, light refraction occurs at the site of ray incidence on the surface of the material and the refraction angle is measured from the same perpendicular line as the reflection angle, with just an extension inwards the light-refracting material.

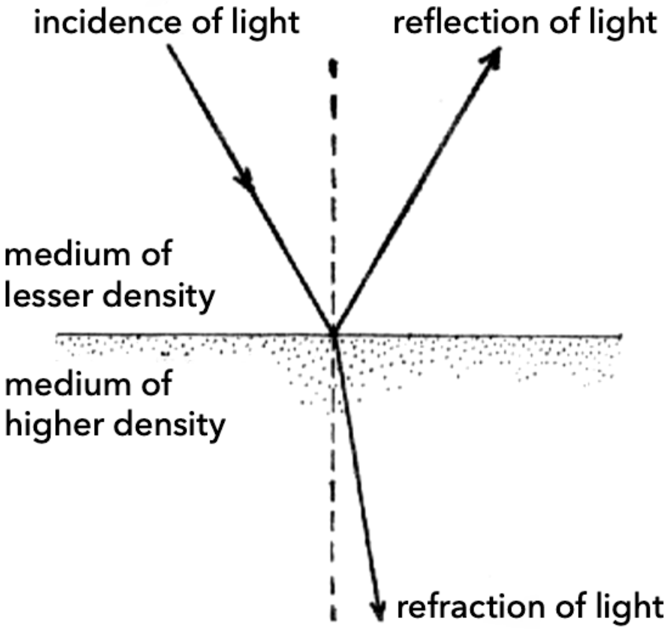

Fig. 19

If a ray of light enters an optically denser substance from an optically less dense substance, it refracts on the interface (fig. 19). However, optical density is not always identical to the mechanical density, for instance alcohol is less dense than water mechanically although it is denser optically. Water is optically denser than air, glass is denser than water, diamond is denser than glass. In physics, the optical density of substances is expressed by the refractive index (n)[1]. The higher the refractive index for a substance, the higher its optical density and light refraction are. For example, air is roughly 1, water 1.2, common glass 1.5, diamond 2.3. Individual spectral lights demonstrate different refractions. The spectrum obtained via an optical prism is a result of such varying refractivity. Light of long wavelengths (red) refracts the least. The other lights along the spectrum have increasing refractivity, with the maximum refraction recorded for the shortest wavelength light, i.e. violet.

TOTAL REFLECTION

If a ray of light strikes a less dense medium on its path from a denser substance it is refracted at an angle to the normal of the surface (fig. 20). With a certain increase of the angle, the refracted ray merges with the boundary between the two media (fig. 21).

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[1] The refractive index is the ratio of speed of light in vacuum to the speed of light in the substance.

If the incident angle is even bigger, the light does not enter the other (less dense) medium at all, and all of it is reflected by the so-called total internal reflection (fig. 22).

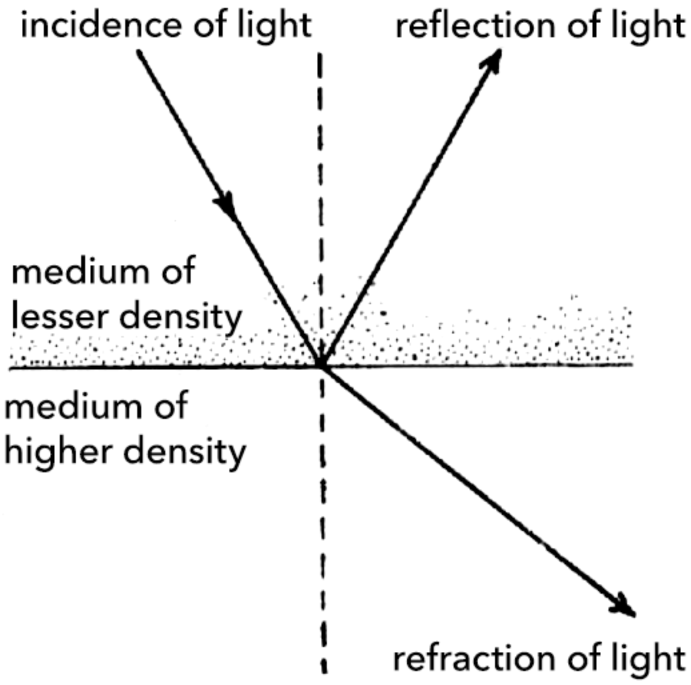

Fig. 20

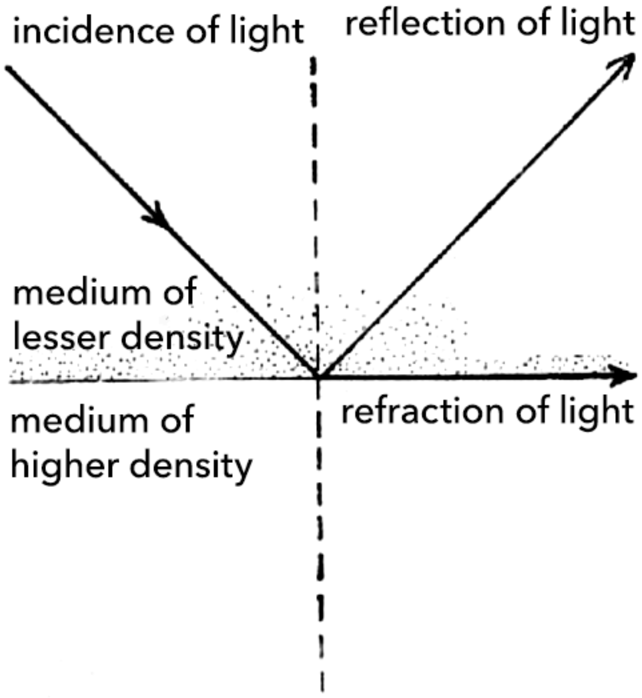

Fig. 21

Such total internal reflection is practically used in many ways. For example, it is how light is reflected outwards from the polished facets of diamonds. Total internal reflection can even direct light along a bend. This is often used in the visual design of light fountains. Light directed into the outflowing stream of water passes by tiny, total internal reflections, maintaining its course even if the water flows downwards (fig. 23).

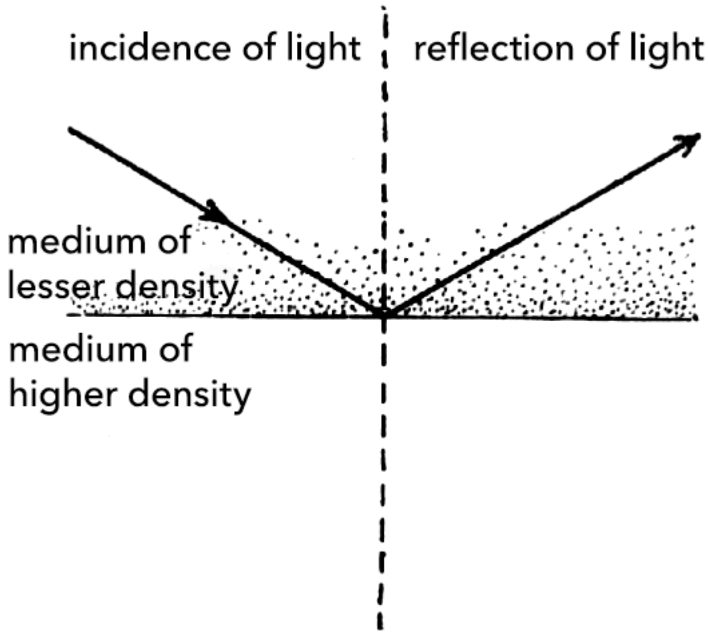

Fig. 22

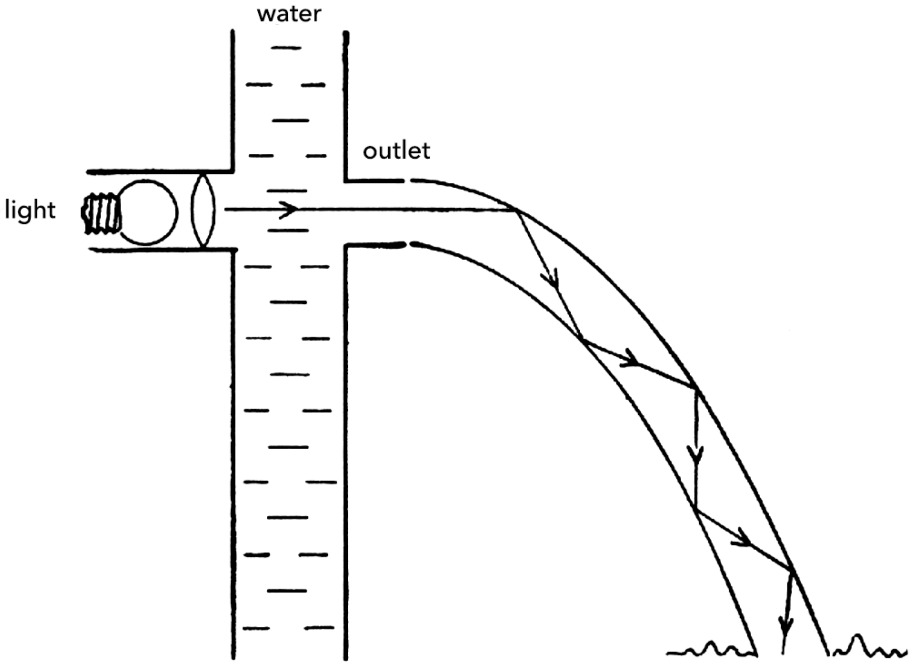

Fig. 23 Total reflection of light in a stream of water

Total internal reflection can be observed in nature, too. Light passing through air into water is redirected back to the water surface by reflections from the bottom. A part is reflected totally and returns to the water again. Therefore, the water surface appears to have a shining silver underside. The whitish colour of the lower side of fish acts as a protection against any danger threatening the fish from underneath. The fish blends in with the light entering water from the air, as well as with the silvery shine of the light totally reflected under the water surface. The silvery glow of fish scales has a similar purpose from this point of view. The so-called fish silver obtained from the scales is important in the production of small decorative items.

DEPENDENCE OF REFLECTION AND REFRACTION ON THE RATIO OF OPTICAL DENSITIES OF THE MEDIA

Light reflections and refractions on the boundaries of two different environments increase with the difference of optical densities of the two media. That is why we can see e.g. a glass made of clear glass although its material is as transparent as the surrounding air. Light shines and refractions in its glass material make the glass visible. It is less visible when submerged in water though, since the optical density values of water and glass are closer than those of air and glass. Therefore, light reflections and refractions are lesser and the shine is less noticeable. A sheet of white paper is shown under a microscope as slightly sticky, entangled transparent, glassy-looking fibres. A drop of oil or other grease, if absorbed by the paper, changes its appearance considerably. The oil fills the voids between the fibres which were previously occupied by air. As the optical densities of paper fibre and oil are closer than those of air and the fibres, the paper layer becomes more coherent optically: there are fewer light reflections and refractions. The greasy paper becomes more permeable for light, allowing us to notice or even read print from under the paper. Tracing paper works on a similar principle and allows direct copying of drawings. Air layers of different temperatures also constitute interfaces of uneven optical densities which allow total reflections to create fata morgana images.

LIGHT REFLECTING FROM SURFACE

Rough surfaces, as well as even smooth surfaces which are not glossy, consist basically of more or less tiny uneven areas with facets of various inclination angles. Therefore, light hitting such surface is reflected from the minute facets according to the law of reflection; however, it is reflected into various directions. This is called diffuse reflection. If we watch such a surface, just a minor proportion of the light reflected thereby enters the eye; the rest is reflected outside the eye (fig. 24).

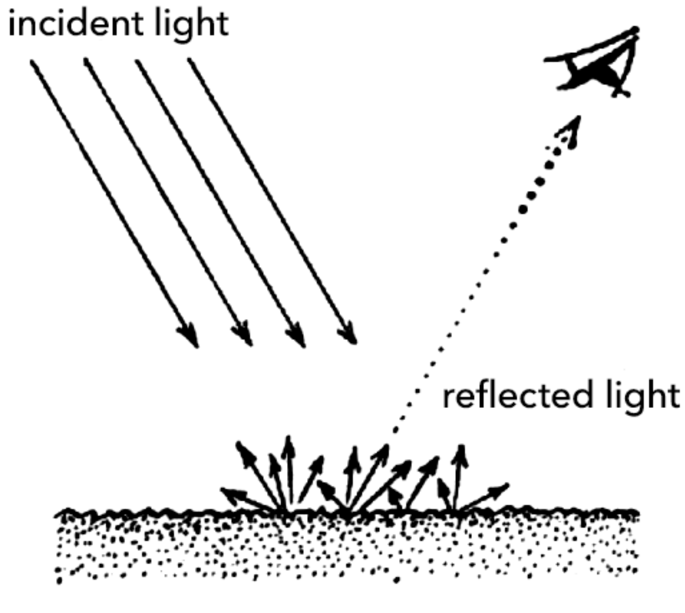

Fig. 24 Light is reflected diffusely from a non-shiny surface

GLOSSY SURFACE

A glossy surface, i.e. a surface the smoothness of which is maximised, behaves differently. If such surface covers a flat area, it reflects incident light from a certain direction, e.g. direct sunlight, at just one reflection angle, i.e. as undiffused but directed (fig. 25) light. This concentration of reflections into a single direction increases the volume of the reflected light in comparison to light with diffuse reflection. Such directed light reflections are usually called “shine” or “gloss”.

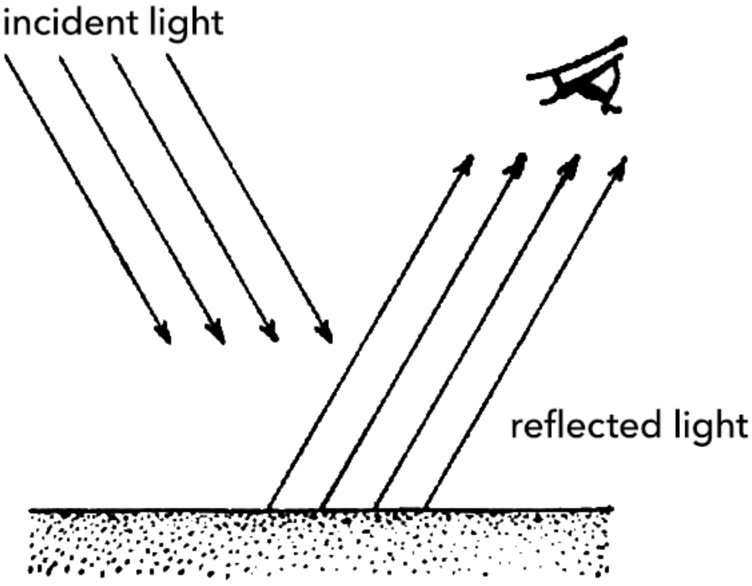

Fig. 25 Light is reflected directionally from a shiny surface

Shiny, glossy surfaces are achieved in practice by various methods, e.g. polishing, i.e. smoothing an area out as much as possible, or by applying coatings which create smooth surfaces, like varnishing wood, glazing pottery pieces etc. Sometimes, polishing paste is rubbed into the surface to fill in the minor imperfections, making the surface smoother. Ideally, such polishes should have identical or closely similar optical density as the polished object. Polishing is actually a process during which the roughness of the surface gradually diminishes and where the threshold for achieving the maximum possible shine is defined as unevenness of 1 tenth of a micron (1 mm is a thousand microns). According to the degree of polishing achieved, surfaces are classified as high-gloss, semi-polished, dull etc.

SPECULAR REFLECTION

Light does not always hit a glossy area just from the source and in a single direction. For example, the calm surface of a pond is hit not only by direct sunshine but also by light from the shores, trees, the blue shining sky etc. Such lights are also reflected from the water surface according to the law of reflection, and the mirror image of the surroundings can be seen on the surface of the pond. This kind of image is called mirroring, and gloss is basically also a mirroring phenomenon of intense light, e.g. sources of light, light-emitting openings, e.g. windows, or areas with massive light reflection. If the water surface is rippled by tiny waves due to wind, the reflection becomes diffuse and the mirror image disappears. Even the mirrored image of the Sun is diffused here, lighting up the water surface with the sparkling shine of tiny ripples.

The direction of reflected light on rounded surfaces changes gradually; on a convex surface, the reflected rays diverge (fig. 26) while on a concave surface, they converge (fig. 27). Therefore, such surfaces show shine only on narrow sections which direct the reflected rays into the eye. The counterpart is mirrored in a variable size and with variable level of distortion based on the curve of the surface. For example, if there are ripples on the water surface, the angle of light incidence changes, which means the reflection angle changes as well, and the mirrored image is bent over the waves.

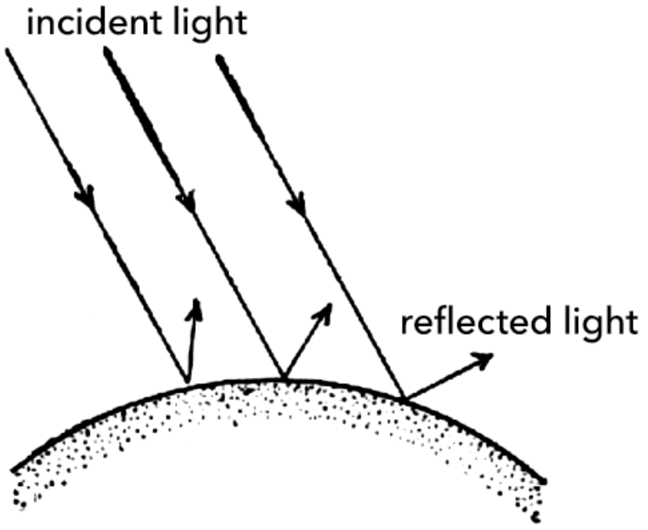

Fig. 26 Shiny convex surfaces make reflected rays of light diverge

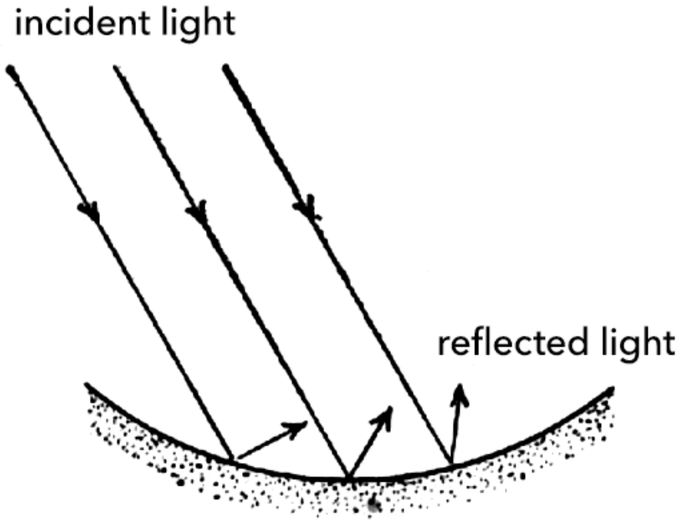

Fig. 27 Shiny concave surfaces make reflected rays of light converge

An interesting phenomenon of this kind is the so-called Japanese magic mirror. It consists of a cast metal disc with a cast design, either an image or calligraphy etc. on the reverse side. The face is polished flat and shiny. For a long time, it was a mystery why some of the mirrors project an image of the reverse side on a wall upon light reflection from its mirror surface. The metal disc of the mirror is non-transparent; therefore, the reverse side should have no effect on the reflected light. Indeed, it has no effect although the mechanism of effect is different, as explained by two English scientists who watched the production of the mirrors in Japan. The local craftsmen finish the mirror surface of the metal disk by hand, sanding and polishing it, while it rests on a flat wooden mat.

The pressure applied against the balancing tool during the polishing makes the thinner parts of the metal mirror plate deflect a little while the thicker spots against the relief design on the reverse side resist the friction a bit more and, therefore, are sanded off a bit deeper. Therefore, the face side of the mirror is not absolutely flat; there are unnoticeable indentations against the relief protrusions. When one looks in the mirror, it has no effect while when reflecting light on a wall, it acts by deflecting the rays reflected from the unnoticed bends in the mirror surface. The reflected light projected on a wall will show lighter and darker spots, following the shapes of the design from the reverse side.

COMPLEX REFLECTIONS

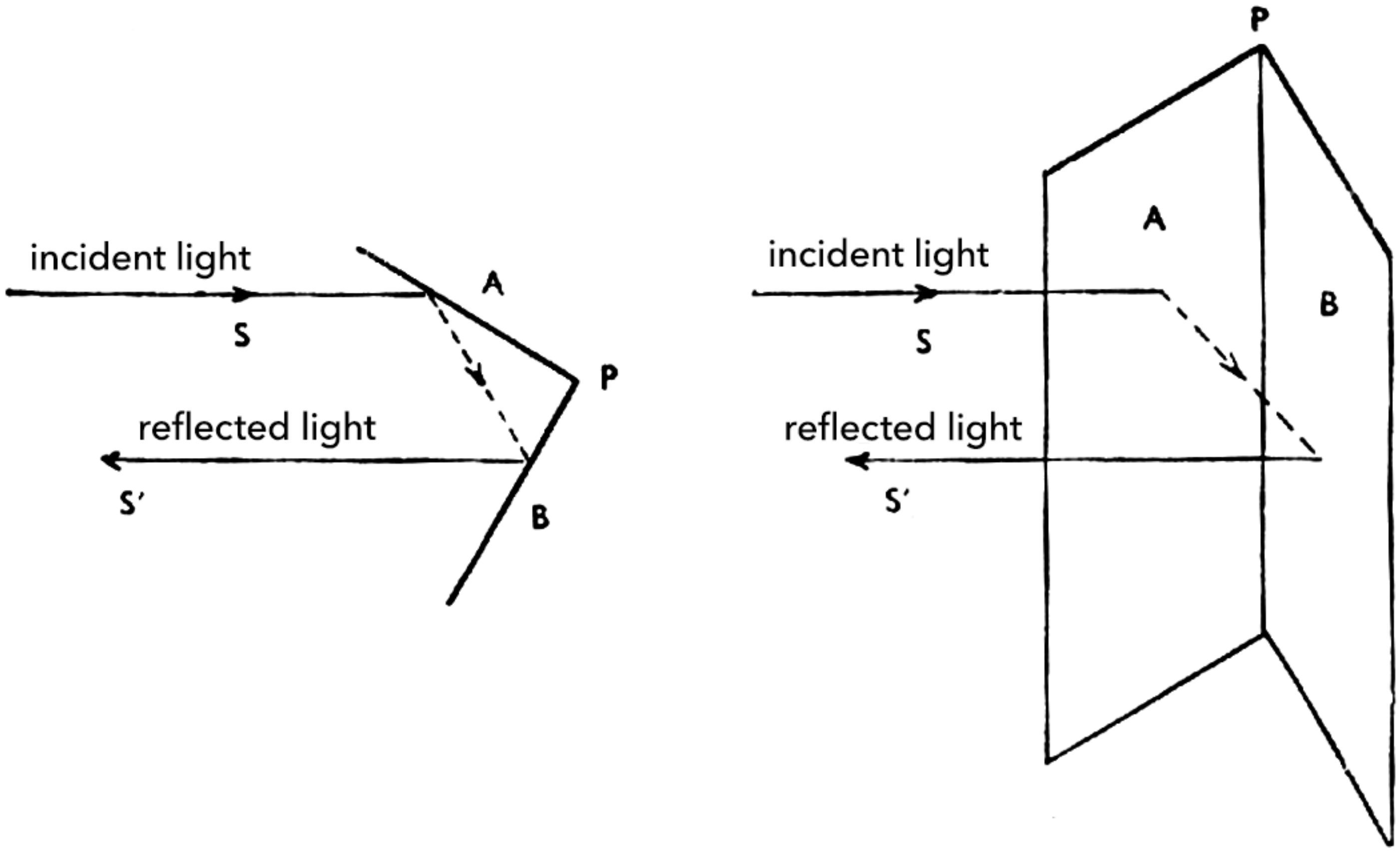

Fig. 28 Light perpendicular to the edge of shiny surfaces forming a right-angle corner is reflected back in the same direction

If three mirror surfaces (A, B, C) perpendicular to one another and combined to form a three-sided corner are used, the rays (S) entering such corner are reflected back in the same direction (fig. 29). This is the basis for e.g. adjustment of vehicle reflectors. Their reverse surfaces are shaped with tiny, closely adjoining and protruding pyramids. In such pyramids, light is reversed by reflection back to where it arrived from.

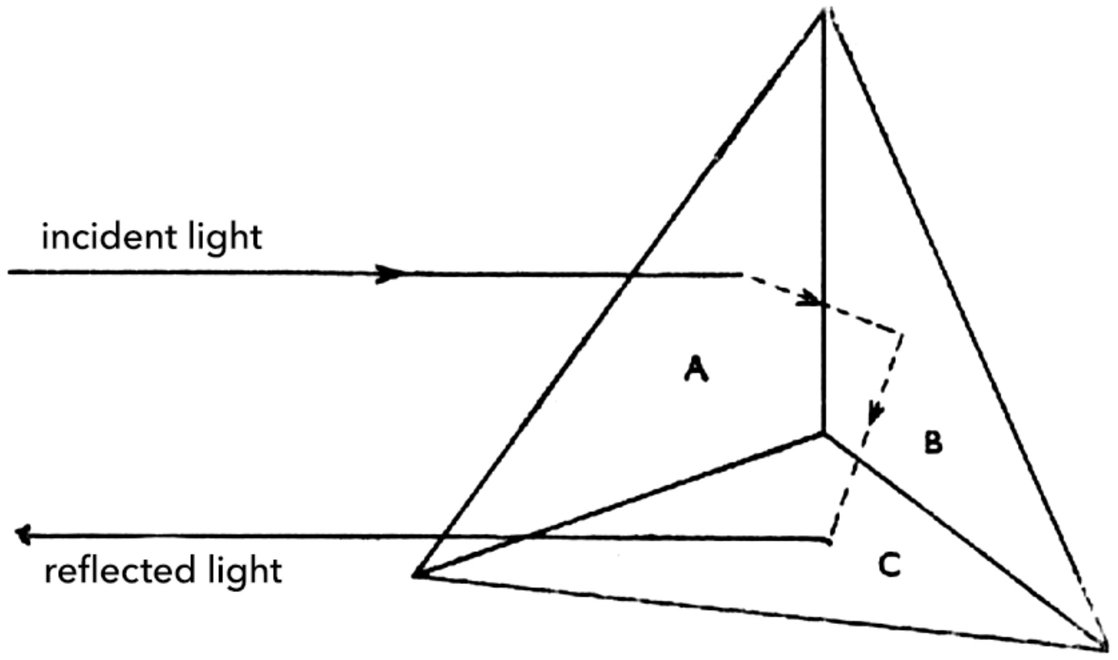

Fig. 29 In a right-angle corner made of three shiny surfaces, light is reflected in its original direction.

COLOUR OF SUBSTANCES WHEN LOOKED THROUGH

Only a part of the light hitting the surface of media is reflected; the remaining part enters under the surface, into the medium. All substances permeate light like this – some in massive layers like e.g. the air or water, others in thinner layers; metals are only translucent if in the form of thin sheets.

If light passes through a substance without being diffused on the surface and inside, the substance is transparent, e.g. air in the absence of fog, clean, still water with no waves, a sheet of cellophane etc. If a substance diffuses light upon entry, it only appears to be translucent, e.g. frosted glass or glass with abraded surface, thin paper etc. Some substances only come close to full transparency, and are just partially transparent as they diffuse some of the light, e.g. clear plastic, tracing paper etc. Various media behave differently when light of varying spectral composition passes through them. Many media are permeable for rays of all wavelengths, e.g. air, clear glass, translucent white substances etc. However, the majority of substances absorb a smaller or greater proportion of the spectral components of light as it passes through. The passing light then has a different spectral composition, which means a change in its original colour. If, for instance, white light passes through yellow glass, its cyan, blue and violet spectral components will not pass – they will be absorbed by the glass. The remaining spectral rays, i.e.

red, yellow and green, will pass through the glass and the sum thereof will appear as yellow light (fig. 30). This is the phenomenon of light absorption by media.

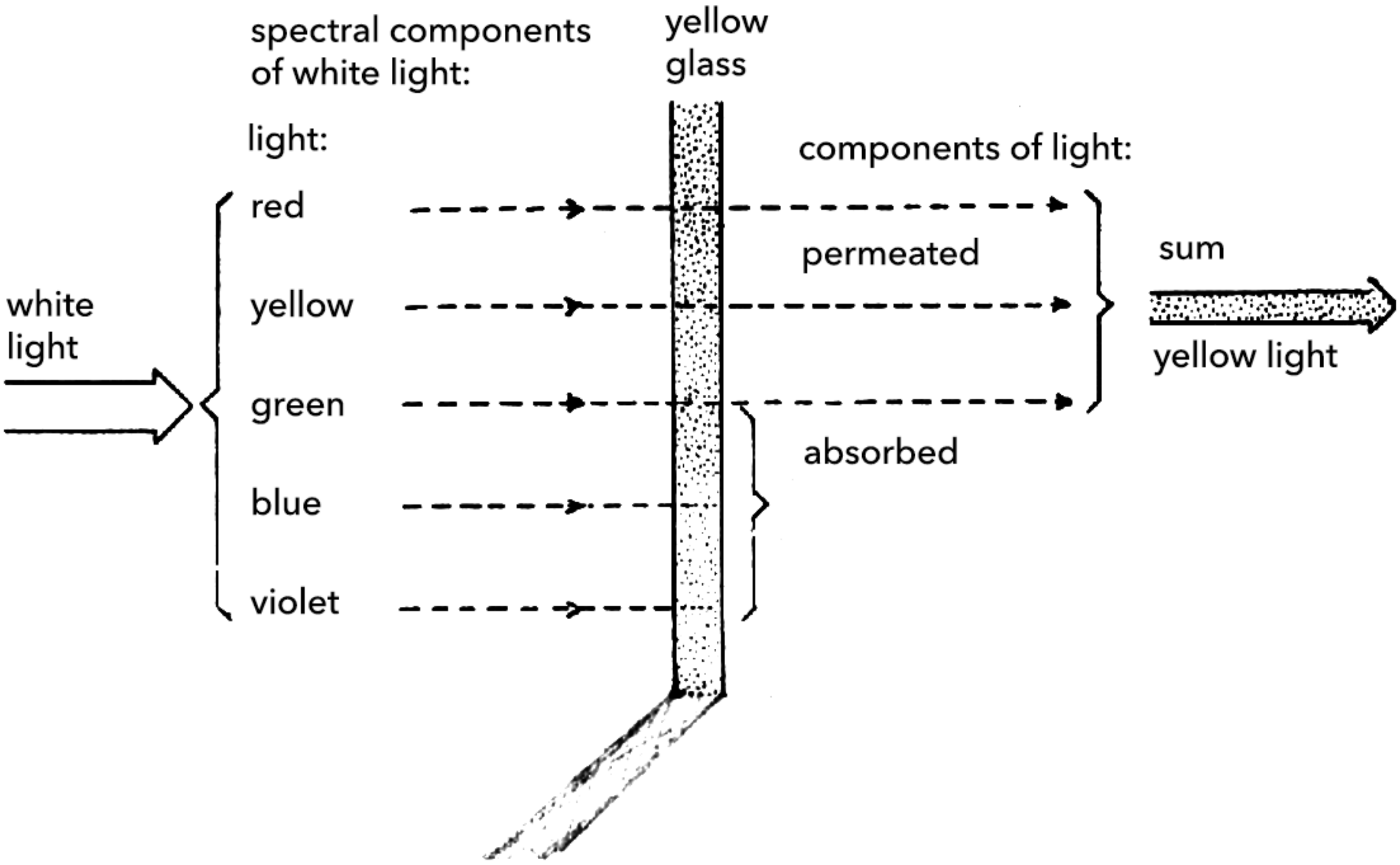

Fig. 30 Yellow glass permeates just a part of the spectral radiation of the white light; together, these form yellow light.

LIGHT ABSORPTION AND ATOMIC COMPOSITION OF MASS

The spectral components of light absorbed by a medium make the tiniest particles thereof oscillate. The oscillation uses photon energy and, therefore, radiation of certain frequencies causing the resonance in the atoms and molecules fails to pass through the substance – it is absorbed by the atoms of the substance itself. Radiation of different frequencies causing no response of the material particles still passes through the substance. All radiations of the visible part of the spectrum pass through clear and white substances.

If the atomic composition of molecules changes, the absorption process changes as well. The particles of the substance oscillate in rays of other wavelengths, which they absorb, and the substance permeates the remaining spectral composition, i.e. other colours of light. An illustrative example of such a transformation is the molecule of indigo (fig. 31). This blue dye is insoluble in water which is a valuable advantage for fabric dyeing. The dye does not run in water. However, to dye fabric, indigo must be transformed into a water-soluble substance. Therefore, hydrogen atoms (fig. 32) are linked to its complex molecule by chemical processes. Although indigo becomes soluble, it no longer absorbs light of long wavelengths and is colourless in this state. Once the fabric is taken out of the dye bath, the indigo molecule starts reverting to its original composition and the fabric turns blue. Similar colour transformations are common in nature, e.g. the colours of leaves change in the autumn.

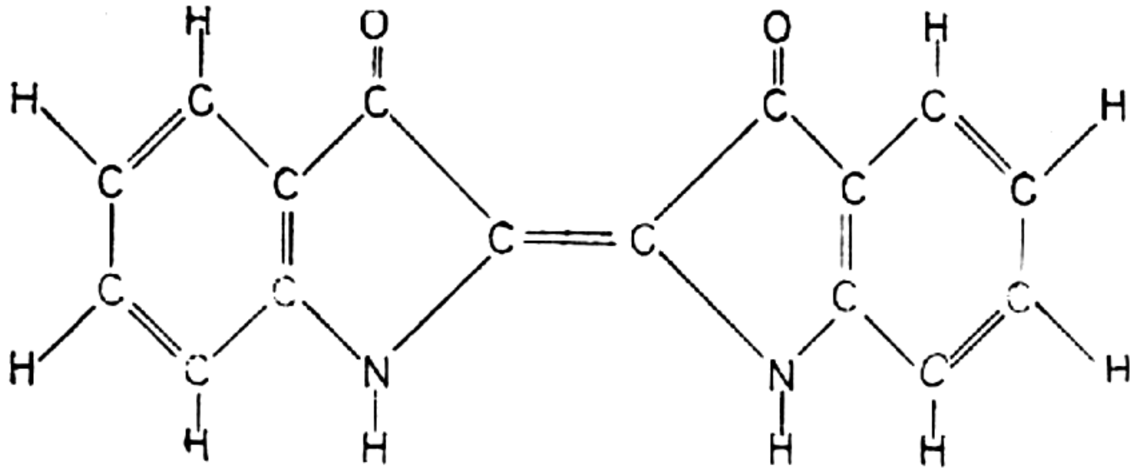

Fig. 31 Molecule of indigo

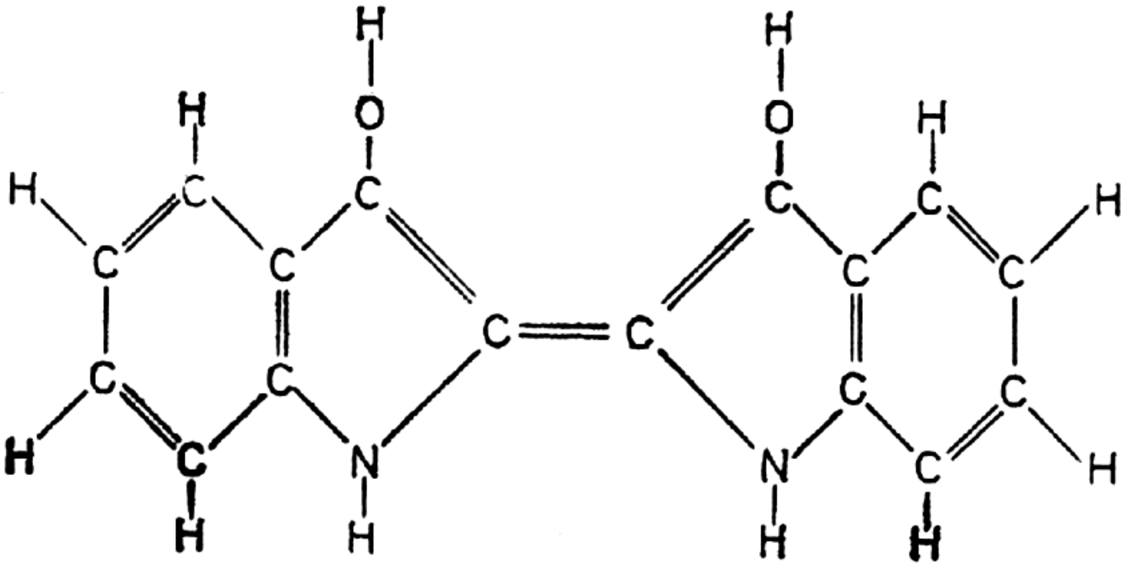

Fig. 32 Molecule of water-soluble colourless indigo

The light energy absorbed is transformed in the substance in various manners, most frequently to thermal energy – therefore, particularly black surfaces heat up in sunshine as they absorb a huge proportion of light. Light also causes chemical conversions in substances; e.g. coats of many paints bleach if exposed to light. Light causes a fast transformation in a sensitive photographic layer. It induces electric voltage in photosensitive tubes in the light meter. Some substances transform certain radiations into radiations of a different frequency. This also applies to invisible radiation, e.g. ultraviolet is converted to light radiations, which causes some fluorescence phenomena. The vast majority of the colour phenomena in our surroundings result from the aforementioned absorption processes.

COLOUR OF SUBSTANCES

The origin of the colour of a substance is not a simple process of light reflection. The light reflected right on the surface of the substance does not create the bright and abundant colour composition of our environment. If light were just reflected like this, we would see objects around us as just white or in various degrees of grey in daylight, based on the way of lighting or shading, and on the quantity of reflected light.

The surface reflection does not change the colour of light; the same spectral composition as in the lighting is maintained. Therefore, it is reflected as white in white light, as red in red light etc. This is most obvious with shiny surfaces of objects of saturated colours, e.g. a lively, highly polished bonnet of a car. The more polished the car, the more the colour tends to disappear at the shiny spots, the whiter the shine is, or the more the colour of the counterpart, e.g. blue sky, is mirrored in the shine.

INTERNAL REFLECTION

Light is not reflected off substances just on the surface. Some of the light which entered the substance also encounters boundaries it is reflected from, for example in the case of a pane of glass, light is reflected off the bottom plane as well.

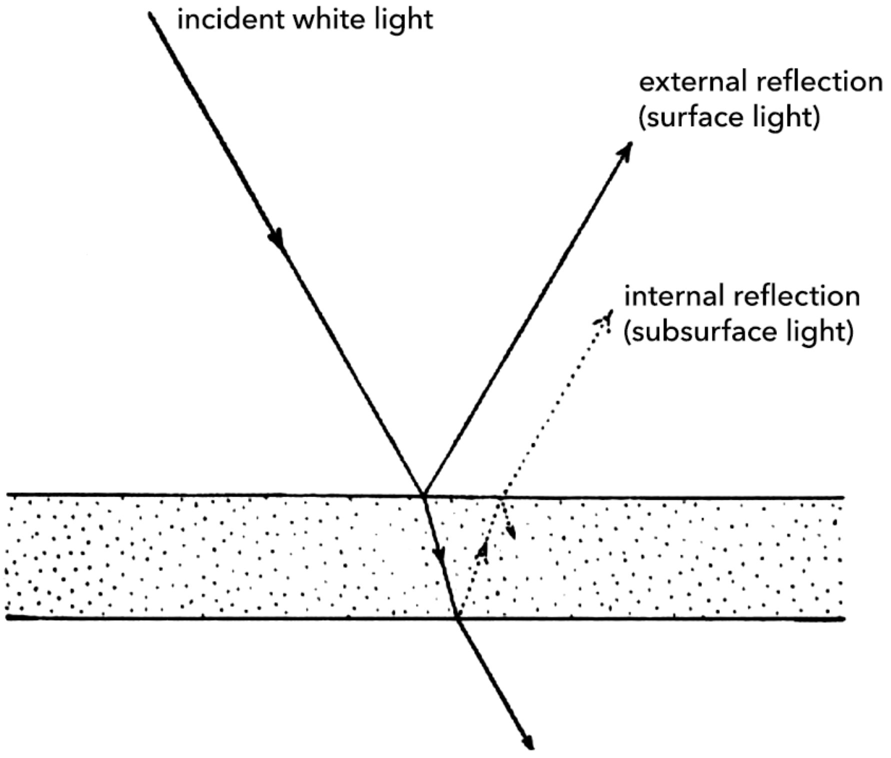

Fig. 33 Internal and external reflection of light

If the light reflected from inside has passed through a layer of coloured glass, e.g. yellow, it will leave the glass as coloured light (fig. 33).

Light is reflected off substances in two possible manners, namely straight from the surface – this is called surface light, and from inside, under the surface of the substance, which is called the subsurface light. Both kinds of the reflected light combine to create the colour of the substance.

DIRECTIONAL LIGHT REFLECTION

Light is reflected directionally off a smooth internal area, thus creating the internal shine. For example in cut diamonds, light is reflected not only off the external facets but also off inside ones, too. If the substance is coloured, e.g. the red in rubies, the internal shine adopts the colour and lights it up with colourful beauty.

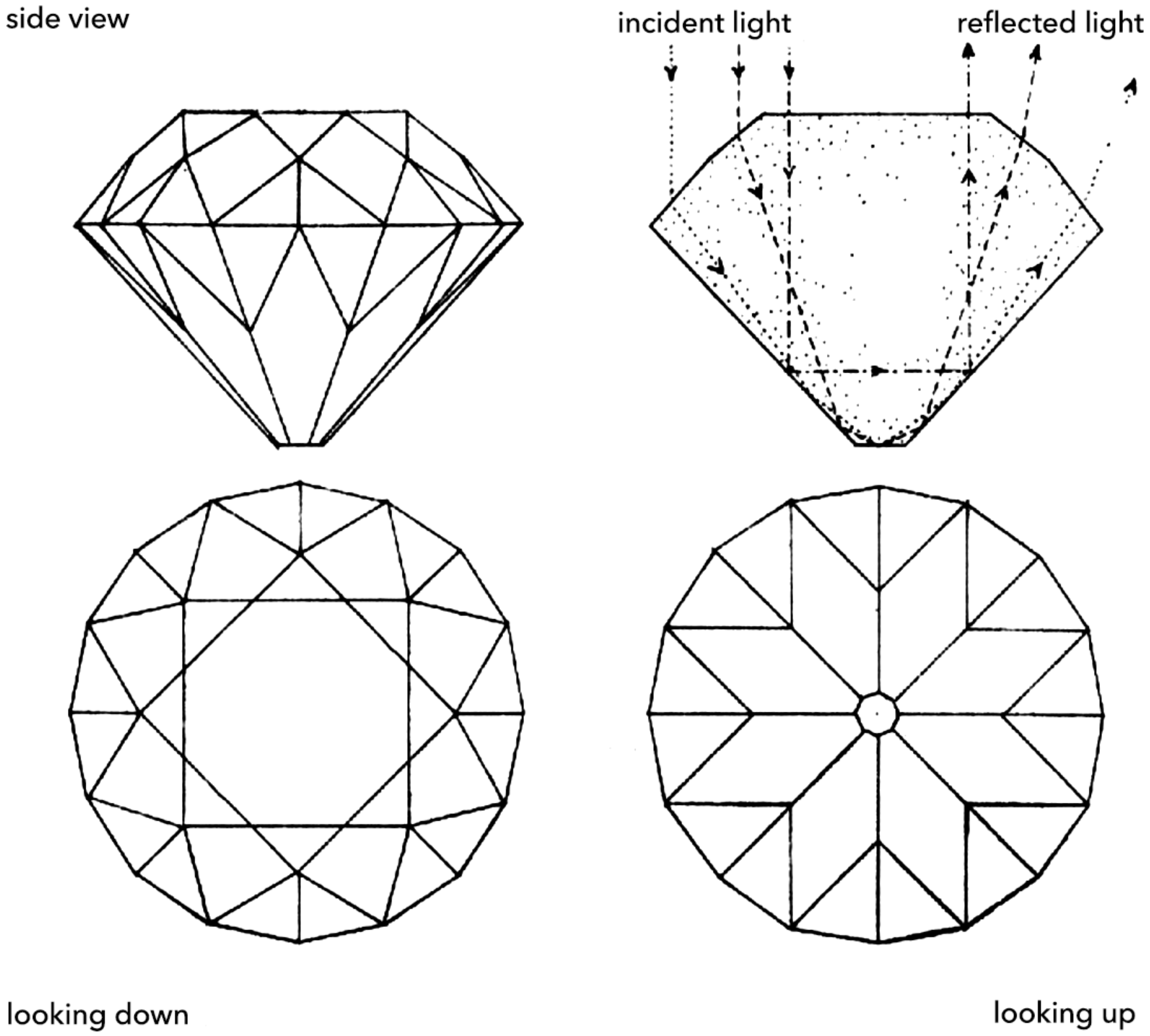

Fig. 34 Diamond cut – brilliant. The section demonstrates the light reflection sequences.

To achieve the most powerful reflection possible, enhancing the beauty of the precious stones to the maximum, the facets are polished to provide total reflection. In this regard, the diamond stands out, particularly the complex cut called the brilliant. Diamonds are characterised by a high optical density, making the light reflections off the facets especially distinctive. Holding a brilliant with the bottom section towards the eye and looking through it towards light, it appears black as all of the light which entered it has been cast back by total reflection. In the opposite direction, following the direction of the light into the top part of the stone, the brilliant radiates a strong shine of the reflected light (fig. 34).

DIFFUSE INTERNAL REFLECTION

Substances consisting of tiny particles (e.g. the fibrous composition of wood, crystalline composition of rock) which reflect light in various directions, involve a diffuse internal reflection. This is how most substances reflect light from inside, like soil, bricks, marble, paper, milk etc. If the substance is coloured, the internally reflected light takes on its colour.

COLOUR SATURATION OF LIGHT COLOURED BY ABSORPTION

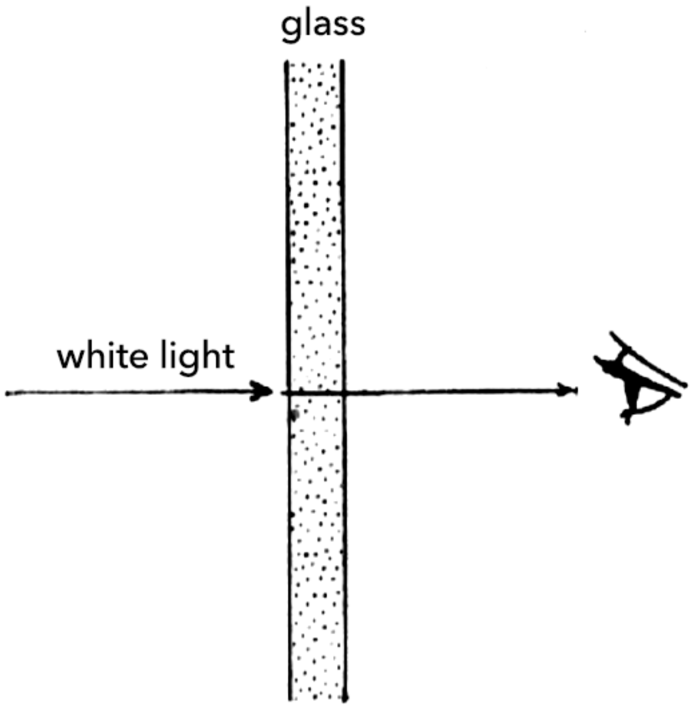

Fig. 35 Looking through coloured glass, its colour appears less saturated since the light only passed through

The length of the ray of light passing through the substance is important for the degree of colour saturation. With a longer path, the light accepts more colour. For instance looking at light through red glass, the saturation level of its red is lower since the light only passed through the layer once (fig. 35). Its colour saturation will be demonstrated more obviously if the glass leans against white paper. In such a case, light has passed through the glass layer twice; once towards the white paper underneath and for the second time, when it was reflected back (fig. 36).

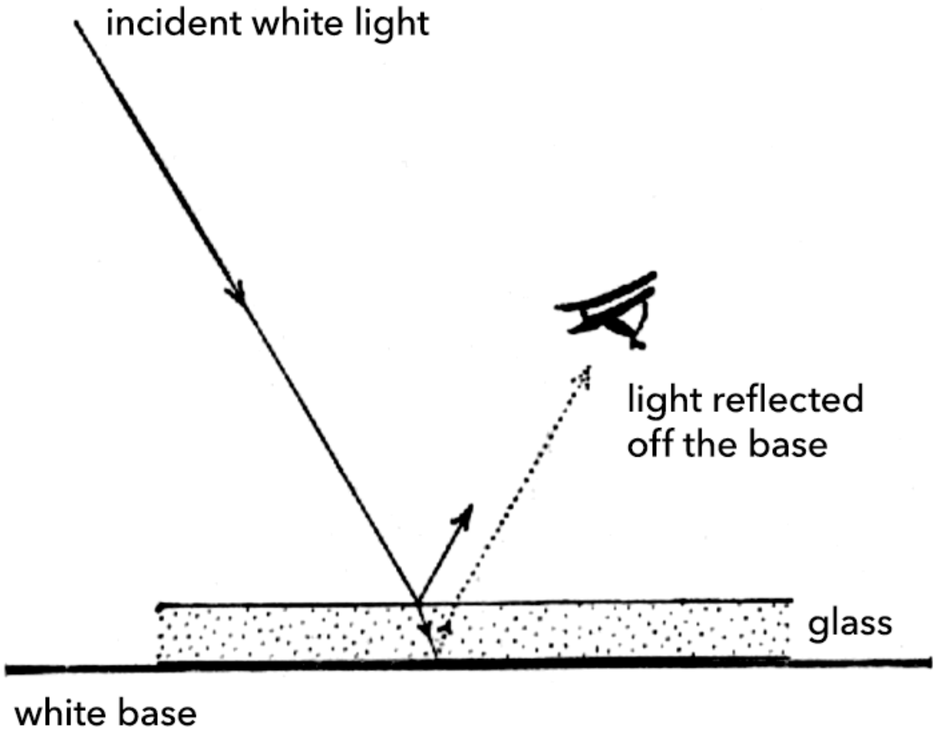

Fig. 36 Coloured glass put on a white base appears to possess more saturated colour since the light has passed twice through the glass layer

This is the optical basis of the glazing and layering techniques, particularly watercolour glazing. The glass pane is replaced by a transparent layer of a paint.

The first case, looking at light through glass, i.e. a single passage of light, is analogous to e.g. looking at transparent slides against light, or projecting slides. The colouration of the image must possess much more saturation to grant the right level of saturation when projected. The situation of window mosaic glass colouring is analogous.

The path of light when passing through a substance is also shorter if the transparent coloured substance is crushed to a fine crumble or powder. For instance coloured glass, bluestone (copper sulphate) or other transparent coloured substances, if crushed, lose their colour saturation noticeably and turn into a weakly coloured, whitened dust or powder. There is a simple explanation for this: in a mass of transparent substance, light travels along a longer path before it is reflected from the internal surfaces and, therefore, it acquires more saturation (fig. 37). Contrastingly, in tiny fragments of the powder, much of the light is reflected back after a short journey through the substance already, thus failing to acquire a lot of colour (fig. 38). This is further influenced by the addition of diffuse reflection of white surface light. The whitish coating of old oil paintings has a similar mechanism. The firnis (surface paint coat) turns into a mass of dense, fine cracks which provide diffuse reflection of light, and the colours of the painting lose their liveliness. If, for instance, alcohol vapours are used to amalgamate the cracks and create a smooth layer, the colours become lively again.

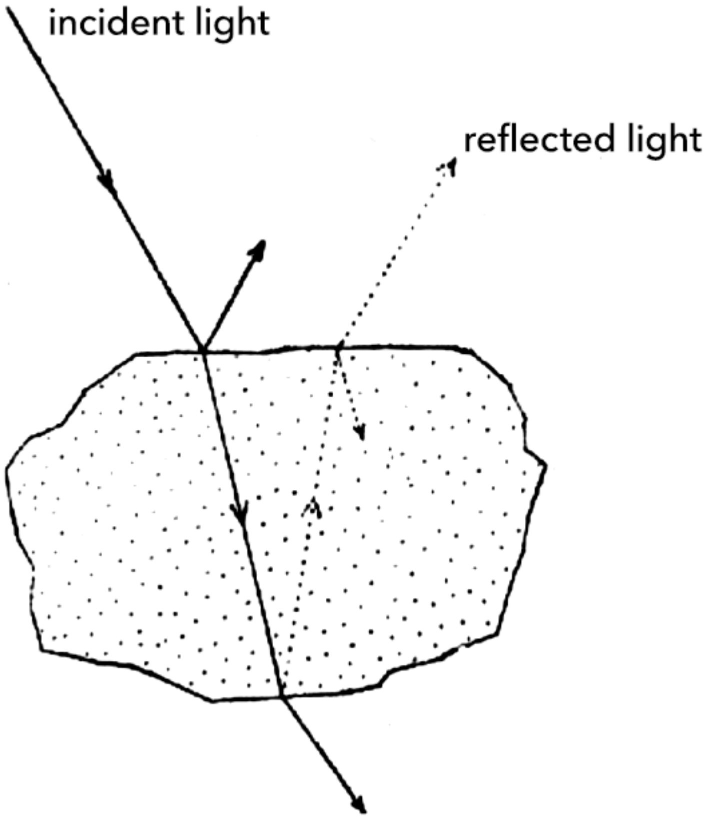

Fig. 37 Internal reflection in a homogenous mass of a transparent substance

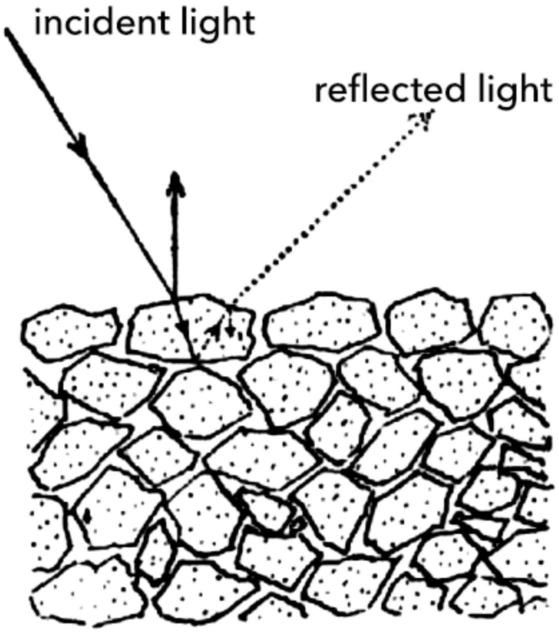

Fig. 38 Internal reflection of light in crushed material

So, if a certain substance is to demonstrate a more saturated colour even in a thin layer, or when crushed, it needs a more effective absorption ability. This means that certain spectral components of light passing through must be absorbed as much as possible even by a thin layer of the substance in order to lend deep colour to the remaining, unabsorbed portion of the light.

This applies particularly to tiny particles of dyes crushed for paints (so-called pigments). For example, the “smalt blue”, a rather rare colour used in watercolours, is made with finely crushed cobalt glass. The crushed glass must have a particularly effective absorption if the tiny fragments are to turn even a thin paint coat distinctively blue. However, this causes darkening and a loss of saturation of colour in thick layers of substances – this is how e.g. a watercolour button of rose madder, carmine, Berlin blue or other glazes appears dark and less saturated.

COLOUR OF UNPOLISHED SURFACES

We have explained the properties of light reflected off the surface; its colour remains identical to the colour of the light, i.e. white in white light. In contrast to that, the light reflected from the subsurface of substances which absorb a fraction of its spectrum is modified in relation to the illuminating light.

Unpolished, non-shining surfaces of e.g. wood, rock, paper etc. reflect both of the aforementioned types of light, surface and subsurface, in a diffuse manner. The two types mix together then, while white surface light reduces the saturation of the colour of light reflected from inside the substance – diluting the colour with its whiteness. At the same time, both types enter the eye regardless of the direction we watch the surface from (fig. 39). Non-shining colours of the image thus seem unmodified upon a change of the viewpoint.

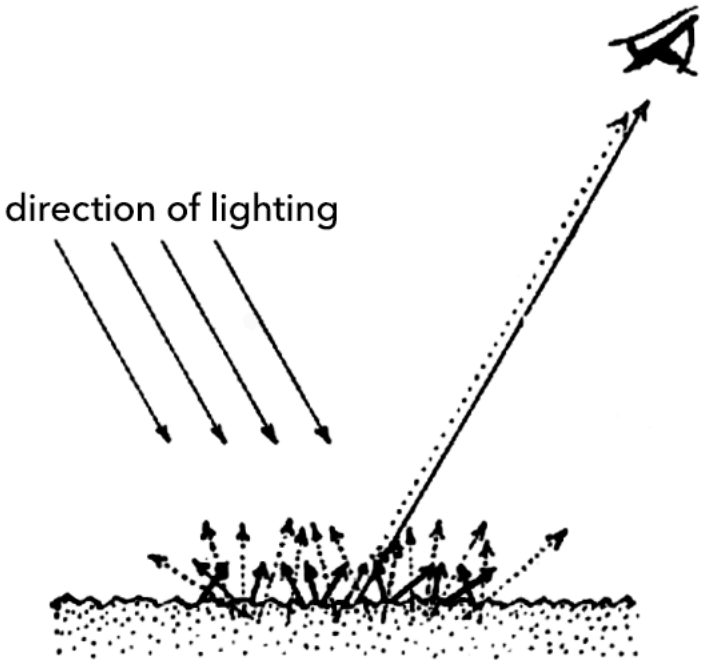

Fig. 39 Diffuse reflection of light from the surface and from inside a non-glossy area. Both components of reflected light are present in any viewing angle

SHINY SURFACE COLOUR SCHEMES

Shiny surfaces reflect surface light directionally. Our eye captures the light if we look against the direction of the reflected rays. If there is diffuse reflection of the internally reflected, i.e. subsurface light, it is mixed with the surface light solely in the direction of sight (fig. 40a). Due to its concentration in the angle of reflection, the surface light is so intense that its shine suppresses, or almost suppresses the internal coloured light below the recognition threshold. The light reflected from inside, i.e. the colour of the substance, is only recognisable with a lower level of polish.

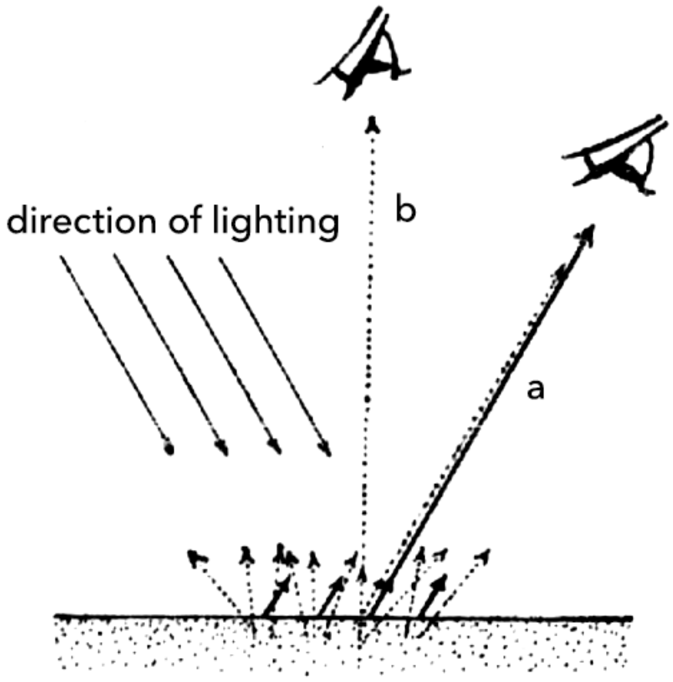

Fig. 40 Directional reflection of light from a shiny surface and diffuse reflection from inside.
The shine prevails in direction *a* while internally reflected light and the colour thereof prevail in direction *b*

Observing a polished surface from a direction other than that of the reflected surface light, the only light viewed is the subsurface light which means that it shows the full strengths of its colour with no dilution by the white surface light (fig. 40b). In this viewing direction, the surface of the substance stands out due to a higher level of colour saturation compared to an unpolished surface.

BRIGHTNESS RATIOS OF POLISHED AREAS

If just a part of a surface, e.g. of red marble from Slivenec is polished, the polished portion will show more distinctive, more saturated red than the unpolished part, and it will be darker, too. This is because the unpolished part sends surface light towards the eye, too, which makes the part seem lighter while the polished part reflects this light elsewhere, not towards the eye, which makes the part darker. Only in the direction where our eyes capture the shine of the polished part, the light characteristics of the surfaces change and the polished part shines brightly while the unpolished part appears comparatively darker.

Putting water on a part of a black board causes a similar situation. The wet part of the board appears darker. Water has filled the tiny voids in the surface and created a shiny surface. This is darker because light is no longer diffused and is projected outside the eye by directional reflection. If we find the spot where such directional light can be viewed, the wet part of the blackboard will light up brightly for the eye. Therefore, even a coat of watercolours appears darker and more saturated when wet than once it has dried up. Firnis coat application (covering dull spots in watercolour paintings with transparent layers of a shiny material) makes dull spots livelier with more saturation. Al fresco painting (painting in wet plaster) is an important experience of testing paints once they have dried up.

WHITE AND BLACK SURFACES

White substances basically consist of tiny particles of transparent glass appearance. Light is diffused on the small facets by both surface and internal reflection into all directions, and the substance seems white. For instance snow is tiny crystals of a clear substance and snowflakes are aggregates of such crystals. Clear, colourless glass crushed to a fine powder turns into a snow-white material. White feathers or white cotton wool are basically tangles of delicate fibres of a clear substance.

From the objective perspective, the ideal whiteness would be delivered by a substance of full, i.e. 100% reflectivity of light; however, white substances just come closer or less close to this state. Amongst white substances, barium sulphate in particular has a high reflectivity level and, therefore, is used inter alia as the base underneath the sensitive layer in photographic paper (so-called baryta), pastel pencil fillers, or in barium white etc.

Contrastingly, black substances should absorb all of the incident light. This, too, is the ideal situation which is more or less approximated by such substances. A substance can only absorb such light which has entered inside, not the light reflected straight on the surface although even black substances reflect such light. This is why we can see lights, shadows or shine on black objects, allowing us to realise their 3D nature. For instance, the folds of a black garment, black paint on car bonnets etc. If the black absorbed all of the light, there would be no lights and no shadows, and the objects would seem flat with no 3D aspects.

Surface light considerably reduces the darkness of black substances, therefore, if the light is directed outside the scope of sight, the black appears noticeably darker. This can be achieved by suitable finishes, e.g. polishing, coating etc.

POLISHING A WHITE SURFACE TO CHANGE ITS LIGHTNESS

A polished white surface is less light than an unpolished surface. Similarly to a polished black surface, the decrease in lightness stems from the surface light being reflected outside the eye. From a viewpoint where the eye can capture the deflected surface light, the white surface seems to radiate light and shine.

However, the decrease in lightness on a white surface is less noticeable than on a black surface. This is a consequence of the properties of perception: the eye is more sensitive to differences in low lightness levels than to identical differences in high lightness levels (Weber-Fechner law). Therefore, even substances with relatively low light reflectivity (approx. 70%) already appear to be white.

OPTICAL PROPERTIES OF FABRICS

The yarns used to weave textile fabrics are spun with thin fibres of glassy-looking, transparent substances. If the fibre substance is colourless, i.e. clear, the resulting yarn reflects light with both surface and internal reflections in its unmodified colour, and the yarn appears to be white in white light.

If the fibres are e.g. red, the light reflected by the surface remains white although the light reflected from inside the substance takes on a red colour. It is the same double reflection we have been talking about. This is also how the two reflected light components create the colour of the fabric woven with the yarn. The proportion of the two light components in our visual perception determines the saturation and lightness of the red colour.

The manufacturing of fabrics involves, to a considerable degree, primarily controlling the efficiency of the light reflected on the surface, i.e. the white light, and follows various paths. Let us first introduce the two extremes:

1. **The weave of the fabric emphasises the white surface light**. This is the case of the so-called satin weave where the design of the surface uses the weft yarns as economically as possible. The warp yarns float over multiple weft yarns without interfacing.

   If a patch of such fabric (silk satin) is put on a table and turned around, still lying horizontally on the table, it will light up and shine only when the warp yarns are positioned at a certain angle to the directions of the incident light and the line of vision (fig. 41). This phenomenon will occur twice within the full circle, i.e. 360 °, both times when the warp yarns are at the same position.

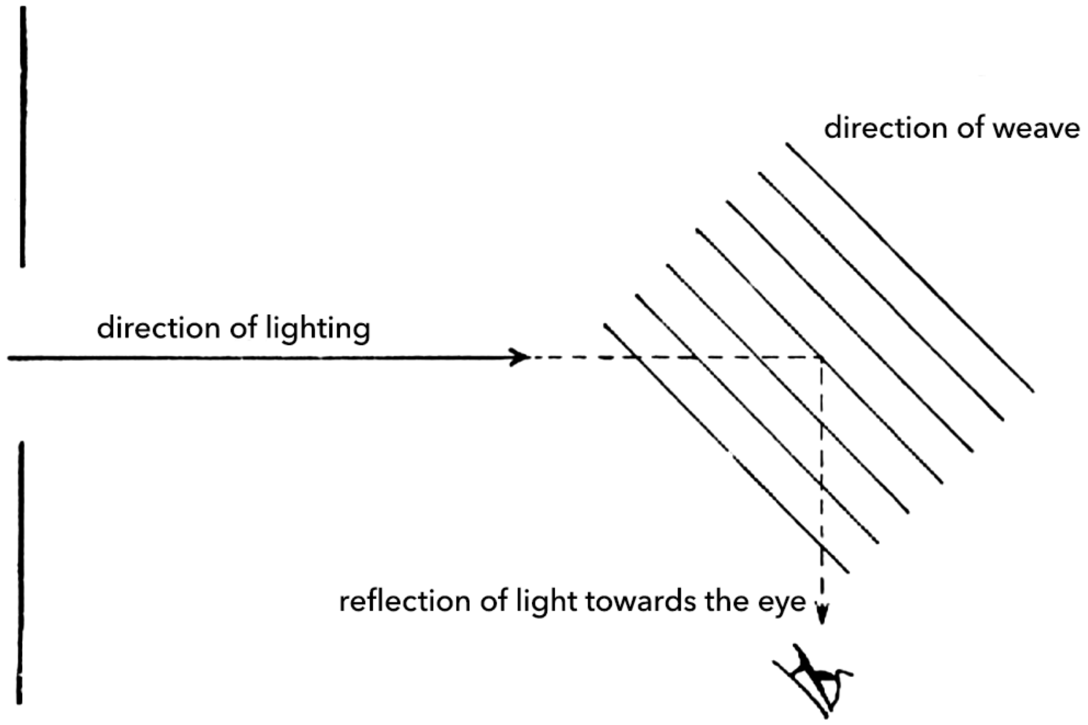

Fig. 41 Reflection of light from a fabric with satin weave directed towards the eye

The shine of satin will disappear when the fabric is turned to position the warp yarns along the direction of the incident light and line of vision. In this case, light is reflected away from the eye (fig. 42). This is the case where the satin fabric looks its darkest but its colour seems more saturated.

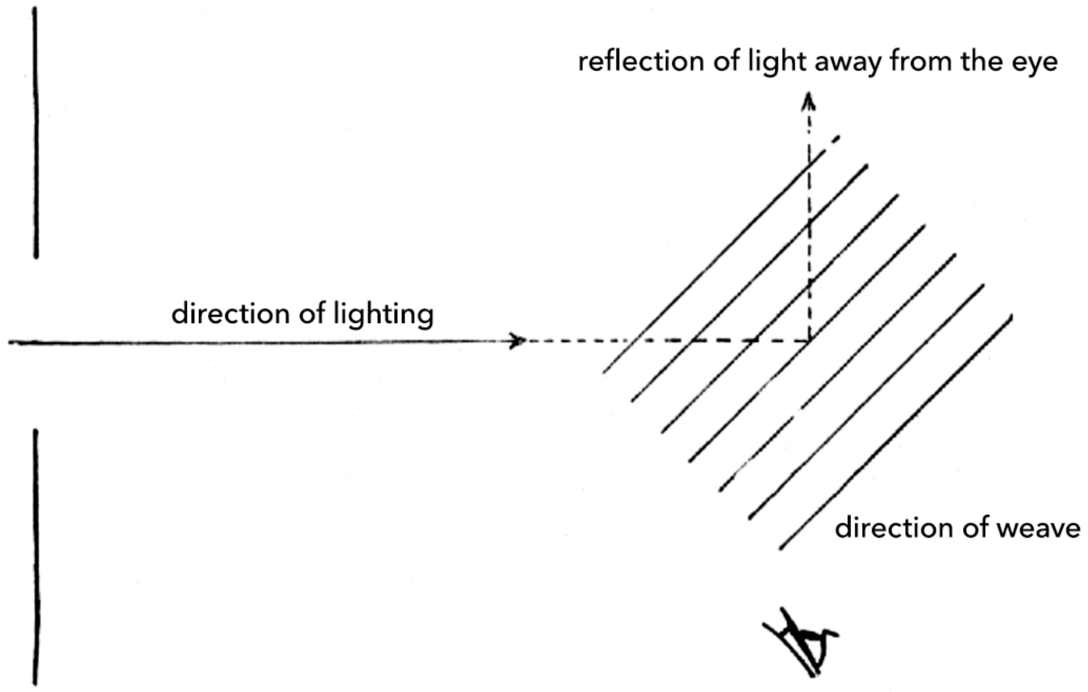

Fig. 42 Reflection of light from fabric with a satin weave directed away from the eye

Some ways of weaving apply such optical phenomena smartly when arranging the weave into patterns in various directions (cotton duck and damask). This achieves a peculiar effect of a pattern in a single-colour fabric.

The aforementioned light reflection phenomena can be verified easily for instance by putting a glass or metal stick or tube or just a fountain pen, pencil (even rectangular) of a shiny surface on a table instead of a fabric patch. Keeping them horizontal and turning them (fig. 43), we will observe increased light reflection, i.e. shine, in the same positions as in the case of the satin yarns.

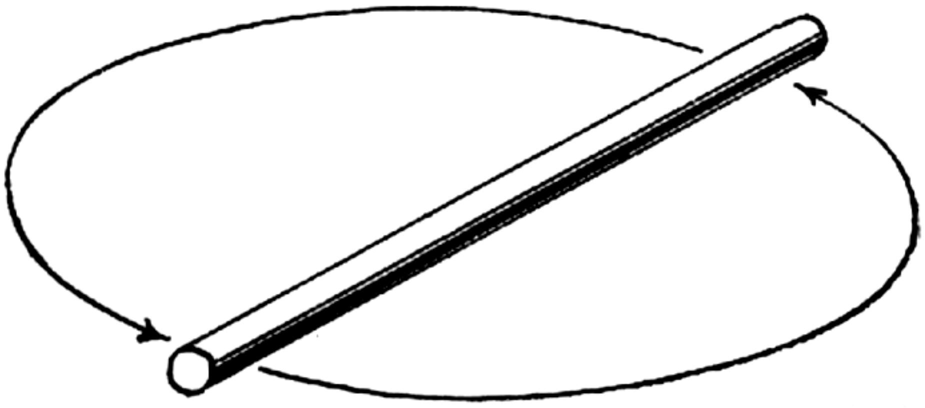

Fig. 43 In a certain position during the rotation, the glossy stick will acquire distinctive shine

To achieve the most directed reflection of surface light and, consequently, most intense shine possible, the surface of some fabrics is smoothened out by appropriate means, e.g. by ironing and, particularly, squeezing the fabrics between cylinders while hot (so-called calendaring). Sometimes, fabrics are impregnated with substances aiming to keep the yarns in their orderly positions as well as to fill the air voids between the yarns, creating an optically compact medium for light reflection.

These finishes lend the fabrics two kinds of appearance, rather different from each other. In a certain viewing direction, they emphasise the surface light and decrease the saturation of the colour of the fabric, in another viewing direction such light is directed away from the eye, emphasising the saturation of the colour. A garment made with such fabric features both kinds of light reflection in its folds; and so its overall appearance is hard and distinctive in 3D and, therefore, less peaceful. It alternates shining, lightened-up spots with darkened spots with no shine in the viewing direction.

2. **The fabric finish reduces the surface light as much as possible**. The colour of such fabrics is not diluted by the whiteness of the light and, therefore, the saturation of the colour is enhanced. This is achieved to a great extent in velvet.

The white surface light has just a limited possibility of reflection, mostly off the extreme tips of the fine pile tufted into the weave. If the pile is brushed in one direction, the surface light is reflected off the sides of the pile more, and with such brushing the velvet appears lighter and its colour less saturated.

If the light reflection is restricted, particularly dark blacks are achieved in black velvets; especially silk velvets reflect just a tiny quantity of light, thus standing out as distinctively dark.

Satin and velvet constitute a certain optical contrast, the former emphasising shine while the latter restricts it. There is a scale of various options between the two extreme methods of fabric finish; the plain weave could serve as the midpoint since it distributes shine equally in two directions perpendicular to each other (fig. 44).

Plain weave fabrics also include shots (from French: changer, changing the yarns). The warp yarns are in one colour while the weft yarns in a different colour. According to the viewing direction and light direction, light reflection from the warp yarns or weft yarns is more prominent. If the fabric is crumpled, the colour appearance will be more complex.

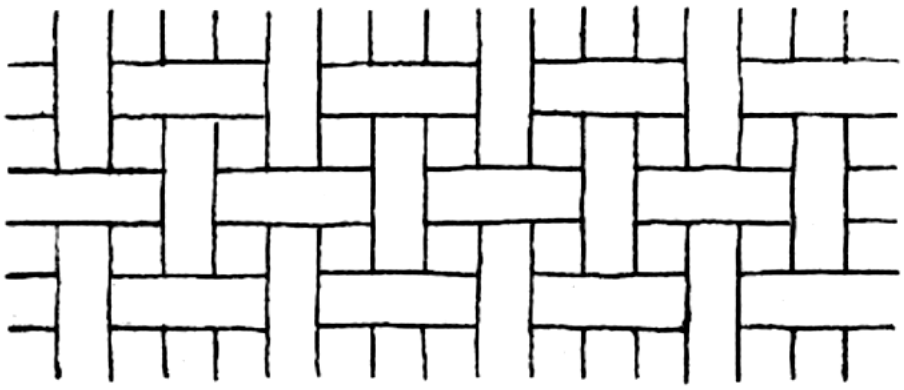

Fig. 44 Plain weave

THE COLOUR AND EXPRESSIVENESS OF SHINE

The determining factor is the lightness of the surface colour. Shine stands out the least on white and very light-coloured surfaces, more on less light surfaces and the most on black and other dark-coloured areas. Therefore, the mirror effect is most noticeable on shiny dark surfaces. The mirror effect increases with increasing level of darkness of the mirroring area, shading of the area and lighting directed at the counter-image (mirrored object).

If, for instance a wall inside a building is furnished with a tiling of light-coloured polished marble and plenty of light comes in through the windows, the mirror effect will be rather modest. Contrastingly, if the tiling is dark and the wall is shaded, the mirror effect and shine will stand out prominently.

METALLIC SHINE

The surface shine on objects is whitish, although it may be coloured if mirroring the colours of its surroundings, as e.g. the surface of a pond mirrors the blue of the sky. However, there is a narrower group of substances which deviate from the rules of shine as explained so far. These are primarily metals which maintain their colour even in shine. For instance, copper shines with a pinkish hue, gold and brass shine in yellow, zinc and chrome with a suggestion of blue, nickel with a hint of yellow etc. Besides, metals have another optical specificity, too: when viewed, they have a different colour than that observed when looking through them.

For instance, gold leaf is blue-green when looked through. The optical nature of metals is considerably more complex; we could roughly say that their special and powerful shine is predominantly the internal shine, originating in the very thin surface layer and, therefore, coloured all-through. When thin leaves of transparent substances, e.g. mica, gelatine, cellophane etc. are layered onto one another, the light reflection from inside will have a metallic shine to it. The overlapping folds of plastic raincoats take on a hint of metallic shine in this manner, too.

COLOURS OF THIN LAYERS

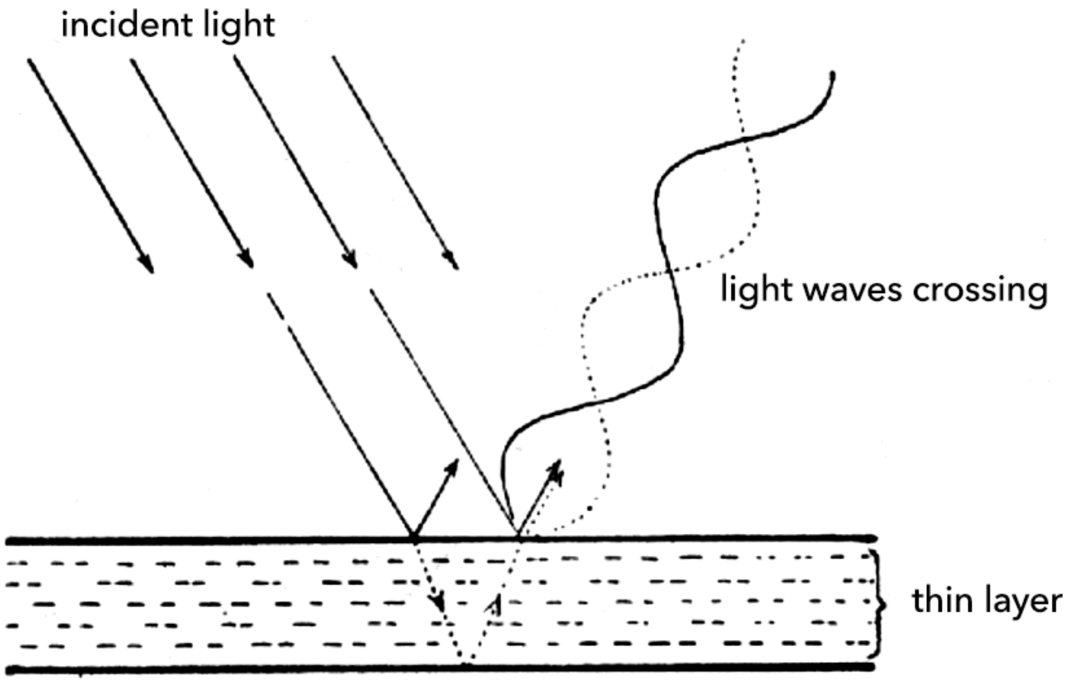

Fig. 45 Interference of light. Reflection of light in a thin layer and light waves crossing

Very thin layers of transparent substances take on colours the origins of which cannot be explained by the absorption processes. For instance, if oil spilt over a water surface forms a thin layer, its surface will flourish with the colours of the rainbow. The colours are formed by a certain combination of waves of the individual spectral lights. The light reflected from the surface of the oil layer is mixed with the light reflected, in the same direction, off the bottom edge of the layer, i.e. from its interface with water. If, within such reflections, the waves of a certain spectral light overlap one another and their peaks and lows are identical, the strength of such light increases thanks to the wave composition. However, if the waves combine in a way putting the peaks of one ray together with the lows of another ray, mixing with the former (fig. 45) – if the waves cross – the light diminishes. The remaining, undiminished spectral light components will manifest themselves with the resulting colour of their composition. Such crossing of waves is called interference of light; the colours resulting therefrom are usually called interference colours. Oil pools of lively colours are often seen on wet, oil-stained street pavements.

Colours formed by the crossing of light waves occur on thin layers of solid, liquid or gaseous substances. Blowing a soap bubble, we can see how the rainbow colours occurring on the surface of the bubble gradually change. As it grows, the thin film becomes even thinner; the different thickness of the film has different waves crossing which causes different colouration. A bubble film blown too thin loses its ability to induce wave crossing and the bubble loses its colours.

Heating polished steel to high temperatures, a layer of oxide forms and manifests itself with interference colours. At approximately 200 °C, the surface of the steel takes on a yellowish gold colour which turns red, blue, green and grey as the heating process continues. Metallurgists apply this method to lend a certain colour to annealed steel instruments in accordance to the heating temperature necessary to achieve the level of ductility of annealed (hardened) metal.

The surface of lenses in modern photographic equipment shows a hint of blue colouration formed in the thin, anti-reflex layer.

Iridising glass or glazed ceramic adds a rainbow coloured hint (iris) to the shine of the substances. This is achieved either by etching the glass surface or by applying a thin layer of certain metal compounds which introduce glass interference. Iris in dark, non-translucent glass tends to have a distinctively metallic shine to it.

COLOURS FORMED BY LIGHT BENDING

The bending of light is a term used for a particular phenomenon when light, in the absence of any obstacle to its course, changes the direction of its movement. Although it does not bend as such, its component diffract into specific directions and continue travelling in the new direction. This process occurs e.g. if light passes through a tight, narrow slit. The stream opens up and undergoes spectral dispersion. The red components deviate from the original direction the most, the violet ones the least (fig. 46).

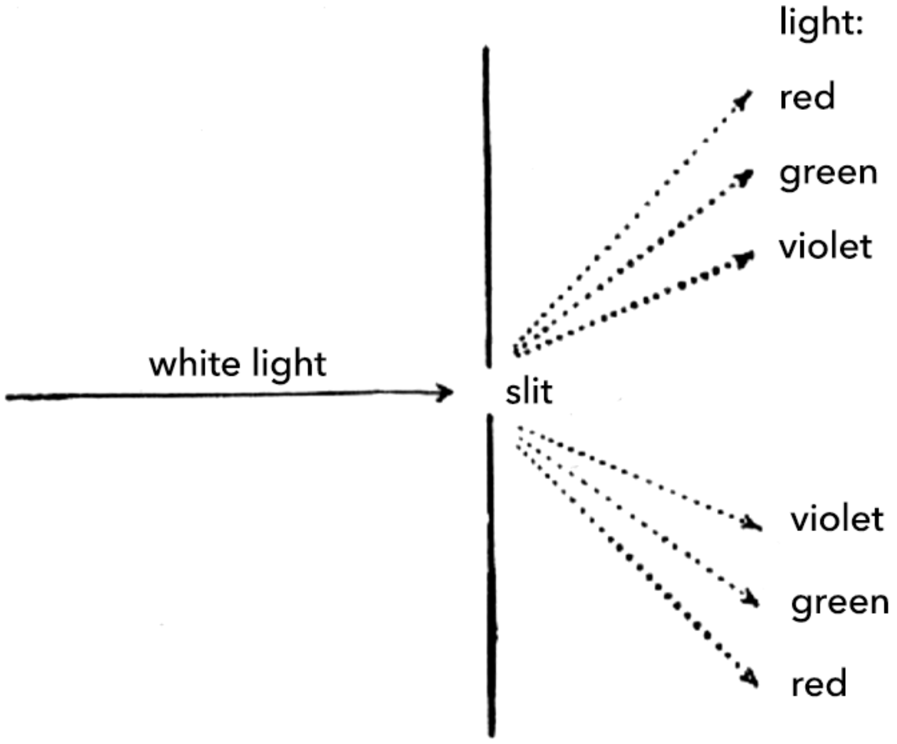

Fig. 46 Refraction of light. Light passing through a narrow slit diffracts.

A single slit lets through very little light and, therefore, the phenomenon is not too obvious. However, if multiple slits are placed next to one another, as in diffraction grating, the results of the bending are clearly visible. The grating is a plate of either glass or metal with a sequence of delicate, unnoticeable slits (1,000 to 1,500 per millimetre) engraved in them. A narrow area with no engraving is left between the individual slits — in the case of glass, for light to pass, in the case of metal for light to be reflected. The grating acts similarly to a prism, diffracting light into a spectrum.

Rainbow colours formed by a similar light diffraction process are encountered randomly in the nature. The variable colour shine on butterfly wings, beetle elytra, bird feathers is a light diffraction phenomenon. Nacre is formed by the continuous growing of very thin, scaly layers of the shell. Its fine and delicate corrugation diffracts light in a way similar to the diffraction grating. If soft wax is pressed against nacre, to reflect the corrugation, a hint of the mother-of-pearl colour shine will appear in the wax, too. Even man-made mother-of-pearl is sometimes made by a similar delicate surface finish. (So-called fish silver is used to make mother-of-pearl imitation; it is applied to a glass-like material of a glass pearl). Colours formed by light diffraction also adorn synthetic silk.

Another light diffraction phenomenon is also the “well” around the Moon. Diffraction occurs on the layer of vapour in the atmosphere. A similar phenomenon is observed when watching the light of a street lamp through a misty glass. The misty glass will feature a ring of light resembling the Moon ring. If the shadow of one's head falls onto dewy or frosty grass, a lighter-coloured ring with a suggestion of halo is seen around the shadow.

COLOURS IN SEMI-TRANSPARENCY ENVIRONMENTS

Substances of all physical states – gas, liquid as well as solid matter – may constitute so-called semi-transparent environment. If light passes through them, it encounters more or less fine particles of the foreign substance. Based on the proportion of the dimension to the wavelength of the light, various optical processes occur, resulting in certain colour phenomena.

If the particles of the foreign substance are larger than the wavelengths of the light, light reflects off them. This is how e.g. light reflects off clouds formed by accumulated vapours in the air. From the lit side, the cloud is viewed as a snow-white mass while it is grey when viewed against the light.

If the particle size is approximately the same as the wavelength of light, the particles cause light diffraction phenomena. This is the case of the vapour particles creating the Moon ring.

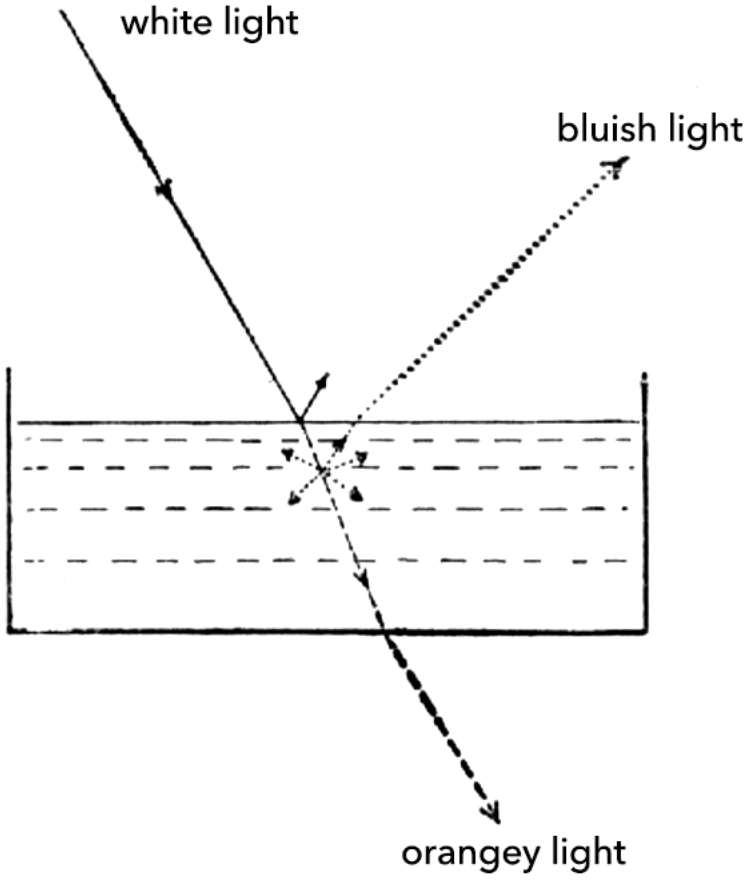

Fig. 47 Colours of semi-transparent environments – bluish when looked at, with an orange hint when looked through

If light passes through an environment where the particles are smaller than the wavelengths, light is diffracted in all directions. The short-wave components are diffracted more efficiently than the long-wave components which pass through the environment more easily. It is similar to larger waves rolling over a larger obstacle more easily than smaller waves.

Milk or water with delicate particles of white pigment seem slightly bluish when looked at. The short-wave light components are scattered on the delicate particles constituting the colouration, and create a suggestion of a bluish hue. If the liquid is contained in a narrow glass and viewed against the light, there is a hint of orange. More of the long-wave light has passed through the foreign substance (fig. 47).

Smoke emitted by a cigarette is usually bluish. If inhaled, its particles accept water vapours and increase their volume; the exhaled smoke thus does not disperse the short-wave light components. Nothing but light reflection remains and the smoke appears to be grey.

The sky blue is not the result of long-wave light being absorbed by the air, causing the remaining mixture of short-wave lights to form blue. Quite the contrary, the long-wave lights pass through the air most easily. The sky blue is explained by molecular dispersion. Due to the chaotic movement of molecules, the atmosphere always hosts denser and thinner spots, which disperse sunlight; blue rays are dispersed more than yellow and red rays. However, the blue of the sky is not identical in all landscapes and under all weather conditions. A higher proportion of water vapours in the air or loose dust diminishes its distinctiveness.

The light of the Sun low over the horizon passes through the less transparent layer of air close to the ground, which contains more vapours and dust. The spectral components of red, orange and yellow pass through the foreign substances more easily and make the setting Sun appear orange to red, depending on the content of the foreign substance in the air. Clouds lit by the red light of the Sun after the sunset are seen as the sunset glow. The part of light which was dispersed by the atmosphere creates an obvious fog and lends a bluish hue to the distance against a darker background of e.g. forested hills and shadows.

The colours of semi-transparent environments are everywhere around us. For example, the iris in blue eyes is not blue but semi-transparent. The bluish hue is that of the skin over larger subcutaneous veins. Let us put a rather thin milk-coloured frosted glass on a black-and-white base. The glass seems bluish over the black segments – the reflected, dispersed short-wave light components prevail over the long-wave components, part of which passed through the glass and was absorbed by the black of the base. The glass seems yellowish above the white segments – the long-wave lights are reflected off the white base and prevail over the short-wave lights dispersed in the glass. A similar phenomenon is mentioned by Leonardo da Vinci – the smoke coming out of chimney seems bluish against a dark roof while it looks brownish against the light.

White glaze on a black base seems bluish while black glaze on a white base has a brownish hue. A mixture of white and black paints does not yield a neutral grey but a bluish grey which is usually neutralised by a tiny addition of yellow ochre.

In a sequence of street lamps on long streets or along the embankments etc., the more distant lights take on a hint of orange, which increases with the distance and the amount of pollution in the air. With distance, light loses more of its short-wave components by dispersion, which means its colour is thrown off towards orange.

So-called fog lights are special vehicle lights for driving in the fog at night. They have yellow glass covers; since their yellow light lacks the short-wave spectral components, it is less dispersed by the fog. Longer-wave light travels through fog more easily and vision is not restricted by a thick veil of dispersed light. A yellow filter put on a camera lens has a similar effect. It facilitates a better resolution for more distant details of the photographic shot, along with a distinctive rendition of the distance.

LUMINISCENCE

The luminescence effects originate in different ways and are classified accordingly. If the radiant energy absorbed by a substance is transformed into a radiation of a different frequency within the visible portion of the spectrum, causing a luminescence phenomenon, it is called fluorescence. This is a term derived from fluorite, the rock, the violet crystals of which give off a greenish luminescent effect. Fluorescence if often caused by radiations not perceived by the human eye (namely ultraviolet ones). This is very well illustrated e.g. in kerosene which is transparent when looked through – this means it does not absorb light and all of the radiation of the visible spectrum passes through. However, it has a bluish luminescence when looked at.

Artists' paints, if lit by invisible lights in the darkness, also give off various luminescent effects. This property assists in the verification of authenticity of old masters' works. Some artists' paints are the products of a later time; for instance zinc white is more recent in painting practice as opposed to lead white. In ultraviolet light, the colours fluoresce with different colours. If zinc white is discovered this way in an allegedly old painting, it is likely to be a fake or to have been repaired more recently.

Fluorescence only lasts for the duration of the radiation; however, some substances fluoresce without any incentive, such as fluorescence due to chemical processes, e.g. oxygenation of phosphorus, which fluoresces in the darkness on its own; it gave this type of luminescence its name (phosphorescence). Similar phosphorescence phenomena are caused by chemical conversions in biological processes, e.g. in some kinds of bacteria, fungi in rotting wood etc.

Certain substances, like some metal sulphates, act as light accumulators. When lit, they continue to give off light in the darkness for some time afterwards. The luminescent substances are a significant part of light sources in light tubes, and are also used to achieve different colours of their light.

APPEARANCE OF SURFACE FINISHES

Polished surface. Particularly intense, high-level shine usually finds effective use in small-scale application. It lends a pleasant accent to tiny decorative accessories, e.g. precious stones and metal parts of jewels, costume jewellery, tiny glass products or chrome-plated small parts of car bonnets etc. Large areas of extreme polish may be too blinding, and thus violent, particularly from up close. They transmit a negative restless and tiresome feeling in longer views. However, they might be unpleasant even if viewed for a short time, or when eyes move over them, as they cause a lot of interfering afterimages of the so-called successive contrast. Once the retina has been stimulated by intense light, the afterimage of such light excitation stays for some time in the eye and interferes with the images of the subsequent views. If the effect of the strong shine lasts for a longer time, it might interfere even though it is not straight against the eye but comes from the side and is captured by the lateral parts of the retina which is particularly sensitive to light differences.

If a shiny surface acts as a mirror, it stops being a surface with a definition of distance for the eye; in sight, the distance disappears and a mirroring image is taken which seemingly extends the depth of space beyond the surface. However, a shiny surface informs us, through its mirror effect, of the perfect or less perfect finish of its flatness or roundness. A perfectly flat, shiny surface of e.g. mirror glass or polished stone manifests its condition by an undistorted mirror image. Such mirroring gives a very pleasant feeling whereas mirroring off imperfectly flat surface feels disharmonious and disturbing, distorts or fragments the mirrored image, informing us of its unevenness.

Shiny surfaces, if acting as mirrors, also give the impression of being dematerialised. If defining a room or even just serving as a wall of a room, they create the impression of indefinite space through the mirror effect. If a polished surface of lively colours is viewed from a position where no shine and mirroring applies, it uncovers the full power of its colouration. This lets for instance polished stones, marbles, granites, syenites etc. show off the beauty of their colour scheme, grain structure or granular composition. This way, polished stone is most effective if its surface is flat, i.e. with no complicated profile that would introduce distinctive lights and shades, thus assuming leadership in expressivity. Based on this e.g. classical Roman builders often left marble columns smooth, with no vertical fluting which was so common in the Greek days.

Unpolished smooth surface. Unpolished surfaces reflect both surface and subsurface light diffusely. Ideal reflectivity of the kind would be demonstrated by a surface that would diffuse light evenly in all directions. This is approximated e.g. by the surface of sketch paper, whitewash coat on a wall, watercolour or pastel painting etc. Unpolished surfaces with smooth finish appear to have identical colouration from all viewpoints.

However, unpolished surfaces also have other advantages; for instance, they are best at reproducing the lights and shadows, particularly their soft transitions over rounded surfaces. Let us compare them to polished and rough surfaces, respectively: the former introduces the excitement of shine and mirror effects or even considerable differences in colour saturation levels while the latter amplifies the play of shadows and lights over its rough spots. Contrastingly, a smooth unpolished surface appears to be overly simple and easy and, therefore, objects and environments of such surface finish create a more relaxed feeling.

A smooth surface of a single colour does not provide an option for the eye to focus and, unless there are other stimuli to determine or suggest the distance, it is more difficult for the eye to estimate the distance. If a surface of an indistinctive colour is finished in this manner, it gives an impression of receding, i.e. a longer distance. Due to that, such surfaces are the most appropriate backgrounds for objects intended to stand out and emphasise their position. Such surfaces, if in light and indistinct colours, lend themselves readily to creating an impression of airy spaciousness, if e.g. serving as the ceiling and walls in a room.

Rough surface. Roughness of surfaces may be achieved in various manners – e.g. tiny, regularly distributed indentations or fine, parallel grooves as well as more distinctive, sharp-sloped and less regular roughness. All that significantly modifies the appearance of the surface with a rough finish as well as its expressive effect. Finer and regularly distributed granularity or fluting on an area delivers a calmer, more balanced effect while steep and, particularly, less regular roughness intensifies excitability and conspicuousness and, with escalated roughness, even restlessness.

The appearance of a rough surface is co-determined by its colour, too, which has an impact on the varying levels of impressiveness of effect. If both, i.e. the colour as well as the roughness, are calmer and less flamboyant, they will act in conformity with identically distinctive effects of both the roughness and the colour. Discordant, contradictory effects can be achieved as well – e.g. a surface with steeper indentations, if furnished with a less distinctive, less saturated colour will emphasise its roughness more while a less rough surface finished in a more saturated colour will be noticed more thanks to its colour.

The surface of a smooth flat area appears 2D when viewed; if transformed into a rough surface, the elevations and indentations of its unevenness make it a 3D object. With light coming from the side, the roughness is manifested in a distinctive emphasis on lights and shadows.

The emphasising effect of rough surfaces must be borne in mind wherever a rough surface acts as a backdrop for objects in front of it. If the surface is noticeably rough as well as of a saturated colour, it creates the impression of standing out. If the object in front of it, e.g. a finely modelled, smooth and unpolished statue etc. is just soft in its expression although it should be dominant in the view, i.e. if it should clearly stand out, the rough, eye-catching backdrop could steal some of its distinctiveness.

A surface filled with a 3D pattern is actually also a sort of rough surface, albeit on a higher artistic level. This is how the surfaces of various substances, e.g. metal, wood, leather, plaster etc. are often artfully finished. This is also the objective of textile material presentation, particularly in the case of 3D knitting patterns.

With deeper, steeper finish of the roughness, the level of colour saturation of the rough area stands out even more. An explanation of this state was provided by Leonardo da Vinci already – in the lows of the rough surface, light is reflected several times which reduces its surface white light and makes its colour more profound (Fig. 48).

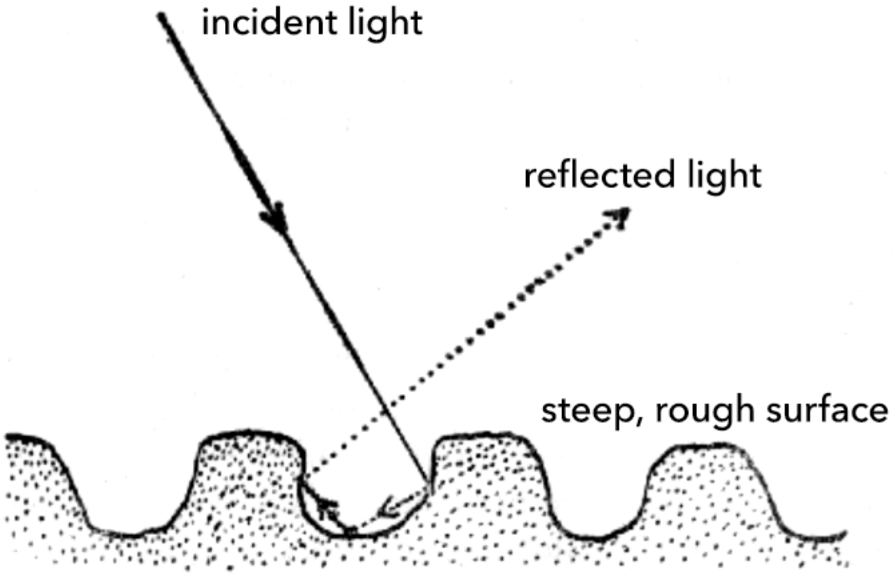

Fig. 48 Complex reflections on a steep, rough surface lend light a more saturated colour

This phenomenon occurs particularly in the folds of crumpled fabrics which acquire additional colour saturation in the shadows of the crumples.

From the perspective of expression, roughness of surface must be subordinated to more complex regards. Particularly to the character of the substance which is supposed to carry the rough surface, e.g. different ways of rough surface creation will be required by fine-grained rock, coarse-grained rock, crystalline rock or pebble composite rock; this also applies to various textile materials etc. The viewing distance from which the surface should be observed is a determining factor, too. When viewing from a distance, the eye does not recognise the rough finish of the area so the surface appears to be flat.

On a polished surface, the impression of the weight of the substance disappears due to the shine and mirror effect of the surface. Smooth, unpolished surfaces give off an airy and lightweight impression. Contrastingly, rough surfaces create a feeling of mass and weight, all the more with increasing size and strength of the roughness. Therefore, e.g. the use of rough surfaces on pedestals for statues, buildings etc. is an apt means of expression for placing the centre of the object's weight at the bottom thereof. If the taller part is less rough, or if it has a smooth or even polished surface, the impression is even more powerful. The opposite finish, i.e. a smooth or polished pedestal wherein the top part is rough, may create the impression of a levitating heavy mass.

A large rough area does not appear to possess the same level of clarity overall in short viewing distances. Where viewed along the direction of light, it shows off particularly the lights of its roughness whereas in the opposite direction, against the light, it tends to show primarily the shadows in the rough surface. This applies all the more to rounded surfaces. Therefore, a rough surface does not show an evenly distributed lightness in its entirety.

COLOURED PAINTS

In a paint coat, powdered colour pigments are bound to cohere with a transparent and, ideally, colourless substance (called binder) which also facilitates paint adhesion to the base surface. The ratio of optical densities of the colourant and the binder determines transparency or opacity of the paint coat.

GLAZE

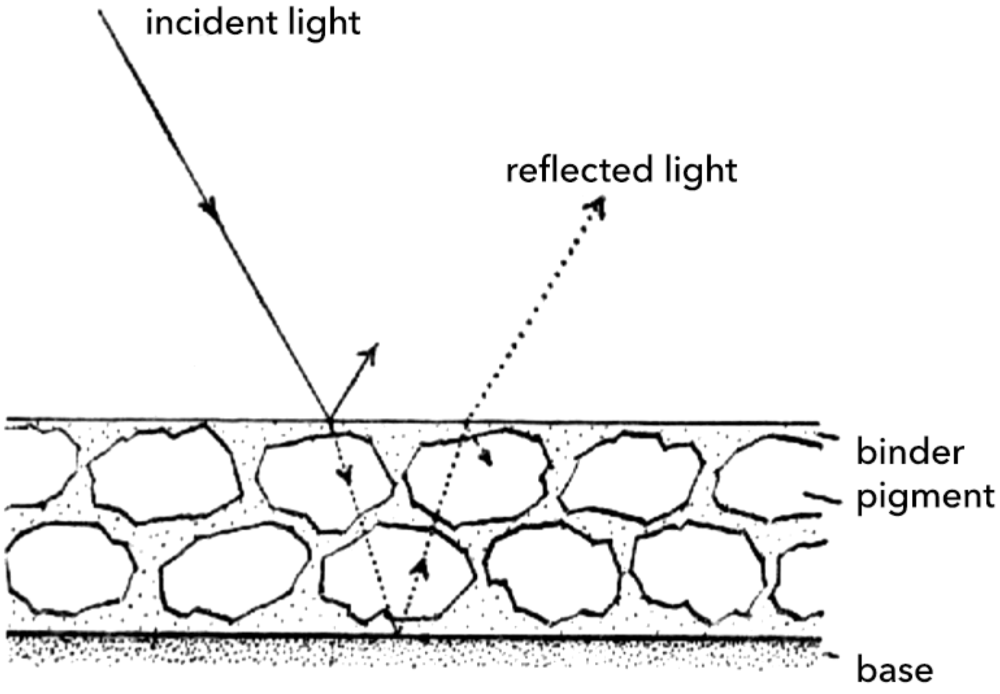

Fig. 49 Reflection of light on a layer of glaze polish

If a paint coat is to be transparent even in thicker layers (i.e. glazing), the optical density of the binder must be identical with or as close as possible to the optical density of the colourant. Light passes through the paint coat undisturbed until it reaches the base from which it is reflected and travels back, again, still undisturbed. This is illustrated in a simplified form by fig. 49.

TOP COAT PAINT

If compared to glazing, the top coating paint has the opposite ratio of the optical densities of the two components, i.e. the colourant and binder. The more different the optical densities, the more opaque the paint is even in a thinner coat layer (improved covering ability). Light diffracts and refracts more on the interfaces between the two substances, i.e. the colourant and the binder, and leaves the layer with its colours without having reached the base (fig. 50).

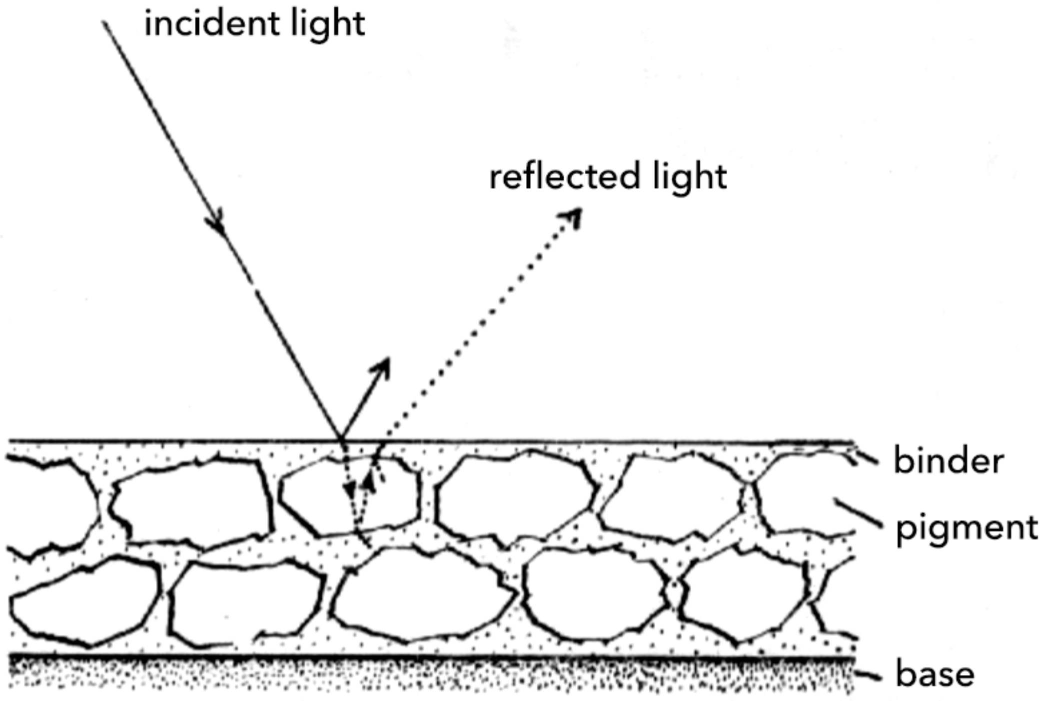

Fig. 50 Reflection of light in a layer of finish paint

WATERCOLOUR PAINTING (GLAZING)

White paper which is used as a base for watercolour painting reflects all of the spectrum colour lights. Depending on which watercolour is applied to a spot, and on the thickness or density thereof, the layer applied starts absorbing certain spectral elements of the incident light and light reflected off the base, which is demonstrated by the visible colour. The watercolour surface devoid of shine diffuses white light with surface reflection in all directions; the light is added to the lights reflected off the base and coloured by absorption. This is detrimental both to the saturation of the colours and to the darkness of dark colours. In spots coated by transparent lacquer finish, directional reflection light will replace the diffused surface light. If reflected outside the eye, the colours in such places will increase in saturation and dark colours in darkness. For light colours, this subtraction of white surface light means lower level of lightness. If a part of a picture is repaired by transparent finish, the spots intended to radiate should be left without the finish layer.

OIL PAINTING

It differs from watercolours optically primarily by the fact it does not count on light reflected off the picture base. Light is reflected back within the thicker layer of paint that is common for oil paints. Glazing which is sometimes used even in this technique is usually done with a thinner glaze applied to the underlying colour layer with which it is intended to create the ultimately desired colour. Light passing through the thicker layer of paint accommodates more efficient absorption and, therefore, more profound colour saturation. This is facilitated also by shiny surfaces which often occur in oil paintings, albeit just in the viewing direction which avoids its whitish shine.

SATURATION OF COLOUR AND SATURATION OF COLOURANT SOLUTION

We are used to call colourants “colours” although colours are nothing but perceptions. This results in some terminological problems, particularly with respect to colour saturation definition. For instance, a mixed thick yellowish ochre is called a saturated colour although it is but a more saturated solution of the colourant and actually just a reduced level of saturation of orangey yellow colour in terms of perception. A thick solution of white is often considered saturated white if compared to a thinner solution thereof. Similarly, the degree of opacity in frosted glass is called thinner and thicker.

The level of saturation of a colourant, if called colour saturation, is merely the ratio of concentration of the solution, and allows for mixing substances of even negligible colour saturation as e.g. umbra, sepia etc. Only when mixing a colourant of a higher saturation level, like yellow cadmium or vermillion, the real colour saturation degrees may be roughly identical to the saturation of the colour solution.

Structure of the Eye; Vision

Visual art takes advantage of a multitude of various substances which are processed or modified in many different artistic ways. This is reflected in the range of various visual art techniques (techné = Greek, know). However, what is common for all visual art methods and, basically, what is the essence, the fundamental thing which is visually processed or, to use a better word, modified – is light. A painter projects various transformations of light onto an area, a sculptor's or carver's works actually model various ratios of light intensity; similarly, other fields of visual art compose various modifications of different light ratios in their works. The underlying sense and purpose of visual work in all visual art fields is also the same – they all strive to elevate people's emotional experience above the everyday living level. Ultimately, there is also the common mediator which makes the beauty of visual art accessible to us – our vision.

Our thinking so far has been dealing with the nature of light from both the physical perspective, e.g. the spectral composition, reflection, refraction etc., and from the point of view of a psychological phenomenon, i.e. its colour, saturation and brightness characteristics. In this section, we will give a brief explanation of the structure and activity of the visual system which facilitates perception of light, i.e. the physiological nature of eyesight.

Structure of the Eye

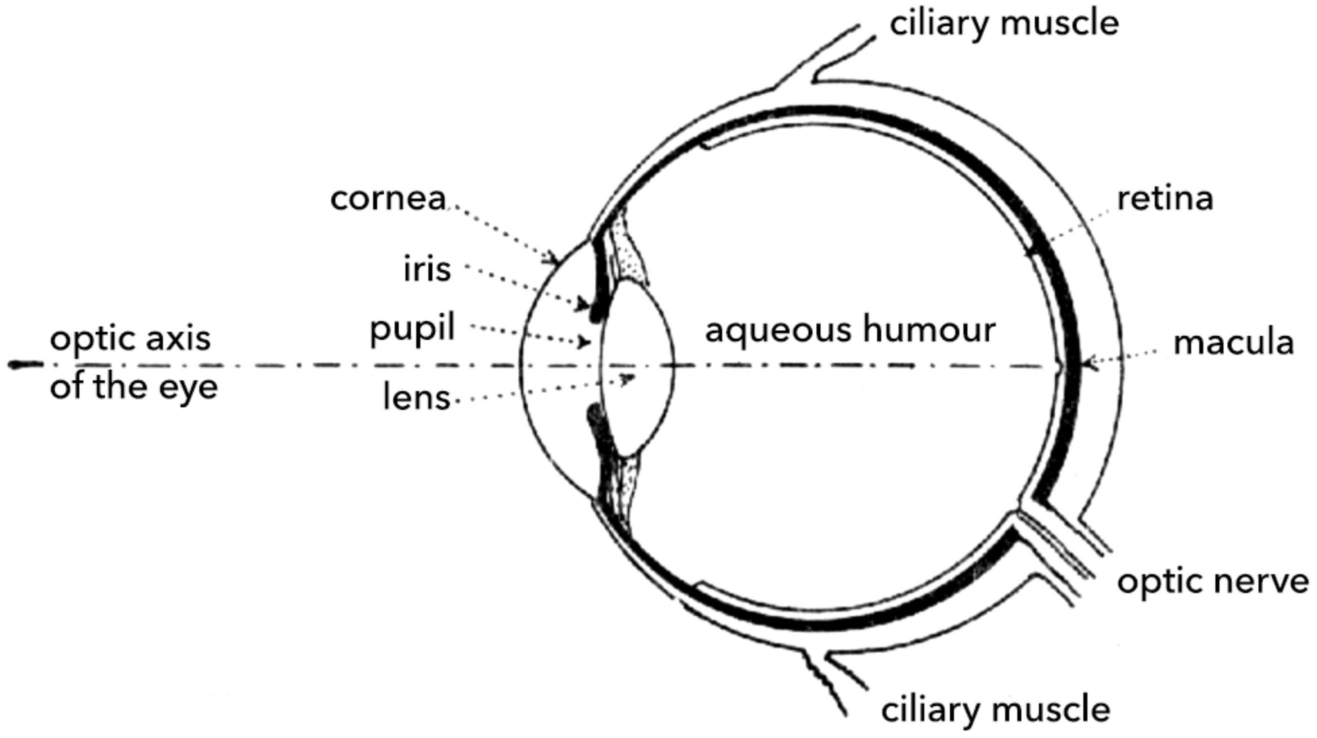

Fig. 51 Structure of the eye

Nature has been developing visual systems, the various structures of which are assigned to living creatures, for a very long time. The systems are optimised for the needs of the creatures; e.g. insect eyes are different from those of fish, birds, not to mention mammals and, in particular, mankind. The earliest evolution of vision probably meant hardly noticeable recognition of dark and light. Over the long term, many creatures have developed a marvellously perfect and powerful vision. Numerous advantageous properties are possessed namely by human vision, which is characterised by, inter alia, an outstanding resolution. It is adapted to distinguish even minute differences (so-called recognition threshold) not only in the intensity of a light stimulus but also in any changes to its spectral composition. This lends sight an extensive range of options to inform us of the light situation in our surroundings. This provides a greatly improved level of ease, enrichment and beautification of our lives.

The human eye is therefore one of the most amazing creations of nature. It is a small, circular, light-tight chamber (fig. 51) wherein only the front, slightly convex, protruding part (the cornea) is transparent. This is where light enters the inside of the eye. First, it comes into the space behind the cornea, in the eye’s front chamber. Then it passes through the circular opening in the iris which is capable of changing the size of the opening, thus controlling the quantity of light that proceeds further on inwards in the eye (to the rear chamber). Iris can have various colours; based on that, eyes are called blue, grey etc. Just behind the circular opening, there is the lens, the most important part in the eye’s optical mechanism. It is asymmetrically biconvex with a layered composition, quite like e.g. the layers in an onion. The individual layers keep refracting light as it proceeds inwards which reduces the distance necessary for an image to form on the back side of the cavity, on the retina. The hollow between the lens and retina, the rear chamber of the eye, is filled with a transparent, jelly-like mass – the vitreous liquid. So, the eye’s lens is basically all of its transparent system, from the cornea to the vitreous liquid.

Although the retina is but a very thin layer (of approximately one quarter of a millimetre) it possesses a very complex mechanism. The central section of its area hosts a yellow patch with a small dip. Along with the centre of the lens, iris and cornea, this is where the optical axe of the eye runs. The central part of the retina also contains several million tiny, delicate sensors, cones whose numbers decrease towards the edge of the retina. They merge with many millions of similar bodies, rods which prevail towards the edge of the retina. At the rear part of the eye, the visual nerve runs from the retina towards the brain.

EYE MECHANISM IN OPERATION

The movements of the eyeball are controlled by six muscles which are responsible for the positioning of the eye in the direction of vision. The task of the eyelids is both blocking light from coming into the eye and protecting the eye, its sensitive cornea in particular, from damage. Besides, the eyelids are also supposed to keep the cornea clear, wipe any dust off, wash and hydrate it with tear liquid. This keeps the cornea shiny and as transparent as possible. The opening in the iris (the apple of the eye – pupil) adjusts the quantity of light necessary to illuminate the photosensitive retina by opening or closing. Processes adjusting the retina to the intensity of exposure occur in the retina itself, too. This allows the eye to adapt to varying light intensities, and this process is called adaptation of the human eye. It may have two forms, either the eye adapts to light when we e.g. come out of darkness or dusk to light. Or the other way round when we go from light to dimness. The course of the latter adaptation is slower; it usually takes longer for us to start seeing in a dim setting. The range of adaptation of the eye is quite extensive; let us recall the ratio of intensity of sunlight during the day, to moonlight. Even with the several hundred thousand-fold weaker light, our eyesight allows us to recognise things around us.

The eye lens is elastic; along the perimeter, there is a muscle which either compresses the lens, making it more convex and more light-refracting, or relaxes the lens, thus making it less convex. This is how the eye focuses for closer or more distant looking, creating a sharp image of closer or more remote objects on the retina. This ability to focus is called the accommodation of the eye. The light-refracting mechanism of the eye is convex, that means, the rays entering the eye from a point are merged together again in a point (fig. 52). The viewed image of our surroundings is nothing but a sum of countless points each of which is represented like this on the retina where a tiny image is created out of all of them. The image is upside down – however, our vision follows the direction of the rays, allowing us to see things as they are, i.e. in their natural position.

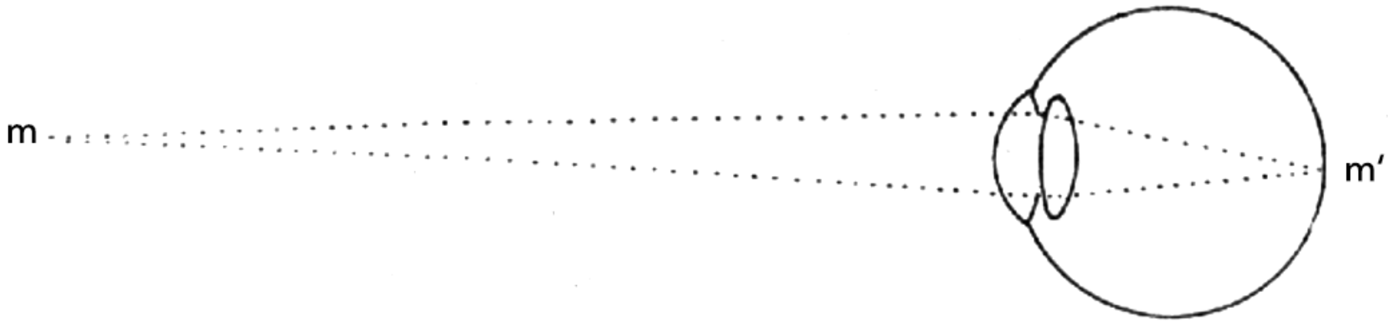

Fig. 52 Light rays emerging from a point are connected by the light-processing system to form a point on the retina again

The projection area of the eye, the retina, is a photosensitive area. In its complex organisation, the light of the projected image is absorbed and generates a stimulus which is carried on by the nerves to the brain where the stimulus is transformed into the sensation of light. The upside-down tiny retinal image metamorphoses into a large image of the environment as perceived by our eyes.

RANGE OF VISION

The range of our viewable surroundings is called the visual field. When our eyes move, our vision is capable of taking in the horizon, or the field of view. Although each of the eyes into which the visual mechanism divides is an independent system – if one eye is covered, we can still see with the other eye – both of them create a unified, identical and single image. This is seeing with both eyes, or binocular vision. However, the projected images are not absolutely identical on the retinas of both eyes, and the visual fields of the two eyes are not identical either. The distance of the eyes means that the left eye sees the observed object more from the left, while the right eye sees it more from the right. The axes of view angle of the two eyes are not of identical directions, either. Both of them are directed towards the point at which our sight focuses. So they are at a more or less sharp angle, depending on the distance of the observed point (fig. 53) – this is called the accommodative convergence of the axes of the eyes. It is remarkable how our vision is capable of obtaining a single, undoubled image from two retinal images which are not absolutely identical. If we apply a light pressure on one eye with a finger to put it off its normal position, the objects in front of us will double in our vision.

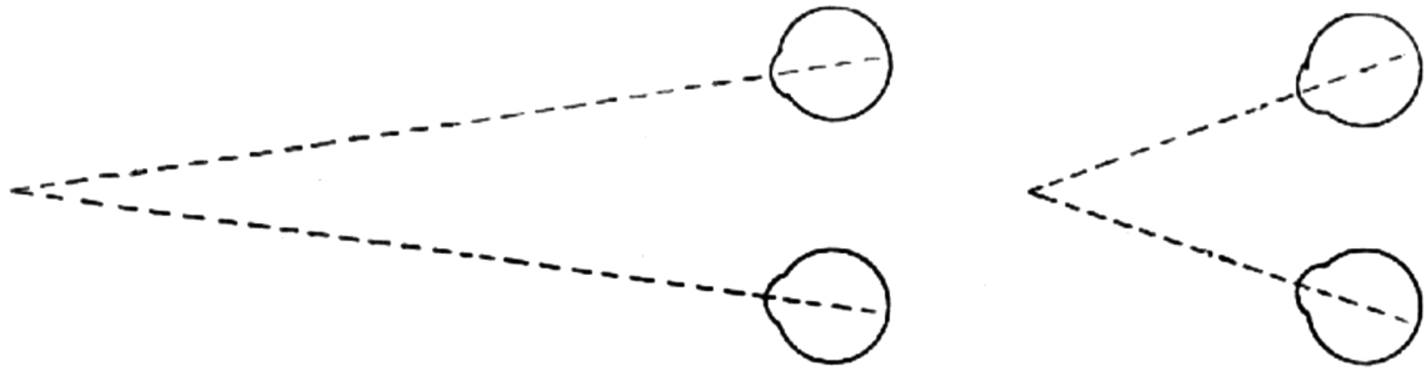

Fig.53 The convergence of eye axes in distant and close views

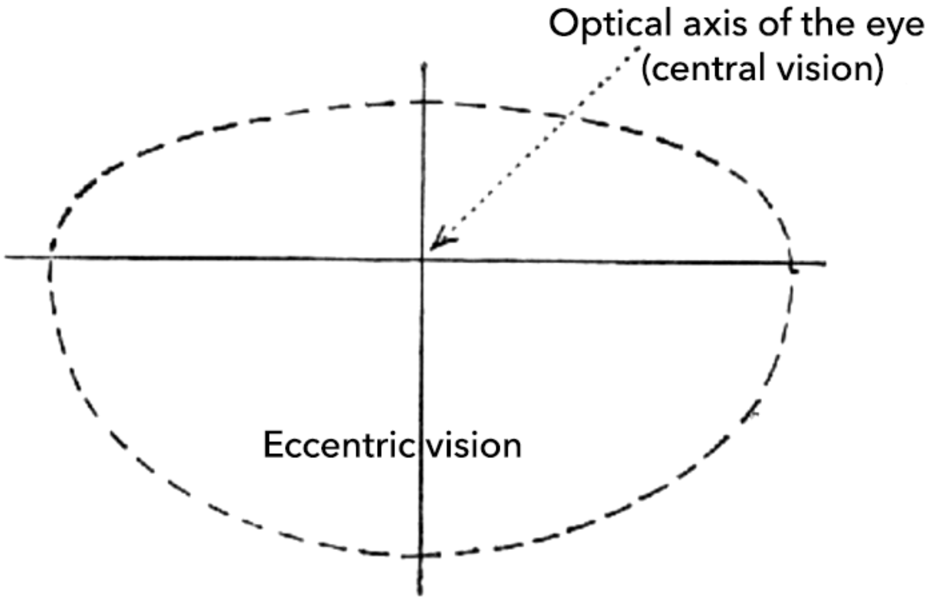

Fig. 54 Shape of the eye's field of vision

The visual field of both eyes together is of an oval form, more developed downwards and sideways than upwards (fig. 54). The downwards prevalence is justified biologically. Humans are creatures living close to the earth, and walking in particular requires us to pay attention to what is down there. In nature, most light is usually above us, and limiting its access to the eye from above is a practical way of protecting our eyesight from excess light. Such limitation of sight in the upwards direction also has a negative point to it – we can easily bump into things located just above our head. This is observed particularly in production operations where there is a risk of injury from above. Upon close looking, the visual field is wider while it narrows down when we look further into the distance. With more distant views, more things enter the visual field, thus increasing the number of impressions in the range. A narrower visual field reduces the range and helps achieve more concentrated vision.

VISUAL FIELD AND VISUAL ACUITY

Sharp vision is facilitated by just a tiny portion of the retina, namely the area with the macula lutea, where the optical axis of the eye runs through. It is the only location where the sight projects an identical representation of point (a) on which both eyes focused (fig. 55) for both eyes. This visual directionality makes our look focused and distinctive, e.g. we are capable of telling what another person focuses on. The remaining parts of the viewed image are not identical on the retina of the two eyes, their locations are not in the same or even corresponding spots (fig. 55, points b, c).

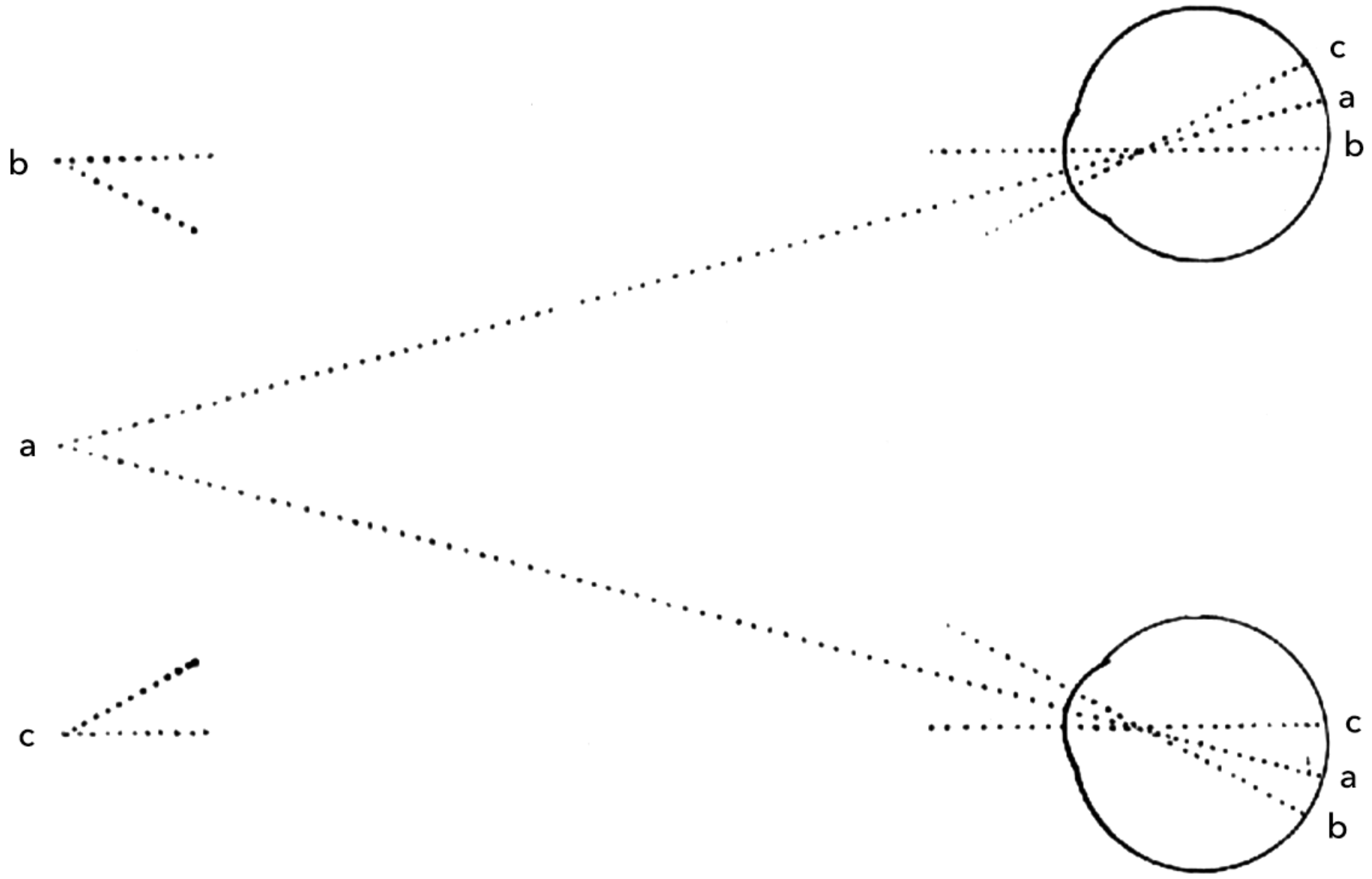

Fig.55 The distribution of the points on the eye’s retina in central and eccentric vision

The sharp vision of the central part of the retina is the central (direct) vision. The remaining, non-central part of the retina renders an unfocused image and shapes are recognised with less acuity. This vision is called indirect. The advantages of indirect, blurred vision were pointed out already by J. E. Purkyně. It encourages our consciousness to consider the sharp image in the central part of the retina more closely, more attentively than if we were distracted by a sharp image with high resolution all over the visual field.

Healthy eyesight is characterised by outstanding visual acuity. From the practical point of view, the threshold angle for noticing details is indicated, namely the one-minute angle. According to that, e.g. a line of 1 cm thickness can be recognised from a distance of 35 metres. However, this distinctive ability of the eyesight has a more complex mechanism, the psychological aspect of vision plays a role here as well, and the one-minute angle is but a rather approximate value.

VISUAL FIELD AND COLOUR PERCEPTION

The colour-sensitive area of the eye is the central part of the retina; the remaining part of the retina facilitates seeing just along the neutral grayscale. As the central part of the retina houses the sensitive bodies, the cones, while the peripheral part mainly contains rods, we believe that the cones facilitate colour vision. What is worth noticing is the fact that we do not realise this division into colour versus grey vision at all. For example, standing in front of a large coloured wall, we perceive the whole area of the wall in full colour, not just the part that corresponds with the retinal image in the central part of the retina.

However, we do realise the double nature of vision at dim light conditions or in moonshine when bright colours are not perceived when illuminated with lower intensity. We only see in degrees of grey. Therefore, greyish colour palette is best suited to creating the impression of dusk, twilight, and grey colours lend themselves more readily to suggesting shadows in the environment. As well as too low illumination intensity is incapable of lightening up bright colour palettes, too intense, blinding intensity is detrimental to colour vision and we can only see less saturated colours rendered blindingly white.

THE NATURE OF CENTRAL AND PERIPHERAL VISION

Even though the central part of the visual field takes leadership as to visual acuity, colour perception and concentrated viewing, this does not mean that the remaining parts of the retina are something inferior or less important. Quite the contrary; peripheral vision is a necessary complement to central vision in some of our actions since peripheral vision has certain significant benefits in comparison to central vision. Although it seems to be a minor agent in the act of seeing, it is particularly sensitive to the light-dark differences, and more sensitive to the perception of movement than central vision. Peripheral vision allows us to notice, with great sensitivity, if there is something moving sideways around us, for instance when concentrating on a book page, a random movement to our side will disturb us. These properties of peripheral vision must be taken into consideration in some professional operations.

The importance of peripheral vision for our movement is reflected by some retinal disorders. A central vision disorder, central blindness, means that the person cannot read while still well capable of moving and getting around space. In the opposite case, if peripheral vision is affected, the person keeps bumping into things around him and must be assisted like a blind person although he maintains his ability to read. This hints at another important benefit of peripheral vision – it lends us the ability to get our bearing while in motion.

PERFORMANCE OF OUR EYESIGHT

The structure of the eye is sometimes compared to the mechanism of a photographic camera. A comparison of the performances of the eye and even the most perfect camera would be more difficult. The eye is a perfect automatic machine, directing itself according to our intentions, extensively and automatically adapting to the changes in light intensity, and even focusing the retinal image. Then it develops this image in our consciousness, in lively colours and enlarged in great dimensions into a large, 3D image.

The smooth sequence of such viewed images gives us a real-life impression of our surroundings, the movement therein, the transformations, beauty and banality alike. While we are awake, experiencing the world with our eyes forms one of the most important parts of our life.

On top of its performance, our eyesight also attempts at achieving perfection of the viewed images rendered so that they capture reality as well as possible. However, its complex mechanism as well as the complicated procedures of achieving awareness thereof often create obstacles to that. So, seeing also involves some phenomena biasing the exact assessment of the actual situation which are generally called visual illusions. Under certain circumstances, for instance, we tend to estimate lengths, directions, straightness of lines, size of angles, proportions and sizes of shapes etc. incorrectly. In relation to the perception of colours, it is particularly the so-called colour contrast when colours affect each other as to their appearance. The eye lens is not adapted to colour, or chromatic, defects. Out of white light rays, it combines the more refracting spectral components, blues and violets, closer while the less refracting ones, reds and yellows, are combined further away which means there is a diffracted colour image on the retina rather than a single one. However, we do not realise this phenomenon in our everyday life; it does not interfere with our vision which is therefore practically free of this defect.

The excitation of the eye caused by light lasts slightly longer than the duration of the light stimulus or change thereof. Therefore, a very fast exchange of light variations cannot be captured by the eye, which combines them into a single resulting impression. This makes rotating coloured wedges merge into a single colour sensation, as well as the fast sequence of images screened in the cinema merges into a smooth rendition of movements as well as gradually changing colours.

Great differences in lightness induce the noticeable phenomenon of so-called irradiation: Light parts in a dark environment appear to be slightly enlarged, e.g. white lines seem wider against a black background. The same applies vice versa, black lines against a backdrop of white seem narrower (fig. 56).

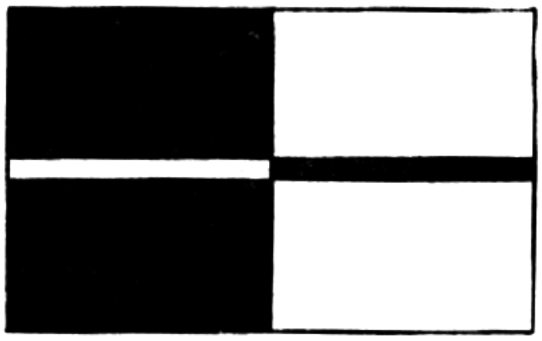

Fig. 56 Irradiation. The white stripe seems wider while the black one seems narrower

IRRADIATION

Irradiation is explained as the phenomenon of light spots in the retinal image stimulating the retina also on the outer side of the contour, thus seemingly enlarging their image. The red-hot filament in a light bulb is a good example of this. For instance, if it is charged by a weak torch battery only, the lesser incandescence makes it seem just slightly wider. However, if charged by a fresh, fully loaded battery, it will light up and demonstrate a considerable enlargement. This enlargement does not stem from thermal expansion which is negligible in this case; it is caused by the powerful effect of intense stimulation of the retina.

Astronomers encounter irradiation when assessing star sizes by sight. If a star is brighter, it seems bigger. Galilei and Kepler already took the effects of irradiation into consideration, and studied its laws. If summed up, they are expressed as: The smaller, narrower or lighter a light element in a darker environment is and the darker such environment is, the more the element is seemingly magnified. And vice versa, the smaller, narrower or darker a dark element in a light environment is, and the lighter the environment is, the more it is seemingly diminished.

An appropriate imitation of the irradiation phenomena lends a painter a means of interpreting the robustness of the light portrayed, particularly the light of a light source. For example, darker, narrower things are painted narrower in the parts standing against intense light. And vice versa, a light source portrayed, e.g. the sun setting over a mountain, will shine over the contour of the mountain slightly.

Classic Greek builders made corner pillars thicker than the remaining pillars of the temple porticos. This compensated for the irradiation effect as, in front view, the corner pillar appeared dark against the light sky and, therefore, seemed narrower. Contrastingly, the pillars in between appeared lighter against the shaded temple gallery and, therefore, they were seemingly expanded by irradiation.

COLOUR VISION THEORY

The various theories trying to explain how the sensation of colour is formed are mostly hypotheses. A significant earlier theory assumes that the retina is sensitive to three primary colours. The resulting colour sensation is created based on the ratio of the individual colours in the light stimulating the retina. If there is equal stimulation for all three primary colours at the same time, the result is a sensation of white.

In the last century, the visual purple (rhodopsin) was discovered in the retina; it is eliminated in light and restored in the retina in the dark. This encouraged the efforts to explain the formation of colours in our eyesight by means of chemical processes in the retina. For instance, the theory that vision involves procedures consuming and restoring substances facilitating colour vision was formulated. Certain colours cause some of the substances to disintegrate while the opposite colours restore them.

Another colour vision theory is looking for an explanation in electric voltages created by light absorption in the retina. Depending on the frequency, the oscillations generate the sensations of various colours. Thermal effects caused by light absorption in the retina are also considered.

EYESIGHT AND VISUAL ARTS

In conclusion, there is no need to point out the enormous importance of vision for our life; however, let us recall its role in visual art activities. It is a prerequisite for visual art; there would be none without vision. The images springing from a man’s visual art feeling may be transferred to reality and materialised solely with the help of vision. Eyesight makes it possible for an imagined picture and its real rendition to be as identical as possible. Eyesight is both the assessor and the scale in the work procedures which transform the idea into a work of art, and it keeps checking their identity. It verifies the dimensions, surface and colour ratios, expressiveness and the demonstration of the entire visual life of a work of art. Eyesight is also an agent presenting the story, life and beauty of a visual art work to the recipient.

Deriving colour shades/tints

MIXING PAINTS

This method is applied most often when colour shades are created. The addition of white, black or various degrees of grey to a saturated colour provides the individual shades of certain lightness and saturation. However, the method involves some serious difficulties. The more complex spectral composition of colour light reflected by the paints causes minor or major changes to the original colour treated in the mix. A particularly adverse effect is demonstrated in the case of mixing black with yellow. The resulting colour is not a dark yellow, i.e. yellowish-brown but rather an olive green.

Saturated yellow has a very broad range of spectral lights it reflects, from red to orange and yellow to green. Long-wave lights, i.e. red lights, enter the paint coat with more ease, thus being more effectively absorbed by the black component. In such depleted light compositions lacking the red component, the green components prevail and, therefore, the darkened hue leans towards green. If such greenish variance is to be eliminated, the prevailing green must be neutralised by an addition of red, i.e. the loss of the red spectral components must be compensated for.

Sometimes, the greenish aberrations of the darkened yellow inspired the incorrect explanation that brown is a special colour not included in the spectrum. Browns are actually darker shades of yellow, orange, or orangey-red colours. In this regard, let us note the darker shades of yellow or orange which result from darkening these colours, e.g. shadows on yellow- or orange-stained wooden furniture. Unless modified by another colour reflected off its counterpart, they are brown. Darkening of orange or orangey-red yields orangey or more or less reddish browns, while darkening of greenish yellow (lemon colour) yields olive brown hues. Olive green is a darker shade of greenish yellow colours.

Lightening yellow or orange with an addition of white, the lightened mixture tends towards green as well. However, in this case this is not as obvious; it may be noticed when the exact complementary colour is determined for the hue obtained by mixing. The complementary blue is usually more violet than in the case of unshaded saturated colour.

As we know from the preceding explanations, white mixed with black does not yield a neutral grey but a bluish grey instead.

USING ROTATING WEDGES TO DERIVE COLOUR HUES

This method modifies the ratio of the shaded to the neutral colour by altering the angle of the respective wedges (fig. 16). It is a method offering the widest range of possibility to create colour hues. Based on the result created by the wedges in their rotation, we can imitate the corresponding shade as required with paints. The shades obtained by darkening very saturated colours with an addition of black are often so exquisite that mixing paints rarely achieves such liveliness of colour. The most beautiful darkening occurs when the coloured wedge is rotating in a circular opening of a box the inside of which is furnished with black silky velvet. This delivers a particularly dark black for darkening purposes.

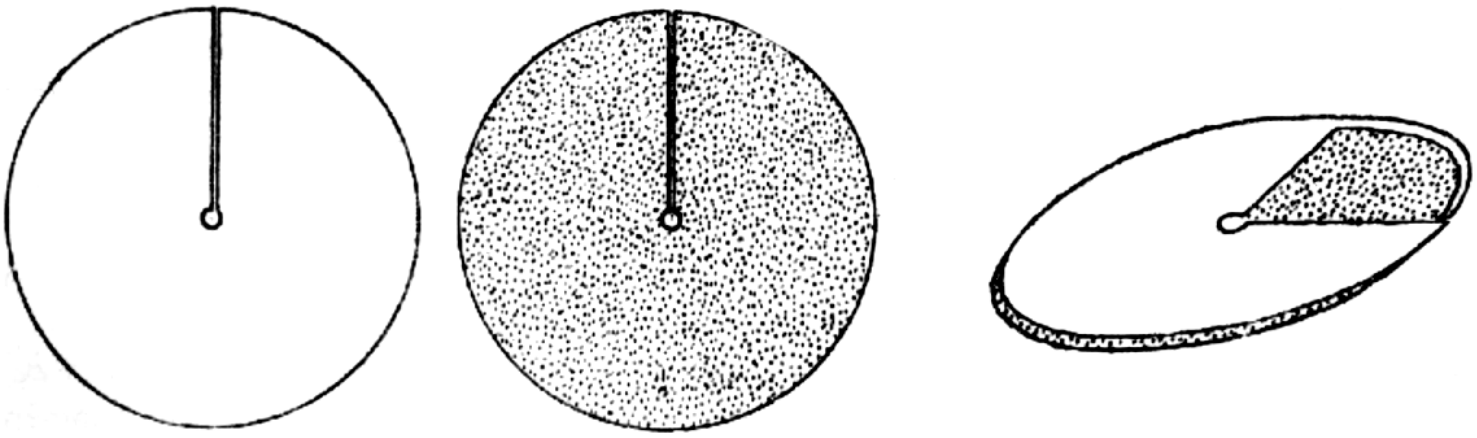

Fig. 16 Colour circle adjustment for rotating wedge set-up

The rotating wedges deliver correct results of colour derivation; the individual hues of the shaded colour have the same complementary colour. However, the strange phenomenon of lightened hues acquiring a slight hint of pink occurs even here, being more noticeable particularly with yellows, if lightened by white.

The rotating wedge method also allows measuring the lightness or saturation of the colours shaded by calculating the angle sizes. However, that is a problem which would require a more complex explanation. For instance, the course of light variability is governed by the Weber-Fechner law. Therefore, the size of wedges must be increased geometrically to achieve an even increase in lightness. The saturation variability follows an even more complicated course: it is only simple in cases where a saturated colour wedge is joined with a grey of identical level of lightness. Any increase in the size of the saturated colour wedge, i.e. a decrease in the size of the grey wedge, results in the same increase in colour shade saturation created during rotation.

VARNISHING

The colour of the clear top coat, the varnish, also includes the colour of the underlying layer. Varnishing a certain colour on a white area, or on areas in various light greys, gives us the opportunity to obtain different shades of the colour. The resulting shade, the lightness and saturation thereof, depend on the density and thickness of the colour varnish. Sometimes, two or more layers are applied on top of each other. In watercolour technique, varnishes are often washed over in various ways.

For instance, when red on a white area is varnished with a thinner or thicker layer of varnish, its hue appears to be not only more saturated but also more fiery and warmer. A thin, or insufficiently concentrated layer gives a blunt, indistinct, less pure pinkness. A thinner layer does not absorb as much of the green spectral light (of which it should absorb the maximum possible) as to make the paint coat distinctively red or pure pink. This creates problems particularly in water colour varnishing, mostly if the technique aims to express a bright, shining lightened hue of a higher saturation level.

If a varnish of a certain colour is applied to a coat of a different colour, the resulting colour differs from both of those. Varnishing such a coloured base layer also means that the double paint layer absorbs more light and, therefore, the resulting colour is less light, too. The effect is less noticeable if the varnish colour does not differ from the underlying paint colour too much; in such a case, the colour will appear more saturated. If the same varnish is applied to several different paints, its colour will influence each of them with a fragment of its appearance, and such modified paints will appear more related and more uniform in their harmony. E.g. yellow varnish on red and green will render the red more fiery while it will make the green turn yellowish-green — that means, both colours will tend towards yellow.

A varnish more different from the underlying colour yields a colour more distinctly dark and of lesser saturation. Some extremely different paints are “added” to dark grey in this manner, e.g. red and blue-green paints. The complementary pairs of this kind are not always identical with the complementary colours which, upon merging in the eye, create the impression of a neutral colour. For instance, the combination of blue with yellow, i.e. complementary colours the sum or merge of which creates white or grey in the eye, gives a special, different result. The green obtained by varnishing the two colours is just the result of light absorption in both paint coats.

The yellow layer absorbs violet, blue and blue-green spectral lights while the adjoining blue layer absorbs red, orange and yellow lights. What is left of white light of full spectrum range and what both varnish layers are capable of letting through when combined, is green lights. Only green lights pass through both layers and are reflected off the white base (fig. 57, tab. II, 1d, e, f).

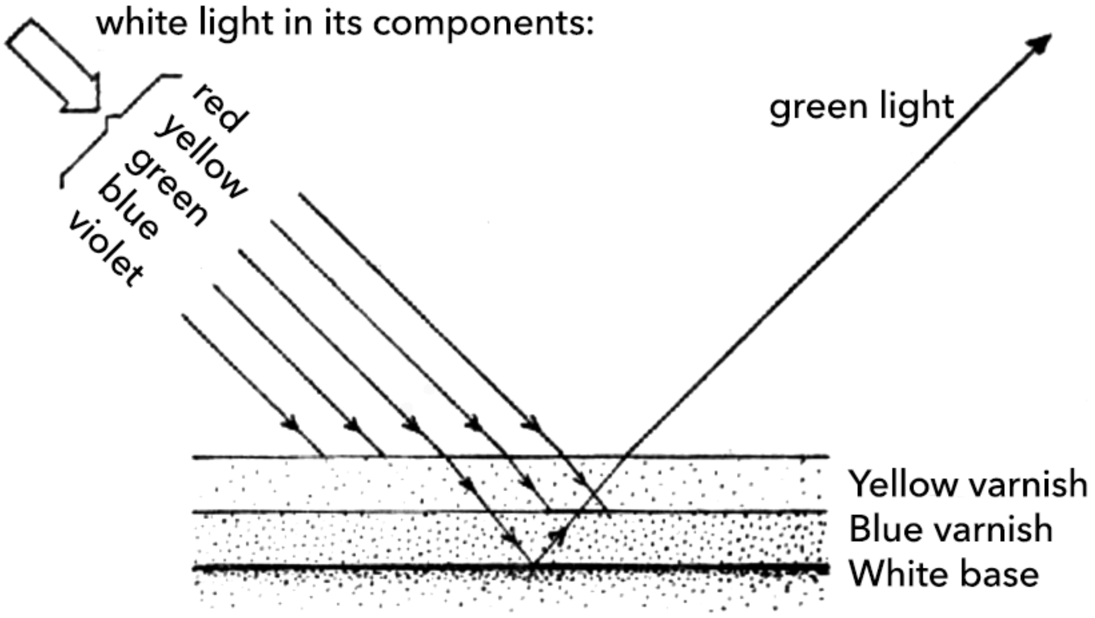

Fig. 57 Light transmittance in double-layered varnishes

The same result is obtained from yellow and blue coloured glass, or transparent films. If put on top of each other when one looks through at a light, the only spectral part of light that passes through is green. Similar green will be rendered if the glass or film sheets are put on top of each other on white paper.

Since one layer takes spectral lights from the other layer (by absorbing them), this absorption process is called subtraction of light.

The same occurs when coloured substances, e.g. paints, are mixed on a palette. The individual coloured substances mixed absorb each other's spectral lights in a similar manner and, therefore, this method of colour derivation is often called subtractive colour mixing. However, it is actually not mixing colours as feelings – it is mixing paints or pigments. For example, green is not a mix of blue and yellow but a particular result of mixing substances of those colours (blue with its complementary yellow combine in their lights to give white or grey).

THE POINTILLIST METHOD

Tiny areas of certain colours, e.g. yellow and white, when put next to one another over an area will create an image of a single colour (lighter yellow in this case) when viewed from a distance. Colours can be shaded with greys of various depth or black in a similar manner.

If various colours are combined together in this pointillist manner, the combination usually has a result rather different from the result obtained by mixing paints on a palette. Only the combinations of colours not too different from each other give roughly the same results.

When colours are combined in the pointillist manner, there is no absorption, i.e. subtraction of lights as in the case of mixing paints on a palette. Therefore, the colour yielded by the mix — how ever different they might be — is not darkened. The individual colour spots actually remain next to one another even when merged in the eye and, therefore, the result is but an average of their respective lightness values. This means that it is neither a sum of lightnesses, although the pointillist method is often (although not too fittingly) called addition.

Not only the hue but also the resulting colour obtained in the pointillist manner differs significantly from the colour obtained by mixing colourants. For example, ultramarine and yellow cadmium, when combined in the pointillist manner, result in a pinkish grey while a dull green results when the paints are mixed on a palette. Therefore, the pointillist painting method requires a completely different set of knowledge of results of colour combination from the set obtained when mixing poster paints. Logically, the resulting colour is based on, and a very illustrative idea thereof can be drawn from, the colour wheel arrangement. It is located on the direct connection between the two combined colours.

The bigger the difference between the two colours, the less saturated the resulting colour will be. Ultramarine is a blue tending towards violet; therefore, it will be located away from blue on the wheel, towards blue-violet. The resulting colour on the chord connecting ultramarine with yellow is red, very close to the centre of the wheel and, therefore, of very modest saturation — i.e. just pinky grey (fig. 58). In these types of combinations, the result is determined also by the lightness and saturation ratios of the colours combined, naturally together with the ratio of the surfaces concerned. With a majority of ultramarine, the result would be shifted towards violet and vice versa, if yellow prevailed, the result would tend towards orange.

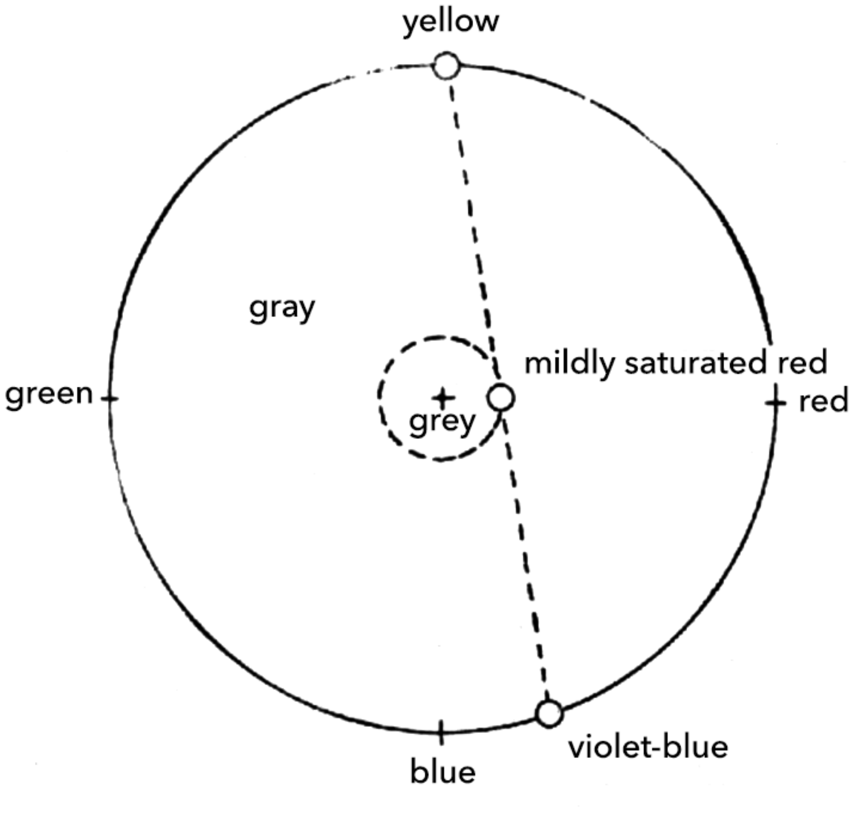

Fig. 58 In a pointillist combination of very different colours, the saturation of the resulting colour is reduced

The resulting colours in pointillist combinations are identical with the results obtained from rotating wedges and this method is a particularly advantageous indicator of the colour elements to use for a certain resulting colour. The mutual ratio of the angle sizes of the two wedges also determines the ratio for the representation of the two colours over the area in order to achieve the required result.

Musive painting, i.e. painting style creating a mosaic image in an area of tiny cubes of various colours, is basically also a pointillist painting method. If a colour is created by composing two colours, it is arrived at through the aforementioned thought process. A special colour effect is achieved by cubes with an iris surface.

The pointillist method of colour composition is widely used in the textile patterns consisting of threads of several colours. The colour of such material is the result of tiny areas of various colours created by the crossing threads of certain colours.

Colourants in paint mixes have a partly pointillist effect as well. Besides subtraction of lights, powder colourants (pigments) also work as a point-by-point composition of colour in the paint coat surface.

SHADING

This method of deriving shades applies to visual art activities involved in 3D handling of mass, i.e. for instance sculpting, wood-cutting, ceramics, stucco plastering etc. Based on the ratio of the sloping of the area curve, we obtain a less or more steep, yet gradual, transformation of the lights into their own shadows. Of course, this also depends on the nature of the surface; the most balanced-out result is obtained for a smooth surface with no shine. Hard differences between shades result from edging. This method is sometimes applied to emphasise curved areas when edging or – also a very effective way – corrugation or so-called fluting is introduced. For example, column shafts often have vertical fluting. The linear groove over the area creates a hard shading image.

The shady parts of the area are more willing to accept the colour of light reflections from their surrounding and this may slightly modify the hue thereof. This does not happen if the surroundings are of the same colour or a neutral colour, i.e. white or grey.

COLOUR NORMALISATION

Colour normalisation aims at factorising an arranged selection of colours and hues thereof out of the full colour range to form a coherent set of fixed, invariable colour units. Each of the units should have a mark, e.g. a numerical code, and stating the code should suffice in any visual or technical practice to indicate the full specification of the colour.

This effort hits serious difficulties. Colours are basically sensations, i.e. something too unstable, variable and, as such, they are impossible to normalise. Normalisation actually is just a choice of colourants capable of creating the required feeling of a colour under the circumstances. However, there is a problem even in that: the question is how well production meets the requirement for pigments of constant colour as well as whether a stable colouring or paint can be prepared with the colourants.

Another tool for selection of a certain colour is colour samplers. They usually contain a system of fewer or more hues derived from the individual colours and systematically presented on loose or bound tables. Such sets, if quite comprehensible, have tables with the hues of a single colour in regular shades.

If the colour samplers are to be comprehensible, they require a high number of colours and hues thereof; all that means that the production is difficult and expensive. In this regard, it is much easier and more advantageous to derive colour hues by means of rotating coloured wedges. In such a case, we can manage with a relatively small quantity of colour rings which are quite easy to make.

MIXING PAINTS AND LAWS OF COLOUR VARIABILITY

We can sometimes encounter an effort to formulate the laws of colour variability and the possibilities of artistic colour composition and conditions for colour harmony in particular, based on the results provided by paint mixing. It would be highly beneficial, especially to painting practice which works with such substances in the most visual manner, and it would simplify the visual part of colour composition considerably. Reality is different and only offers limited options in this regard. The results obtained from mixing poster paints largely differ from the correct results of colour derivation. For instance, we know that mixing black and white does not yield grey; black with yellow does not combine to form brown but green instead, and the mixture of complementary blue with yellow does not yield grey but green. Besides, if more different colours are mixed, the mixture is rather darkened, and some colours complement each other to give dark grey. Such biased results, determined by the physically optical properties of colour substance mixing, have no use as the basis for the formulation of colour composition laws. In this regard, only the pointillist manner can be found satisfactory amongst the painting methods.

Colour and Illumination

INTENSITY OF ILLUMINATION

The lowest intensities of illumination render colour vision, i.e. seeing with the central part of the retina, inactive. Therefore, we only see a scale of greys, and not even a full one at that. The weaker the illumination is, the shorter the scale. It shrinks at both ends, the light as well as the dark one. White, even though it often stands out in the twilight, fails to achieve the radiant whiteness it possesses in full light, and black also loses its distinctive darkness.

As the dusk progresses, lower luminance values fall below the recognition threshold, less light hues become darker and lose their distinctiveness. White remains above the recognition threshold the longest and appears to radiate in the dark. Therefore, some infrastructure parts around roads e.g. in road bends are often painted white to facilitate easy orientation. As dusk progresses, not only the difference in lightness but also the sharpness of contours diminishes since vision converts towards the off-centre part of the retina with blurred vision. The image of dusk and nightly darkness in particular is characterised by softness and lack of definition. If dusk is to be expressed visually, in a painting or on a theatre stage etc., these are the characterizing features we imitate.

Not even moonlight is capable of lighting up our surroundings with colours, even though the light sometimes – e.g. if there is full moon over a snowy landscape – appears to be as bright as daylight.

THE PURKINJE EFFECT

When the illumination intensity of twilight transforms into a higher intensity, our vision becomes more sensitive even to lively colours although the ways differ in relation to the individual colours. Important research in this area was performed in the 19th century by J. E. Purkyně. He observed colours at dawn and found blue to be the first colour that emerges from grey and demonstrates its very own colour character. This colour also appeared to be lighter before the red appeared, some time after. Only in quite full daylight did red become lighter than blue.

Under lower illumination intensity, our eyes are more sensitive to blue while under higher intensities, the eye is sensitive to red. If the intensity of the spectrum is gradually decreased, blue (green-blue) is the last colour to lose its colour character in the suppression process. About 25 years after Purkyně, a similar phenomenon was observed by a German physicist, Dove. During an evening tour through a gallery of paintings, the works kept losing the reds throughout the dusk.

The Purkinje effect, or shift, suggests the luminance distinction between bright colours in full daylight. The lightest ones are yellows, followed by oranges, reds, greens and the darker blues and violets.

THE PURKINJE EFFECT AND THE IMPRESSION OF ILLUMINATION INTENSITY

The principles of the Purkinje effect demonstrate special consequences when the intensity of illumination is perceived. The assessment thereof in our mind does not depend solely on the rates; it is also affected by other dependencies which involve the consequences of the Purkinje shift in particular. In this context, the realisation of illumination intensity generates the following rule: in low intensities of illumination, we perceive the blue components with more sensitivity – and vice versa, blue illumination or a colour scheme tending towards blue creates an impression of a lower light intensity. This is something we encounter quite commonly even without realising. For instance, moonlight appears bluish. Painters imitate it in paintings with a colour palette leaning towards blue; on a theatre stage, it is best imitated by bluish lighting. In reality, moonlight is not bluish – quite the contrary: it tends towards orange when the Moon is lower. Even in lower moonlight intensity, our eyesight is more sensitive to the blue spectral components.

Yellows, oranges and reds are colours which light up to the fullest when brightly illuminated – vice versa, the colours create an impression of a higher illumination intensity. Namely yellow, if not darkened, stands out due to its lightening character. This is contributed to by the high luminance it possesses in its saturated condition when it is the lightest of all saturated colours. Transparent yellow glass, e.g. a yellow photographic filter, provides a very good demonstration of the effect of the colour. If held close to the eye and used to view the surroundings, even a dull day appears to be a day of sunny weather. The same impression is created in a room with yellow window panes, although the light coming through is weaker by almost one half of the spectrum radiation absorbed by the yellow glass.

INTENSITY OF LIGHTING AND COLOUR SATURATION LEVELS

The Purkinje effect applies to colour saturation, too. This formula was aptly expressed by Leonardo da Vinci – “red and yellow are most beautiful in light; blue and green in half-shade”. The saturation of reds, oranges, yellows and yellow-greens increases with increasing light intensity. Contrastingly, if lighting intensity decreases, the colours lose their saturated brightness. With extreme light intensity, the resplendent colours fade, thus losing some of their saturation. For instance, if sun rays are directed to a focus point by a looking glass, the glare of the focus area will make particularly violets, blues and blue-greens dazzlingly whitish. Similarly, in the dazzling heat of the Sun standing high over the summer landscape, lively colours disappear.

COLOUR RATIOS IN DIFFUSE LIGHTING

Colour ratios appear to be most even in diffuse daylight. The light is diffused by the air and clouds, as well as reflected by the interfaces between various environments. Without this, the shaded parts of our surroundings would be completely dark. This is the kind of light that is the exclusive daylight in north-facing rooms, or shady rooms, building fronts facing the north etc. As the light comes from various directions, it does not generate such sharply defined or dark shadows as direct lighting would; the image of our surroundings is softened in this manner. Painters apply paints to the picture in this less intense lighting most often; it allows for the colours to be assessed and adjusted to light intensity if the painting is then to be installed in an environment with this kind of light. Pictures with richly developed colours can handle suppressed light, too, while softly distinctive paintings of less saturated colours require brighter light.

LIGHT MOODS

Various light moods are portrayed in paintings particularly by landscape painters. Such moods play an important role on the theatre stage, colour schemes of rooms are adjusted with respect to the impression of light and airiness, i.e. if the room should appear to be brightly lit all over or not. Building, street or square fronts follow similar principles.

The light range of the artist’s palette is limited by black and white. The ratio of light reflected by the colourants is roughly 1:80 as a maximum. In the nature, bathing in sunlight, creating dazzling shine and glare particularly on water surfaces, the ratio of the darkest to the lightest is much higher. Therefore, the artist’s palette restricts the possibility of imitating this light ratio with the paints available. And yet, the artist is capable of expressing truly contrasting light stimuli aptly, e.g. when portraying the red-hot light of the sunset glow, the sun, glittering play of little waves on the water surface reflecting direct sunshine etc. This is possible because the artist is able to imitate some accompanying phenomena, particularly the colour changes symptomatic to certain states of light intensity.

Certain colours create the impression of higher or lower intensity of light (the Purkinje effect). Besides, there are other means affecting the feeling of intensity. These are adequately chosen light ratios of individual colours, as well as their saturation ratios. Both methods can be used separately, i.e. emphasising the light ratio, or the saturation ratio respectively; still, the methods maintain a high level of efficiency.

In extremely intense light, our eyesight becomes less sensitive to lightness of colour hues that are only slightly different which makes the lightness differences between the colours diminish. For example, in direct sunlight, the lightness level of the lit parts of our surroundings comes close to white. This is also suggested by the Weber-Fechner law logarithmic curve. In the higher parts, i.e. at higher light intensities, the lightness differences (a´, b´, c´) come closer together than in the case of lower ranges (a, b, c) (fig. 59). If this situation is imitated e.g. in a painting, it will create an impression of increased brightness. It primarily means that its lights and light parts are attributed reduced lightness differences.

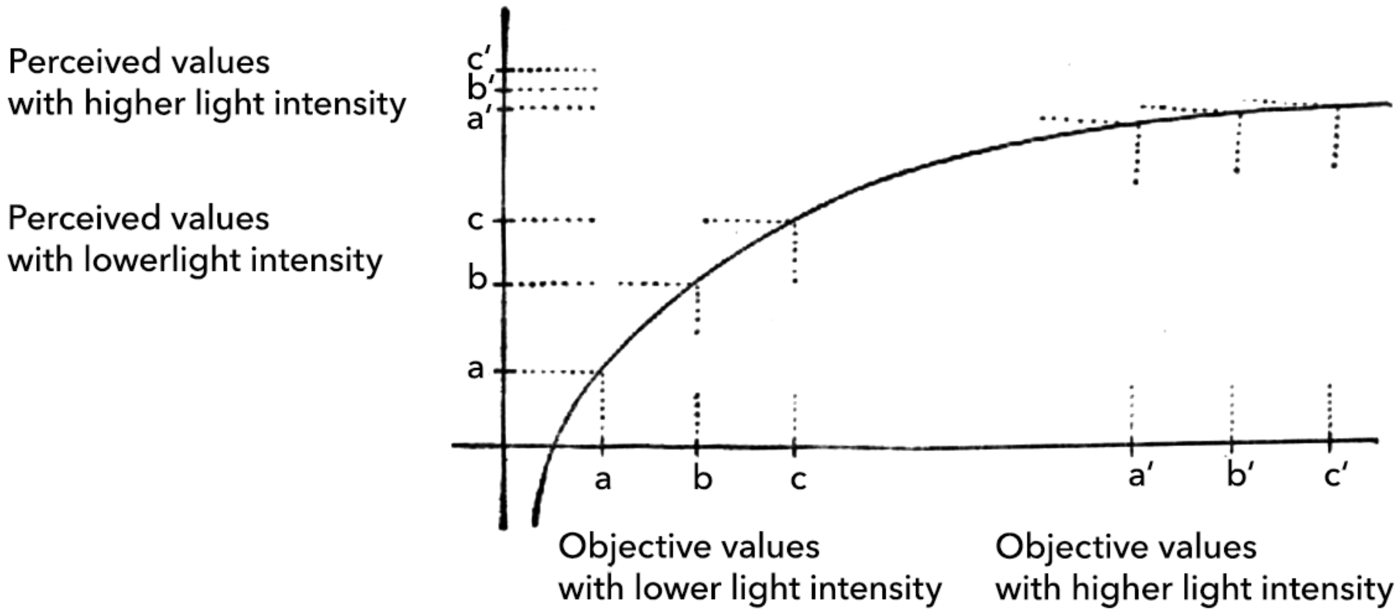

Fig. 59 The Weber-Fechner law. The differences in brightness of individual colours diminish with increasing light intensity.

Let us use a simple example. Using light scales of the black-white range, divided into five grades as used already in the text on light variability of colours. Let us draw an identical motif in two drawings (table IV). Then, mark the lightest parts with white and the darkest parts with black. The only thing distinguishing the two paintings will be the light interstages, i.e. the different greys between the light extremes. In the first painting, let us mostly use lighter greys while darker greys will characterise the other one. The first painting gives the impression of daylight while the other one depicts moonlight. So, the same light scale is employed to render a high-intensity light in one case, and a light intensity roughly half a million times lower in the other case. It is remarkable that the same white, made to glow by contrast in the latter picture, does not introduce any lightening in the mood. This means that the effect of a light mood is dictated not by the lightest and darkest extremes but by the intermediary degrees. If those are pushed towards the light extreme while being the prevailing tone of the painting, they will create the impression of lightening up. Contrastingly, the prevalence of darker interstages and smaller differences between them will bring the colour composition closer to the light ratios of dusk, which will give an impression of a lower light intensity.

The impression of lightening up or dimming down can be created by colour saturation ratios, too. With lower light intensities, colours lose saturation; colours die down in the dusk and we see them in degrees of grey. Even this situation stimulates a response in the light intensity sensation. If less saturated colour palette is compared to the same palette of equal lightness, just more saturated, the latter seems more brightened in comparison to the former (tab. V). Increased colour saturation thus creates an impression of brightening up while reduced saturation has the opposite effect, i.e. creating the impression of dimming down. The grey colour palette, with zero saturation, appears to be the dimmest, shadiest out of the sets of identical lightness.

These properties of colour saturation offer a broad range of practical applications. The advantages include in particular the option of creating an impression of brightening up without lightening the colours. If a painting with a dull, non-shining surface, e.g. a watercolour, is given a coat of transparent shiny lacquer, the light reflected off its surface would be taken outside our eyesight, making the colours in the painting appear darker. However, their saturation would increase at the same time and the painting, although becoming a bit darker, would brighten up in more lively colours. If the harsh grey of pollution on a house front is replaced by a colour of identical lightness but more saturated, the walls of the front will become radiant. This can be applied to whole streets and squares. The wall with the window is usually the shadiest part in a room. If it were painted the same colour, only more saturated, in the same level of lightness as the other walls it would appear brighter. This method would not disturb the colour consistency of vertical enclosure of the room space by the walls as it might happen if this particular wall is painted with a lighter colour.

Shades with precise definition and stark contrast to light occur in more intense lighting, particularly in full, direct sunshine. Imitation of this situation is another tool available to the artist to capture the power of light in a painting. The effect of this tool is contributed to by colour saturation ratios. It is well known that colours not only become darker in the shade, but they also lose a significant proportion of their saturation. This saturation loss does not appear the same in different light intensities. Again, this was expressed aptly by Leonardo da Vinci by words to this effect: – the colours of shadows possess their natural beauty depending on the degree of light; the more intense the light source is, the more splendid the shades are. In other words, with increasing light intensity, the colour saturation of shadows becomes less suppressed. If we, as painters, imitate this by giving the colours of shade in our painting less suppressed saturation, the painting will appear more radiant than with greyish-looking shadows, i.e. shadows of too low saturation. If more saturated colours are concentrated in the shady parts of 3D objects, this will add radiance not only to the shade but also to the overall impression of the painting. Depending on circumstances, this method can be applied e.g. to shady parts of building fronts, bottom parts of protruding lintels, shaded bottom part of lintel, interior parts of archways in buildings etc.

Let us discuss a particular exception from the aforementioned properties of colour saturation, namely creating the impression of brightening up with increasing saturation. In extreme, blinding intensity of light, colours will lighten up considerably, change as well as lose saturation. The saturation of reds is less affected by such lightening; the reds become yellowish. Similar to red, green turns yellowish as well while blue and violet become paler. The painter encounters a similar phenomenon particularly in the portrayal of blindingly powerful light effects, and the imitation of such situation in steeply contrasting lights in the painting creates an impression of intensified shine. For instance, a colour with a suitable addition of white is used to portray a source of intense colour light.

COLOUR OF LIGHTING

The colour relations in our environment depend not only on light intensity but also on the spectral composition of light. The colour of light itself depends on the spectral composition. Sunlight presents all colour components of the spectrum; if the Sun shines on a white surface, its colour does not change and, therefore, this kind of light is called white.

To appear white like this, the intensity of the colour components of the light must have a certain level of equalisation. If one of the colour component groups in the light is weaker or, contrastingly, stronger than the remaining ones, the light will manifest a different colour. This is why the light of low Sun appears yellowish or reddish. The balance of the colour components, resulting in white light, is disturbed more when light travels through ground-level atmosphere and, therefore, the light colour changes. The light of kerosene lamps, candles as well as a lightbulbs is poorer as to the short-wave spectral component and appears more or less yellowish.

For light to appear white, it is not an absolute prerequisite to have all of the spectral radiances. Whiteness may be achieved even by certain compositions of restricted parts of the spectrum, even with just the composition of two narrow spectral lights in complementary colours and an appropriate intensity ratio. It is natural that such a light composed of two narrow bands of spectral radiances, e.g. blue and yellow, would not be capable of irradiating the majority of colours around us. Even the whitish lights of some modern-day light sources, e.g. light tubes, have darker points in their respective spectra and, therefore, their properties merely approximate those of daylight. Only light consisting of components covering the full spectrum range is capable of lighting up all of the colours in our surroundings in a full and unmodified manner.

COLOURED LIGHTING

This is the term usually used for lights of other colours than white. Yellow and orange light lacks, or has weaker, complementary spectral components, i.e. the blue and violet components. This applies also to other coloured lights – they primarily lack or have weaker radiances that are complementary to the colour of the light; therefore, coloured light will not make colours complementary to the colour of the light shine bright. For instance, red lighting will not bring forward greens in particular, as well as blues. Blue light makes yellows, oranges and reds fade while green light makes reds and violets disappear. The remaining colours which can be made to shine by such lights, are tilted towards the colour of the light. For example, with a red sunset, yellows take on an orange hue, white loses its whiteness and becomes pinkish. Even green changes considerably. The yellowish green is capable of reflecting a part of red spectral radiances. However, a part thereof is absorbed and, therefore, the green substance – chlorophyll – demonstrates the adequate black gap in the red end of its spectrum. In orange light, the green of leaves changes into olive green; the redder the light is, the more it leans towards brown.

The assessment of colour in a coloured light is significantly affected by the concept of the colour acquired during daylight. For instance, a navy coloured suit, if seen at yellowish artificial light for the first time, will appear black. However, if we know its colour from a daylight situation, we will tend to perceive it with a bluish tinge. This also means that a picture painted in daylight, when first presented to the viewers in e.g. yellowish artificial light, will be likely to be perceived differently from the author's own idea based on the colours as seen in daylight.

Coloured light is detrimental to its own colour, too, for instance yellow colours are difficult, or even impossible to distinguish in saturated yellow light, unless we know they are yellow from a daylight situation. The light of a kerosene lamp makes a yellow drawing on a white area invisible. A painting made in yellowish artificial light usually demonstrates the biggest distortion in the saturation ratios of yellows and blues, when seen in daylight. Light bulbs made of slightly bluish glass which suppresses excess long-wave spectral radiances (the bluish glass absorbs a part thereof) that push the light emitted by the bulb towards yellow, give a whiter kind of light. However, it usually tends towards blue as painting in such light often involves exaggerated blues and overall bluish colour palette when seen in daylight. In this regard, fluorescent lamps or combinations thereof should be tested for painting purposes. If we were to adjust the changed colour palette in light inclining towards a certain colour, we would primarily have to add saturation, or lightness to those colours which lose distinctiveness the most in this light. That is, for instance in yellowish light, the blues need more saturation and lightness, and yellows might deserve more saturation, too. However, such colour adjustment may only be considered solely in coloured lighting. This is also affected by the time spent in such light. Our eyesight is capable of adjusting to the colour of the light to a certain degree, and then we perceive the individual colours roughly in their "daylight appearance". The same thing happens if, in daylight, we put on glasses with slightly coloured lenses for an extended period. If we remain in the lamp light, we no longer think the light is yellowish; we have a sensation of white light. Therefore, the impression of whiteness of the light materially depends on the nature of perception. When looking out of a well-lit room through a window at dusk, the outside appears to be in a distinctively bluish light. This bluish tinge is a contrasting colour generated by our eyesight's adaptation to the yellowish light.

SHAPE AND LOCATION OF LIGHT SOURCES

This is an issue handled in detail by the relevant specialist literature; therefore, we will only address the common methods of adjusting lighting with respect to the colour palette of the target environment.

The type of light source, its luminous intensity, location, shade type and finish have a significant impact on the image created by its light in the relevant environment. Also the shape, spotlight nature (light bulb) or length (fluorescent tube) of the source, or the presence of a voluminous yet transparent shade must be considered.

When a source of light is placed in the middle of the ceiling of a room, the space will be lit evenly. If the light source is a spotlight, it will create simple shadows cast by the individual objects, with sharp edges. Contrastingly, the longitudinal body of a tube creates a line of light; therefore, the shadows cast are complex, fragmented and less defined in their contours. Complex lamps, consisting of several light bulbs, or a system of multiple lamps distributed within the space will have even more of this effect on shadow generation.

Both these types of lighting, spotlights or complex systems, may have their pros and cons. The simple spotlight cuts the image of the environment to light and shadows with too much hardness; if affixed low, the shadows cast are unflatteringly elongated. In contrast to that, a complex source of light softens the environment in the shadows, making it seem lighter, too. However, the less pronounced shadows are often detrimental to the distinctive rendition and perception of 3D objects, particularly tiny plastic individual details. In this case, simple spotlights might have more advantages, in particular in some work processes and sometimes in the lighting of shop windows etc.

A light placed in the middle is usually unsatisfactory wherever the workspace or other operationally significant part of the room is not at a central location; the visual requirements also have an impact on this. The location of the light source is then chosen according to such considerations, although off-centre location of the central light point means the balance of the overall lighting in the space is disturbed.

When placing a light source, we must avoid the source interfering with the field of vision when one is glancing at something. Particularly in closest looks, the eyesight would be adversely blinded, and the resulting escalated afterimages would create a disturbance as well. In its attempt to adapt to the influx of mighty light, the eyesight is blinded to a certain degree in terms of perception of the lit environment, too. Such lighting fixture is not used to the full and, therefore, such lighting arrangement is uneconomic. The same applies to the positioning of shiny surfaces where the lighting fixture might be mirrored inappropriately. Therefore, it is usually better to place a lamp higher, above the common field of vision circle; light coming from above is the most natural arrangement for our vision, too. If the lamp is at a low position, blinding is prevented by a suitable shade.

Lampshades usually both act as light-reflecting areas and restrict the light influx to a smaller area, which allows them to increase the power of light in such restricted area. Transparent shades allow lighting a part of the premises in supressed or coloured light, if the shade is transparent and coloured. The ratio of the colour of the light passing through the shade and the colour palette of the lit parts of the venue are quite important. The most significant is the relationship of complementary colours: for instance, if the shade gives off red light and the walls are green, blue or blue-green, their colour will absorb the red light and the walls will appear dark. Contrastingly, if the walls were red, white or any colour close to red, their colour will have a lighter appearance in this dim light. Walls painted white or grey with red patterns would be devoid of the pattern, and the walls would appear completely red. Therefore, we adjust the mutual ratios of the colour of the transpiring light and the colour palette of the settings also based on the most appropriate result in the relevant case.

When the lamp is removed further away from the eye, the image thereof in the eye diminishes and the glare gradually disappears, too. A lamp further away thus interferes with the field of vision less. This is used particularly in large social venues where lamps form groups, or light ornaments, and their sparkling radiance helps enhance the festive atmosphere.

In remote views, we usually also perceive coloured lights of neon lamps, particularly when used for advertising. Where the shape, letters, ornaments etc. stand against the background of a fuller darkness of the evening or night, their colour saturation shines with more radiance and, therefore, they are even more noticeable.

At some places, lighting fixtures are completely hidden and the premises are lit just by the light reflected off various reflection areas — ceilings, walls etc. This allows for especially calm, dim appearance of the lighting atmosphere. However, it also means light losses and, therefore, less economical utilisation of the lamp.

Expressive Characteristics of Colours

Colours differ from each other not only by appearance but also by varying effects on feelings. This is felt particularly clearly when we look at objects of the same kind, yet in differing colours. For instance, clothing looks different if it is white, red, yellow or any different colour. Similarly conspicuous comparisons are seen in nature every day. E.g. the appearance of the sky when the blue has been replaced by grey clouds, and how the impression we get of the landscape changes with the colour changes throughout the day or in different seasons of the year.

APPEARANCE OF COLOURS IN DIFFERENT SHADES/HUES

The same, definite colour has a variable expressive characteristic in the different shades/hues. The most saturated shade levels appear different from the less saturated ones. Similarly, the expressive part of lightened and darkened differ, too. We could roughly say that lightened colour grades look happier, give a lighter and softer impression while the darkened grades appear heavier and more serious. With increasing saturation, a colour gains in liveliness, with even more saturation then in excitement along with perturbation, and with extreme saturation, the impression is one of violence. Contrastingly, reducing saturation means the expression of the colour becomes calmer and quieter. Too low saturation degrees of darkened hues may seem dull and grey in some applications though. For example, house walls covered by a dark film of pollution appear harsh and gloomy.

PREVAILING COLOUR

Just looking, we usually see multiple colours at the same time and, therefore, the joint result of their different effect on feelings is more complex. However, one certain colour often prevails in what we see, e.g. green in the nature, or our attention is focused on it which makes it dominant both in the field of vision and in the sensation. The prevailing colour accompanies some kinds of work, when the colour is in front of our eyes permanently. For instance, the colour of the yarn when knitting. IN such cases, the effect of the colour on emotional sensations is manifested more urgently.

The effect of a single colour with no contribution by other colours, or just different shades, is quite exceptional in standard situations. For instance it is a case of standing very close to a huge wall of a single colour, or looking into the blue skies and not seeing anything apart from their colour. Only in such circumstances, when the same colour fills the entire field of vision, may we talk of the “unrelated” colour, i.e. a colour not assessed in the context of the surrounding colours, and unaffected by their effects. A colour viewed through the tube of an optical apparatus, with a black coating inside, is not an unrelated colour as sometimes suggested. In such case the colour is related to the blackness of the tube. What we see is a kind of dichroism where the black affects, through contrast, both the saturation and the brightness of the colour viewed – thus ultimately influencing its effect.

WARM AND COOL COLOURS

The difference in colour effect on our feelings is systematically captured by the wheel arrangement. Let us divide the circle of the wheel arrangement into two halves using the red-green line (fig. 60). The top semicircle has yellow as the central, culminating colour. The remaining colours are more or less affected by its yellowness; all of them are slightly marked by its appearance. The greens are leaning towards yellow and, therefore, called yellowish greens; reds are more fiery here.

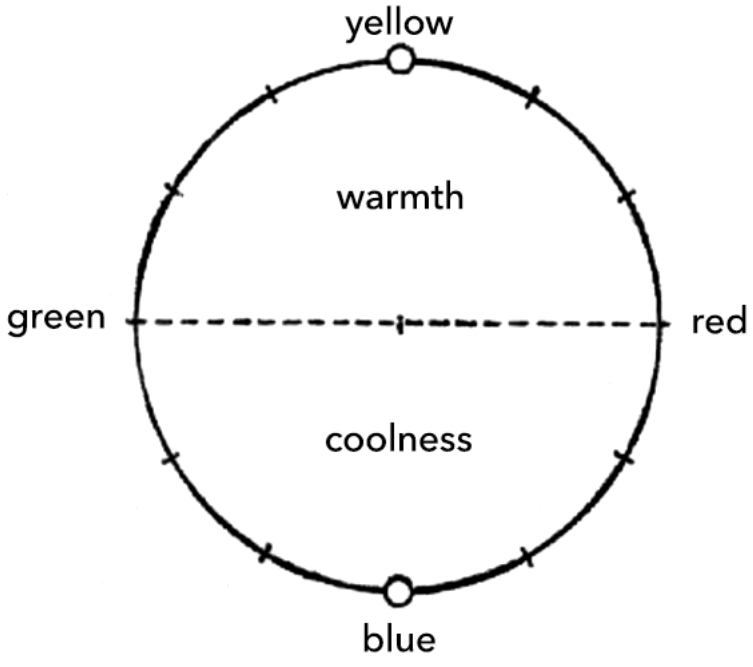

Fig. 60

In contrast to that, the colours of the bottom half of the circle are under the supremacy of blue which is the dominant colour therein. Greens transform into blue-greens, reds take on a violet tinge.

When the lighting is intense, the colours of the top half of the wheel, i.e. those dominated by yellow, become conspicuously more distinctive. Particularly in the sunshine, their brightness and yellowness or yellow inclination become stronger. They have established themselves in our mind not only as the response and image of strength of powerful light but also as its warmth; they create the impression of brightness and heat at the same time. Therefore, they are called the warm colours.

The manifestation of the colours in the bottom half of the wheel is the opposite. The colours assert themselves in their distinctiveness in rather non-intense light. Any decrease in light intensity causes the colour scale to lean towards blue. For example, if a cloud blocks the Sun, we have an impression of a slightly bluish shadow. This situation is often accompanied by cooling down, since the radiant heat of the Sun is blocked, too. In general, the bluish tinge seems to prefer darkness and coolness, e.g. the darkness and coolness of shadows and the darkness of faraway things. The blue of the skies appears to be in contrast to the yellowish brightness and heat of the glowing Sun. The blue and bluish colours inspire a feeling of shade, coolness; therefore, they are called the cool colours.

The transition of the contrast of colour warmth and coolness is the green and red, on the dividing line of the circle. Any shift towards warmth or coolness is most noticeable with these colours. With an addition of yellow, they appear warmer; contrastingly, they look cooler with an addition of blue. As a transition, the neutral colours – white, grey, black – also belong here. If they take on yellow, they appear warmer, while they are cooler when more bluish. In the shade, warm colours lose more of their saturation, which means they seem less warm. Similarly, when shading them, their warmth is affected more noticeably. If the shades are less saturated, they appear less warm.

EFFECTS OF WARM AND COOL COLOURS

Let us compare the effect of colour schemes pushed towards warm and cool, respectively. Clear, sunny ease which lifts our mood up also develops the warm colour scale. Contrastingly, if the sky is overcast, the overall character of the colour scale appears cooler, and its effect on our feelings is more sober and reserved. A colour palette pushed towards warmth and brightness is an encouraging inspiration while cool and shadier palette is more restrained. In this sense, we should point out Goethe's classification of colours[2]: warm colours were termed "active" while cool colours "passive".

Warm and cool colours differ as to their effect in another aspect, too. Fully lit parts of our surroundings, up close in particular, advance against shadows more warmly with their colour, and show their undisguised appearance. In the distance, the lightest, sunlit points appear warmer in colour and share their details more clearly in comparison to the darker, bluer parts. The warm colour range of the dusk and dawn in the distance distinctively defines the contours of the horizon. The warm colour scale is imprinted in our senses as an image of recognition of reality and precision.

The cool colours appear different from this point of view. They are suited to the characteristics of shadows which hide or cover the actual appearance of things. Blue prevails in the indistinctive height of the formless blue skies; a bluish veil of atmospheric mist hides the genuine image of the darker spots in the distance. Even the images of misty nature and uncertain evening dusk

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[2] The important German poet researched light and colour; his scientific activity resulted in an extensive book on colour theory (Farbenlehre).

appear cool, too. Cool colours are accepted by our consciousness more like a feature of something hidden and illusive. Cooler colour ranges help us create the impression of mysterious, fairy-tale like, less real things.

CALM AND EXCITING COLOURS

We can mark another strange contrast in the colour wheel. Let us divide the wheel into halves defined by the yellow-blue line (fig. 61). The left half thus has green as the culminating colour, which assigns a suggestion of green to all other colours in this section. Yellow becomes yellow-green, blue becomes green-blue. Green is a colour which gives the calmest impression when compared with the remaining colours of identical saturation level along the perimeter of the wheel. Biologists believe that out of the lively colours, green was the first colour to be gradually demonstrated throughout the evolution of our eyesight. The predecessors of mankind probably sought nutrition mostly in the green of the nature. As a developmentally earlier colour feeling, more anchored by experience, green gives us a calmer feeling. The fact that our eyesight is capable of distinguishing the most of the tiniest details or thresholds in green also suggests that green colours are an early developmental sensation. Contrastingly, in reds, the eyesight is capable of recognising the fewest differences. In green light, our eyes can detect very small details.

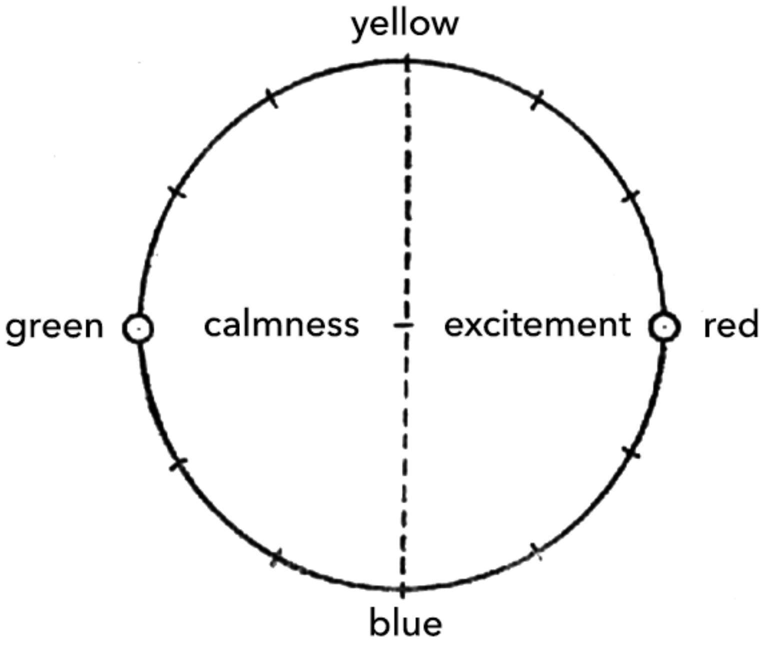


Fig. 61 Calmness and excitement in the circular colour diagram

The opposite pole of the calmness of green is the excitability of red, culminating in the right half of the wheel. While green is a colour rather common in the nature, saturated red is always something out of the ordinary. It is loud and conspicuous, whether in red flowers, red sunset, evening red skies etc. Nature uses red often to give a powerful warning – e.g. distinctive redness announces that many fruits are ripe. In our imagination, saturated red is saved as a feature of strong colour and rareness. Even the remaining colours in the red half of the wheel possess a lesser or greater dose of reddish hue and, therefore, excitability. The purple-tinted red is a special colour. As we know from the preceding explanations, from the physical perspective, this colour which used to be highly appreciated in the ancient world and in middle ages is a composition of spectral lights of the shortest and longest waves, i.e. lights refracted the most and the least. For the eye's focusing mechanisms, this means more of an effort to generate a sharp retinal image of the objects or images of this colour, which probably also increases its exciting effect.

The yellow-blue line thus divides the colour wheel into colours of calm inspiration, centred around the green pole, and colours of exciting inspiration centred around the red pole. The colours neutral towards this contrast, i.e. yellow and blue, and – similarly – white (grey and black), assume the characteristic of calmness or excitation if pushed towards green and red, respectively. For instance, yellow pushed towards orange has a more exciting appeal while yellowish green seems calmer in comparison. The neutral position of blue in this contrast was classified by Goethe in the assessment of the nature of individual colours – blue seemed as the conflict between agitation and calmness.

EFFECTS OF NEUTRAL COLOURS

With respect to the expressive effects of colours located along the perimeter of the wheel, white with its grey shades and with black, is neutral. If lent a hint of some of these colours, it assumes a fraction of their effect. White is the lightest colour and, as such, an image of the full power of light of the given source. Its light, cheerful tone gives no impression of liveliness which is so characteristic of other colours. In this respect, white appears taciturn like snow-covered winter landscapes. Its darker shades, i.e. grey and black, seem even more silent. Sets of degrees of different lightness levels, particularly white with black might generate distinctive combinations; however, they still lack the inner liveliness of other colours. In this regard, we can just compare the effect of a black-and-white photograph with a colour photo. The black-and-white scale of the image appears too sober and poor when compared to the richly developed continuity of lively colours.

COMPOSITIONAL COMBINATIONS OF COLOURS

Joining colours together in arrangements pursuing certain visual objectives is called (colour) composition. Such colour sets are created for a wide range of reasons. Each of the visual arts has multiple special requirements of its own. The shared and most common requirement is for the colour arrangement to generate the most positive and harmonious combination suiting the respective purpose. However, the compositional combinations of colours often use even such relationships which induce unpleasant sensations, i.e. colour dissonances, similarly to music compositions which apply this principle to achieve special expressive effects, or to emphasise the effect of a simultaneous or subsequent harmony by using the dissonance as a contrasting element.

The question of combining colours to achieve the most harmonious effect does not have a single answer due to the numerous applications. A number of circumstances and agents determining the choice of colours and composition finishes are at play and help decide on the effect of such harmonies, for instance the objective use of the colour composition, the purpose of use, the environment, the scale, lighting, even the character of the viewer, his/her age, mood, interests, time of perception etc. From these and other points of view, the effect of colour compositions must be assessed conditionally and in a more complex manner. The assessment of the expressive nature of colours has a validity that is rather general. When designing colours and colour compositions, we have to take into account various circumstances which have an impact on this effect of colours.

LAWS OF COMPOSITION

Compositions may combine the shades of a single colour or of various colours by applying certain visual schedules, similar to harmonious associations of shapes. For example, shapes in a composition are of identical heights, widths, distances, the symmetries or gradations are regular. This suggests the basic laws of composition, a certain version of which applies to colour composition as well.

Balance of colour lightness and saturation levels. If the shades of a colour are of the same lightness level, they are bound together by the lightness balance order. This composition essentially makes this connection even tighter, since all of the shades are derived off the same colour. However, even compositions of various colours can be evened out to the same lightness level.

Similarly, shades of a certain colour (tables V, VIA, B) or different colours can be assigned the same saturation level in a composition.

Even gradation. Colours in their shades can be lightened/darkened or modified in saturation in even steps. Similarly, sequences of steps with gradually changing colours can be formed. Such even scales present an even tension of contrast, i.e. the effect of the difference between the colours, between the adjacent components. Such sequences, if used meaningfully, form beautiful harmonies of shades or colours. They can be positively combined with shape modes, e.g. in glass jewellery, in storefront colour schemes etc. (Table IX).

Regular alternation. If the same colours, e.g. yellow and red, or shades (e.g. light and dark shades) are alternated repeatedly, a rhythm is created in the sequence. However, rhythmical alternation may have a more complex course, e.g. repeated use of three colours. Let us discuss the course of a simple rhythm of two members using practical examples – the scheme of colour shades in clothing.

In men's footwear and attire, the following model can be employed (upwards from ground): black shoes – grey trousers – black coat – grey scarf – black hat. Black (a) alternates with grey (b) and the whole composition ends with the same shade, i.e. black, that it started with. Therefore, this is a sequence called closed rhythm:

ababa

If grey gloves are added, they will form a similarly closed model with the black coat in the horizontal direction:

bab

In contrast to such closed models, there is another option for rhythm as well: for instance in ladies' footwear and attire, white (a) and yellow (b) alternate in the following manner: white shoes – yellow skirt – white coat – yellow headgear. This rhythm has a different finish, consisting of the colour of the second rather than the first member. It is called open rhythm:

abab

Symmetry. Colour symmetry, for instance the schedule of white – yellow – white is fully recognised as symmetrical only if combined with symmetry of shapes. It stands out both on flat areas and on 3D objects. It is developed either lengthwise, e.g. on butterfly wings, or in relation to a centrepoint, e.g. in a daisy flower. A strictly balanced symmetry looks like the equilibrium and creates an impression of calmness and strong discipline involved in the arrangement (table IX). Any derogation from perfect symmetry results in asymmetry.

Dominant. A suitably adjusted scheme allows us to emphasise a certain member of the colour scheme as a dominant, i.e. to make it more noticeable amongst the remaining members (table IX). This can be achieved by various methods, e.g. use of contrast to emphasise the colour of the dominant, or of a different size which distinguishes the dominant from the remaining members, or a different, conspicuous position amongst the others etc. Things of less conspicuous colours can be emphasised by suitable lighting, too. For instance a thing lit by concentrated light while other things in the shop window receive less light.

Proportionality of colours. Shapes are usually assessed with respect to the ratio of width to height which is called the proportion. 3D objects are also assessed by length, too. In terms of colour, the proportionality is considered in more complex relationships. Their mutual proportions as to the lightness, saturation and colour differences are handled — these are all important relationships which must be taken into account in colour combinations.

If a composition employs colours of the same lightness, the lightness proportionality is eliminated. If the saturation level is identical, too, the saturation differences no longer exist, either, and the only proportion left is the ratio of colour differences. This method silences the expressiveness of a colour composition.

Surface area proportions of colours. The same colour composition appears dissimilar in harmony if the mutual proportions of the individual colours are modified. We can confirm this by comparing two patterns of the same size which incorporate e.g. a continuous, smooth sequence of a colour scale. In the first image, the lighter shades occupy gradually diminishing areas while in the other image, the shades are arranged in the opposite order (Table IX). The former way, with prevailing areas of darker shades, usually appears more harmonious. However, this cannot be formulated as a general rule. The two ways should always be compared and assessed, similarly to our consideration of the area proportions for harmonious look of colour pairs, particularly those of complementary colours, as often declared in literature.

Regularity and irregularity. The highest level of regularity is achieved by such arranged colour accord that is combined with regularity in surface areas. If a set of colours in a regular arrangement is compared

to the same colours in an irregular arrangement, the harmonious accords will have varying levels of impressiveness. The calm and disciplined look of the former one will be enhanced with increasing degree of regularity while the latter one will appear more and more exciting with increasing level of irregularity.

The colour composition respects that primarily in relation to its purpose. For example, an environment that should have a calm, relaxing effect, and is to be used for resting or intellectual work, should have a rather regular colour arrangement. In this context, smaller differences between the members in the arrangement, i.e. a more delicate construction of the accord, have a positive effect as well.

In contrast to that, an environment that should accommodate entertainment and fun is more easily created using a more relaxed, less regular colour composition. This is a common requirement for e.g. finishes of waiting rooms, unless the role of entertainment has been taken by other elements in the venue, e.g. posters, paintings etc.

Strict, simple regularity with soft contrasts, free of any enlivening changes or accessories, often appears too uneventful and monotonous. Particularly even, uninterrupted rhythms might inspire a feeling of sleepiness in longer sequences. If the regularity is suddenly broken, e.g. if the regularity of the rhythm is interrupted at a stage, this creates an enlivening that negates the overly calming monotony. Increasing irregularity may create an impression of movement; if there is a strong contrast involved, it may lead to increasing suspense and alarm.

Levels and scales. The colour scale is a significant, inseparable part of the surroundings created by people around them, usually called the living environment. The colour scheme of the furniture, carpets, walls, building fronts, paintings etc., all of those are visual acts intended to make the environment more friendly and pleasant. The fundamental measure of environment creation is the individual himself or herself. Sometimes, the dimensions of the human body are the most important scale – in cases of e.g. chairs, beds, clothing etc. The scale relationship is more complex in other areas, e.g. there are multiple requirements for the arrangement of rooms. Human sight requires primarily suitable lighting (dimensions of windows, luminosity of lighting fixtures) which allows sufficient level of distinctiveness to our vision.

The guidelines for the colour schemes of the immediate surroundings and individual elements thereof are the various, both simple and complex scaling requirements of both human vision and intellectual experience and emotion. They are the governing principles of the colour schemes employed in e.g. clothing, apartments, individual visual art elements etc.

Local colour. Specific requirements for the colour scheme are reflected in one's feel for visual art mostly through certain specific colour composition structures. Such colour rendition, so-called local colour, which lends a colour composition a certain particular style, is often typical not only for individual artists but also for some visual art movements.

Many artists achieve such results also by certain painting technique methods which are typical for them. For example, the methods of underpainting, surface finish etc. However, the painting technique is not the objective but merely the vehicle to the execution of the artistic intention.

COMPOSITIONS OF SINGLE COLOUR SHADES

Thinking about colour composition suggests that a calmer, quieter appearance of a set of shades can be achieved through delicate, smaller differences between the individual members, with soft contrasts, in a regular arrangement with a lower saturation level. Distinctiveness, excitement and disquiet increase with movement in the opposite direction.

Sets of monothematic shades, i.e. shades of the same colour, deliver other special results, too. The shaded colour used therein acts through its own effects, e.g. green in its calmness, yellow or orange in the warm tone. Without the combined effect of another colour, e.g. the colour of the environment etc., the sensation is determined by the single colour which creates the most precisely defined colour atmosphere (tables V, IX). Such sets of shades connected by a single colour deliver the strongest feeling of unity free of fragmentation into various colours in the image. This principle can be applied to individual items as well as sets thereof, or even entire settings (rooms etc.). In a set of clothes, we may combine e.g. yellow shoes, dark yellow (yellowish brown) skirt, light yellow jumper and dark yellow headgear. Unless a light reflection of a different colour is present, the lights, half-shadows and shadows of an object in a single colour create a set of shades of a single colour.

The otherwise very pleasant accord of monochromatic sets of shades may also demonstrate some shortcomings. If such monochromatic combinations were everywhere around us, with no involvement of other colours, its colour monotony would be tiresome for our eyesight and irritating for our mood. Our vision is adapted to colour variety or alternation rather than to colour monotony over a long time frame. The eyesight is tired out faster by saturated monochrome while less saturated monochrome tends to tire out the sense – and soon feels dull. Monochromatic sets of colours are less appropriate if used e.g. in environments where people spend prolonged periods.

However, this colour setting may be appropriately adjusted to more permanent effect, too. Small accessories of another, more different colour are added to the monochromatic solution – in a room, this role could be played by plants, a statue, painting, pottery etc. The same method of a small accessory in a different colour can be applied to single-colour clothes, too. Although this creates a palette of multiple colours, if the monochromatic combination prevails, it will retain its leadership and the accord will remain pleasant in the long run.

SETS OF VARYING COLOURS

Small differences in colour. The most delicate sets are generated by combining colours which are positioned next to one another on the colour wheel. For instance, the combination of yellow – orangey yellow – orange – orangey red – red (table VII). Such a combination of colours with just tiny differences between them is often called small intervals. Already Leonardo da Vinci recommended combining colours in this manner, i.e. putting them next to each other in the way they follow one another in the spectrum. The accords are then particularly positive and calm if this natural order is maintained.

The neighbouring colours in such sequences do not differ too much either in relation to the colour character or to their lightness. Wherever the accord, or even a pair, would look too soft, it can be emphasised if enhanced by a distinctive difference in lightness of the hues.

The link between colours which only slightly differ from each other is expressed as a more strongly defined colour mood. For example, the aforementioned set of the yellow to red transition contains warm colours, i.e. colours with encouraging stimuli. Among them, orange and red are exciting colours and, therefore, the full impact of this set is demonstrated in both these areas.

ENLARGED AND BIG COLOUR DIFFERENCES

A direct combination of yellow with red or with green presents a medium difference in terms of the colour wheel. In this context, both the difference in colour and in lightness is clearly visible. Therefore, it is usually not quite necessary to emphasise the difference in lightness by shading. This will be least necessary for colour pairs of even bigger differences (so-called large intervals), e.g. combinations of yellow with purple or blue-green. Such colour pairs, and pairs of colours with the biggest difference (complementary colours) in particular, appear to be hard and distinctive even if there is no difference in lightness, e.g. the pair of saturated colours: green–red.

While sets of colours with a small difference create rather specific, defined mood of e.g. warm or cool atmosphere, colours with big differences manifest an ambivalent accord in this context. The appearance of one colour, e.g. the warm feel of yellow, contrasts with the coolness of the associated blue. The expressive effect of one colour is set off by the opposite manifestation of the other colour.

All of this has a double effect: what is most desirable for both the eyesight and sensation excited by a certain colour is for such colour to alternate, in the subsequent look, with a colour of the opposite nature, namely the complementary colour. If we look at the two colours at the same time rather than in turns, such satisfaction occurs simultaneously. However, the extremely different effect of the two colours generates a hard tension between the opposites. If the two colours are saturated and in a tight combination, and if we look at them for a longer time, the accord is negative due to the disquiet caused by excess hardness.

The use of such highly impressive pairs must consider even this negative characteristic of their effect. Saturated colours can only serve in situations requiring distinctive emphasis, and for brief viewing or alternating looks, if possible (or if used on a minute scale, e.g. in advertising, company names etc.).

The special satisfaction provided by a suitable rendition of complementary balance of colours has resulted in the formulation of the principle of this balance being the essential condition for absolute colour accord. The requirement of complementary balance, i.e. the neutral result of merging the colours in the combination, was formulated for compositions of multiple colours, even sets of colours in paintings. However, practical experience shows that excellent colour combinations can be formed even if this condition is disrespected. Not even the ornaments classified as the most beautiful works of past times demonstrate a complementary colour balance.

The complementary balance, i.e. the proportion of complementary colours yielding a grey result when they are merged, depends on the shade and area proportion of the two colours. The area proportion is not always balanced out for colours of the same saturation level. Identical areas roughly correspond with colours which are of the same lightness level when saturated – like e.g. green and red. If the saturated colours differ in terms of lightness, the lighter colour usually prevails and, therefore, it should be given a smaller area. This can be easily verified by the rotating wedges of the colours used. The ratio of their angles denotes the correct ratio for the areas. For example, the combination of saturated blue with saturated yellow has a ratio of roughly 2:1. Therefore, blue should be applied to an area of approximately double size. The pointillist method of colour composition would tell us the same result.

If we decide to reduce the saturation level of one of the complementary pair colours, the area ratio for complementary balance will change. The colour with weaker saturation must be granted extra area (proportionately to the saturation reduction). Here, again, the angles of the rotating wedges would indicate the exact ratios. In this respect, we have a rule that the proportion of complementary colours should be modified inversely to the saturation ratio. Such compositional methods for complementary colours can be used primarily in the application of patterns. However, the rules should not be understood as a rigid, fixed code; they should be taken as a guideline that can take us to the target which is ultimately verified and finished by our own sensitivity.

The hard tension and disquiet of colours with big differences can be softened within compositions in various ways. A particularly effective way is reducing the saturations, or if one colour is given more area and less saturation. The old advice, dividing the colours by a neutral colour (grey, white or black), is applicable in many cases.

The complementary opposites allow us to compose more complex colour accords. Ideally, if colour threesomes are formed in this way, the complementary opposite colour to the pair of less different colours is introduced. For instance, patterns of the same saturation and same size in orange and green-yellow colours will stand out with even distinctiveness in a blue area. What could disturb this balance is the imperative sound of the more exciting colour (orange, in this case). If an adjustment is necessary in this regard, the saturation of the colour should be reduced, or its area diminished. Let us design the colour of a wall which would create a complementary accord with the orange of the wooden furniture and its red upholstery. The colour is blue-green. The complementary colour best serves in the function of counterweight to the colour pair, if it is equally close to both colours in the scheme of the full accord. This is the case of putting this colour between the pair, or the colour acting as the background for both of them. Similarly, the complementary colour can be the base against which the pattern of the colour pair is designed.

The metallic colours, particularly the colour of gold in combination with blue, copper with blue-green stand out in combination with complementary colours or colours largely different. The shine of the metal is emphasised in a combination with darker colours, especially with black. In a white environment, colours of metals appear darker and the shine is more obscured.

SOFT COMBINATIONS OF COLOURS IN THREES

A method softening the sequence of different colours by adding another colour is the opposite of hard colour contrasts within a combination of three colours. Let us choose a base colour and orange and green-yellow patterns standing out of the base. This should be the colour which is the softest link between the two colours and has the same difference from either one, i.e. yellow. This means we have linked a third colour to the two colours by means of a small interval accord. We have achieved a delicate, quieter effect of the colour combination. Otherwise, regular arrangements of colours in the sense of putting colours next to each other based on their positions in the spectrum have a very positive effect on the compositions of these and bigger differences. In our case, it would be the sequence of orange, yellow, green-yellow (Fig. 62).

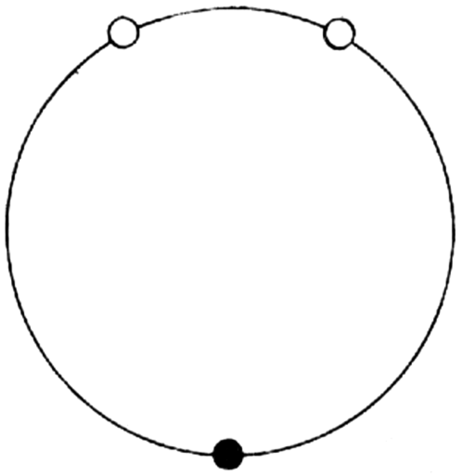


Fig. 62a A third colour is added to the yellow-green / orange pair; the third colour makes the sharpest difference to the two well-balanced colours

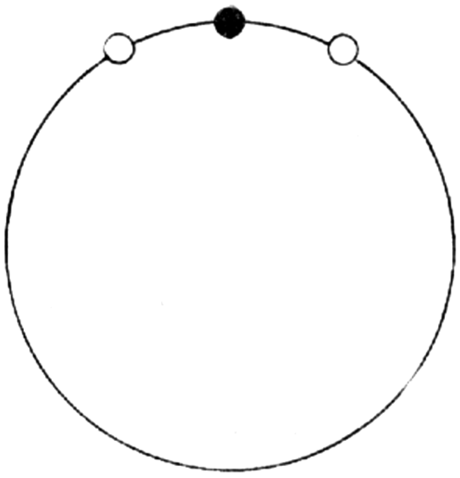


Fig. 62b A third colour is added to the same pair, this time with the softest difference. Similarly to other colour combination sets, a positive effect of such accords depends on the proportionality of shading of the colours, suitably adapted to the intention of use thereof

COMPOSITIONS WITH A NEUTRAL COLOUR

When a neutral colour, i.e. white, grey or black, is combined with other colours, its special properties come out. If such colour is used in a composition as a grey with no – or very little – difference in lightness from the colours it is combined with, it acts as the quieter member. It does not stand out as a lively, distinctive colour like the others in the composition, it does not interfere with them; quite the opposite, the other colours can develop with more emphasis next to it. This creates, in particular, a quiet background for the colour mix in the foreground which is to be presented in all its liveliness.

If grey is put between colours which are more different from each other, particularly complementary colours, it mitigates the effect of their hard contrast both by removing them from each other as well as by forming a neutral intermediate in the accord. If such neutral colour of the composition is added that differs from the other members as much as possible in lightness level, especially if the extreme lightness levels are applied (white or black), the emphasis of lightness difference is strongly demonstrated in the accord.

In connection to another colour, a neutral colour stops being absolutely neutral. Its contrast turns towards the complementary colour of the colour it is being combined with (table VIII). For instance, in combination with blue it takes on a warmer touch, i.e. a slight yellowish hue. This mostly concerns the grey degrees of a neutral colour; this phenomenon is less obvious in case of white and black. If grey should appear neutral even in those compositions, it should be given a touch of the colour it is to be combined with. In the aforementioned example, it should receive a touch of blue.

PROPORTIONS OF SHADES IN COLOUR COMPOSITIONS

The proportions of shades help us control the impressiveness of colour compositions. We can combine a colour with any other colour but it is only the appropriate proportion of the shades that allows us to create more impressive or harmonious combination. Another very important factor is also the appropriateness of the colour composition for the purpose in question.

Let us illustrate the effectiveness of shading with simple examples. Let us combine red and yellow. If the red is darker than the yellow the natural distinction of lightness characterising the colours in the spectrum or in saturated forms will be respected. Such accord looks happier and more open in its expression even if the saturation level of both colours is reduced. If the lightness ratio of the two colours is changed the other way round, the red will be modified to pale pink and the yellow darkened to dark brown, the harmony will be obscured a bit. This applies to the lightness proportions of other colours, too. The phenomenon of shading is most visibly demonstrated in the blue-yellow pair. If the two colours are shaded in contrast to their natural lightness proportion – the blue will be lighter and the yellow darker – the accord will turn more serious and sadder. The blue which is naturally a darker, shady colour, is radiantly shining in this accord while the yellow, a colour creating an impression of light and happy shine, appears gloomy in the role of a dark colour. Light colours like yellow and white are very sensitive to darkening and their happy expression is suppressed more visibly than in the case of colours which are darker when saturated (particularly cool colours). Colour compositions with natural proportions of colour shading are reminiscent of the hard (major) accords in music composition while the opposite shading reminds us of the soft (minor) accords (Table XII).

PATTERNS

Patterns multiply the options of controlling the expressive look of an area. The degree of enlivening and particular expressive effects achievable through pattern application is beyond the possibilities of a smooth surface in a single colour. The guidelines for various colour composition methods are widely applicable to colour patterns, too.

For instance, we can use a pattern on an area using just the shades of a single colour; this leaves the appearance of the area compact in terms of colour. An area with patterns of shades of the same colour, same lightness level but differing saturation levels, will be lent an especially delicate sense of enlivening – it will look compact in its lightness, too. It may look similarly compact though even if various colours with the same lightness levels are used in the patterns (green and grey in table VIB).

Another special type of enlivening is granted to an area covered with patterns in shades of the same colour of identical saturation but varying lightness levels. In this solution, the entire area shines with the same saturation level in all parts, both light and dark.

Soft differences of shades and colours used in the patterns achieve a quieter, calmer appearance of the area. Increasing the level of contrast in the pattern intensifies the enlivening, excitement and agitation. If the area is to appear narrowly defined in the colour mood, e.g. with a warm colour feeling, even with different colours in the patterns, the warm colour should prevail in the pattern and should be similarly enhanced in terms of saturation as well.

The expressive effect of patterns does not depend solely on their colour composition. Other factors are in play here, too: size of the pattern, shapes, arrangements; in this regard, the suitability of the relevant pattern for the application is important as well.

Patterns of simple, clear and regular shapes give a calmer impression. Contrastingly, if complex, irregular shapes are used, a feeling of unrest is created. Some shapes in patterns may create an impression of movement, e.g. vertical elongated shapes look like growing, asymmetric shapes look like movements to the side the shape is leaning towards, rolling shapes suggest waves etc.

Large patterns are noticeable particularly in small areas or on smaller objects, especially when viewed from up close. If the patterns are rendered in lively colours, they become the leaders of expression and suppress the impression created by the shape of the object as such. If necessary, this effect can be decreased by suppressing the colour scheme of the pattern. Smaller patterns give a calming effect, making the area look more delicate.

Regularly arranged patterns give a calm impression, too, particularly if arranged vertically or horizontally. Shapes defined or controlled by those directions are also easiest to perceive by our eyes. The pattern arrangement is very important if related to objects the shape of which should be emphasised, too. The location and arrangement of patterns may enhance the impressiveness of the object's essential shape. The pattern and the shape of the object should be in mutual harmony, for example if a square or other shape is decorated with a pattern along the edges, the contour will be emphasised and will stand out more distinctly. Contrastingly (as also could be the artistic intention), a modified pattern may fragment the shape and modify the impression created thereby, e.g. it may seem longer, wider, distorted depending on the way of division.

Contrast

Visual perception has some contradictory properties: on one hand, it renders colour proportions with as little distortion as possible which is why it e.g. adapts to different light intensities or colours. On the other hand, vision is also capable of modifying colours, or even inducing certain colour phenomena. The results of such activities in our vision are called contrast, and demonstrated in two ways – as successive contrast and as simultaneous contrast.

SUCCESSIVE CONTRAST

It is called successive because its demonstrated immediately after the preceding stimulation of the retina has ended. A negative image of the light stimulus appears in the sight. The more powerful the stimulation, the more powerful the contrast. For example, if we look into a source of light, a dark spot as the afterimage of its light follows once we take our eyes off it. The afterimage changes a bit and disappears in a while. If we look at a saturated colour, the successive contrast produces the afterimage of its complementary colour in our sight afterwards.

Such afterimages, if distinctive, interfere with the images of the subsequent views and, therefore, constitute a negative factor in colour composition. Still, the successive contrast lends itself to a positive use in artistic practice. For example the effect of a reddish mood on a theatre stage or red light can be enhanced if immediately preceded by a mood or lighting in the complementary colour, i.e. green. The effect of a certain colour can be enhanced in a similar manner upon its first appearance in a colour film. This contrast must be taken into account when our views change when moving, e.g. upon entry to a room furnished mostly in a warm colour scale from a room in predominantly cool colours, the first view of the room notices the warm nature of the colour mood more strongly. Or even just eye movements, e.g. red colour is more radiant in direct views when alternated with sideways looks into the greenery.

SIMULTANEOUS CONTRAST

The simultaneous contrast is an important factor of visual art which emphasises the distinctiveness of colour composition. If we are aware of its laws and apply it accordingly, it allows us to achieve a higher level of distinctiveness by subtle, delicate means rather than steep or even harsh colour differences. Although steeply enlarged differences in colours or shades thereof are called contrasting – and it is a common meaning of the term – the word is used to describe the colour differences generated by eyesight itself.

Our eyesight strives to create the most definite and straightforward image of the direct, or central, vision – the vision of the central part of the retina. This effort is demonstrated particularly by the apparent magnification of neighbouring colours or shades thereof. The colour phenomenon thus depends on its position next to another colour. Based on how the contrast modifies the appearance of the colour, there are three types:

1. Contrast in lightness – increases differences in lightness levels;
2. Contrast in saturation – increases differences in saturation levels;
3. Colour contrast – increases differences in colours.

The individual types of contrast are rarely seen alone. For instance, the contrast in saturation (table VIA, B) occurs between the shades of a single colour of varying saturation. The individual contrasts are mostly found acting together (table VII). For example, a light coating of yellow ochre in combination with a coating of Indian red means both a difference in the colour enhanced by colour contrast, and a difference in lightness levels emphasised by contrast in lightness.

CONTRAST IN LIGHTNESS

If a light green is put immediately next to a dark green, the light green will appear lighter due to the contrast while the dark green will look even darker. However, the effect of contrast in lightness is best illustrated by the following example. Let us divide the scale of black to white into five equal sections as has been performed in the discussion of light variability of colours. The sequence will read: black – dark grey – medium grey – light grey – white. Now, let us apply the medium grey from the scale to four identical shapes, e.g. small vertical rectangles. Let us surround the first rectangle with a tight frame of black, the next one with dark grey, the third one with light grey and the last one with white. The appearance of medium grey in the individual small rectangles has mysteriously changed. In a dark grey frame, it appears just slightly lighter while in the black frame, it looks distinctively lightened. In the light grey rectangle, it becomes slightly darker while in the white frame, the darkening is very visibly darker (table IV, framing of medium grey in a simplified illustration by the extremes; table VIB is analogous).

This formulates an important law of contrast in lightness – its effect increases with increasing difference in lightness levels of the individual shades. Therefore, black or black font stands out the darkest against white areas and vice versa, white shines most in a black environment. What is strange is that the biggest differences – which have the least need to be magnified by contrast – are the ones that are extended the most. According to the physiological explanation, our eyesight does this to support sharpness of the contours which, with larger differences in lightness levels in the absence of contrast might appear overly bright and, therefore, blurred.

CONTRAST IN SATURATION

This contrast is most visible if acting alone, unsupported by contrast in lightness. Its effect will be clearly demonstrated by the following example. Let us add grey to a saturated green of the same lightness level. Let us divide the transition of the two colours into five equal sectors: saturated green – less saturated – medium saturation – low saturation – grey. Similarly to the preceding example, let us surround a small rectangle of medium saturation green first with a frame of saturated green, then with less saturated green in the second figure, low saturation green in the third one and grey in the fourth rectangle. The effect of the contrast is amazing even here. In the saturated green frame, the medium green becomes seemingly greyish; in the second picture, its weakening is less noticeable. In the third shape, its saturation increases while in the fourth rectangle (with grey framing) it looks the liveliest (Table VIB). A similar law as in the case of contrast in lightness applies here – the effect of contrast in saturation is magnified with increasing difference in the saturation of the individual shades used.

If the individual shades of a colour are distinguished by a difference in lightness as well, e.g. using the scale of gradually lightening steps, the contrast in lightness will be demonstrated along with the contrast in saturation. A contrasting change of lightness occurs alongside with the contrast change in saturation (Table IX).

COLOUR CONTRAST

In contrast to both of the preceding contrasts, this one is demonstrated clearly even with tiny colour differences. The contrast modifies the appearance of both colours towards the opposite extremes. For example, yellow in combination with orangey yellow tends towards greenish yellow (lemon colour) while the orangey yellow inclines towards orange. For the contrast to act independently, without any contribution by contrast in lightness and saturation, the two colours would have to be of equal lightness and saturation levels.

Let us demonstrate a manifestation of colour contrast by an example similar to the previous ones. Let us mix a transition sequence for red and yellow with five even steps. Let us surround the middle member with the first level, i.e. red, then with the second, fourth and then fifth stage (yellow). The medium level will have very different appearances in the four shapes. The reds push it towards yellow and, since they are darker, render it lighter due to contrast in lightness. The yellows have the opposite effect, diverging it towards red; since they are lighter, they render it darker by contrast in lightness (table VII).

CONTRASTS OF COMPLEMENTARY COLOURS

The mutual effect of contrast between the colours with the biggest difference, i.e. complementary colours, has a special manifestation. If the colours are perfectly complementary, there is no change to the colour; however, both of them influence each other's saturation. This is a special type of contrast in saturation which increases the saturation of both interacting colours at the same time; that is why the hard tension between their extreme differences stands out so noticeably (Table XII).

COLOUR CONTRAST AND NEUTRAL COLOURS

Colour composition presents a special demonstration of colour contrast where a neutral colour is affected by one of the lively colours. The neutral colour assumes a slight suggestion of the colour complementary to the colour with which it is combined. For instance, grey in combination with red obtains a hint of green and vice versa, in combination with green it turns purple (Table VIII). Therefore, grey appears warmer if combined with blue and cooler if combined with yellow. The effect of this contrast is particularly strong if the grey is of the same lightness level as the colour generating the complementary hint. To be more specific, the effect of the natural shading of colours (the Purkinje effect) is at work here. For instance blue generates a complementary, i.e. yellowish, tinge on grey due to contrast. Saturated blue is naturally darker than saturated yellow. If we maintain this ratio and have darker blue and lighter grey, the effect of the contrast will be more powerful. Joining grey with yellow, the contrast will be especially powerful if the grey is darker than the yellow.

Let us try this on an area of saturated colour, e.g. red, and apply minute black pattern or draw black letters thereon. The black colour will stand out thanks to its darkness and, therefore, it will be less willing to adopt the contrast of the complementary colour tinge. Let us cover this area with thin silk paper, allowing both the black and the red to show through. This will soften the difference in lightness and the silk paper will incline towards green, i.e. the complementary colour of red, above the black. The contrast is demonstrated analogously in case of other colours.

THE DEGREES OF DIFFERENCE IN COLOUR COMPOSITIONS

The impressiveness of colour compositions greatly depends on the appropriate degree of contrast application. This allows adjustments in favour of the requirements for beauty, and makes contrast an important aesthetic agent.

The eyesight is usually satisfied by distinctive clarity. In this regard, more contrasting colour compositions are better. The level of contrast also depends on various other factors, it is adjusted to light intensity, nature of the determining factor of the colour composition, as well as the purpose it should serve. A quieter contrast is often sufficient, particularly in colour combinations which should look calm; on the other hand, contrast is emphasised wherever liveliness or stronger warning is necessary. Particularly intensified contrasts are better used in diminutive contexts (see the effect of shine). Steep contrasts of shine can be used not only in jewellery but also in larger areas if viewed from longer distances.

The hard contrast of black and white applies in our vision depending on which prevails, the white or black. The former occurs e.g. when drawing on a white paper with black ink. The eyesight is permanently employed by the prevailing area of white areas, and tires out faster. From this perspective, it is more advantageous to use the opposite combination – not black on white but white on black. For example, drawing with chalk on a black board. The prevailing area of white paper acts also when we read printed materials. Although our eyesight adapts to the brightness of the white page, the retina remains burdened by light. The eyesight adaptation is more difficult if the page with the writing does not have an even level of lightness but has a contrasting background print. Such visual solutions of texts occur e.g. in advertising. Pages boast various dark and light shapes and the lines of the printed text run over them. Such finishes are disturbing for the readers; the alternating higher and lower distinctiveness of the letters against the light and dark background makes reading unpleasant and tiresome.

The degree of contrast is particularly important in photographic imaging, too. The development of contrast is closely watched even during the development process. A positive result usually requires neither too soft nor too hard an image.

THE CLARITY–LIGHT RELATIONSHIP

If the light intensity drops considerably, our eyesight has trouble distinguishing details. For example, the lack of clarity becomes unpleasant when reading at dusk. However, if we do not focus on distinguishing details, the softness of reduced clarity of the evening dusk nicely combines with the fatigue of our eyes after the day’s work, and with the fatigue of our humour. So, even a softly contrasting colour composition can be entirely satisfactory when associated with a requirement for a quiet rest and peace.

In lights and environments with high light influx, softer expressiveness is usually more purposeful. A higher degree of contrast is often necessary in the shade, or in environments with less incoming light, particularly secondary light e.g. in a hallway lit indirectly through other rooms. In any dark spaces, e.g. basement corridors with dim light, a hard contrast in lightness helps orientation. The best way is whitewash on walls and narrow black details in the right places, e.g. vertical lines which serve as guidelines.

VISUAL ACUITY

The point of visual acuity is important as well. Generally blurred images are unpleasant, as we realise particularly when looking through unfocused binoculars or at a photographic image lacking focus, or even at out-of-focus moving pictures in a cinema. Just like soft colour schemes, lack of focus might have its positive uses where it serves as a surrounding for a clear and sharp part, the intended dominant in the field of vision or in the image. The dominant attracts our eyesight and mind more efficiently and regulates the viewing even more. For instance, the theatre curtain may be emphasised in this way, or altars in churches. Contrastingly, clarity extending even towards the sides or merely towards the sides distracts our views.

Sharp, distinctive sight occurs primarily when looking in detail; acuity decreases with distance. Leonardo da Vinci recommends using blur to soften the contours of distant images. The contours are softened for closer parts of our surroundings, too, advantageously in particular wherever shapes therein have multiple sharp edges. For instance, the edges of furniture are curved, as well as wall edges or ceiling edges (cavetto). Also wavy textiles and other curved parts of the environment may be used to set off the prevalent hard and sharp interfaces.

CONTRAST AND PROPORTIONS OF COLOUR AREAS

The effect of contrast also depends on the proportion of areas covered by the colours interacting through contrast. The colour of the smaller area is more influenced by the contrast of the larger area colour. In large areas, the contrast is strongest near the interface and diminishes quickly further on. This also applies to the interfaces between large areas of light and shadow. In square objects, the distinction of light and shadow on the edges is emphasised like this. We use this in imaging, adding darkness to the shadows near the edges dividing the shaded side from the lit side. The shape of square objects stands out with more precision, the shadows acquire an impression of extra airiness and the 3D impression is enhanced (Fig. 63).

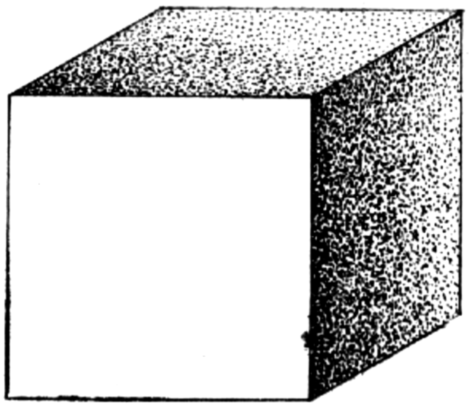


Fig. 63 Distinguishing light and shadow along the edges of the object portrayed with high level of contrast helps emphasise the 3D impression

There are other ways of using the properties of contrast, too. For instance, if we wish to emphasise the lightness of a certain area, we close it in a darker surrounding. The lightness can be pointed out also by a narrow dark frame running around the area which gradually lightens up towards the sides. If the area should appear darker, the method is inverted (Fig. 64). Yet, the central area has the same lightness level in both figures. Contrast in saturation and colour can be used analogously.

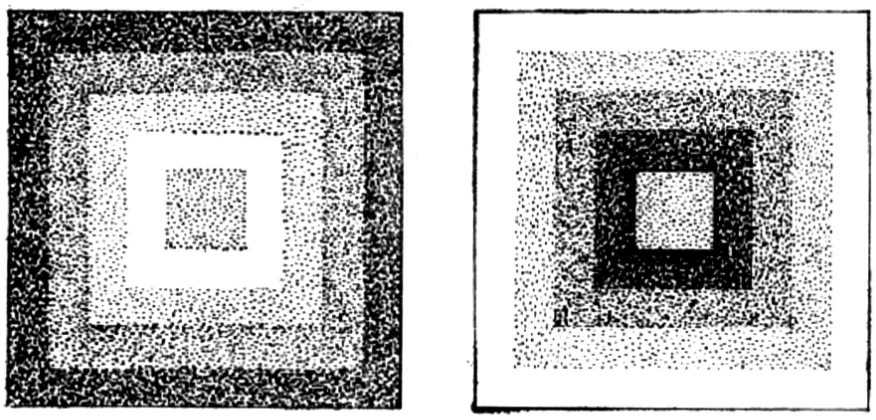


Fig. 64 The central part of both images actually has the same level of lightness. The contrast-related change in the lightness is created by the narrower framing.

The stimulus of contrasting details is demonstrated more distinctively when followed or surrounded by the calmness of blank areas. This makes for instance a band of patterns stand out more, if situated on a dull monochromatic or otherwise blank area, and the same applies to patterns on the edges of empty areas, conspicuous accessories against clothing in a single colour etc. Particularly rhythmic alternation “contrast stimulus – calmness of blank space” is an efficient means that boosts the impressiveness of contrast.

LIGHTNESS OF COLOUR AND DISTINCTIVENESS OF SHADOWS

Leonardo da Vinci points out that the difference between the darkest shadows and brightest lights seems biggest on white areas. However, this applies solely to small or narrow shadows created particularly in direct, intense light. These are influenced by contrast more effectively; the darkness of shadows in the sharp interface with lights stands out more powerfully, too. On contrary, large areas of shadows or half-shade transitions in large, slightly curved areas on a light surface appear softer and more airy.

Minute profiling with steep 3D details acquires additional distinctiveness in relation to the shadows and lights if made of very light, namely white materials. For instance light-coloured plaster or stone. The ancient Greek temple structures had many elements of lively colours; however, white coating or pure white marble prevailed. From the visual point of view, the construction elements had sharp edges or shallow fluting, adorned with grooves or other minute profiles. Full daylight allowed them to present the shiny play of the interfaces between light and shadow in its full splendour.

Shiny surfaces lend themselves more readily to emphasising the difference between light and shadow if they are dark, and best if they are black. Their lightest points – the gloss – shine brightly while the escalated darkness of the shadows brings a hard contrast to the accord.

COLOUR CONTRAST AND LIGHT REFLECTIONS

Colour contrast and light reflections modify the colour in mutually opposite directions. Let us explain their interaction with an example – let us use the skin tone which will be influenced both by contrast of the colour of the clothes and by the light reflections of the colour of the clothes.

If yellow or lemon yellow is used, it will be very efficient in letting the pinkish hue of the skin tone stand out by contrast. At the same time, we can also influence the lightness of the skin tone. With a yellow lighter than the skin tone, the skin tone will seem darker by contrast (Table VII). The light reflection from the yellow will work the other way, too, against the effect of the contrast. This will be demonstrated more noticeably particularly in the shady areas of the skin; the shadows will appear yellowish and slightly lighter.

Let us influence the same skin tone with red, purple or violet. The effect of the contrast of red will make the skin tone appear yellowish, and a darker red will also lighten it up by contrast so it will appear paler (Table VII). However, the light reflection from the red will add reddishness to the shadows in the skin – again, this is the opposite of the contrast effect.

If the two images are compared, it seems incredible that it is actually the same skin tone. Let us put a sheet of paper with small openings cut out to uncover just the skin tone: it will be identical in both the openings.

THE COLOUR OF SHADOWS IN THE SNOW

White is the colour that embraces light reflections of other colours in its shadows the most. When the sky is clear, the shadows on the snow turn bluish, reflecting the blue of the sky. If the sunset is red, the shadows on the snow take a blue-green tinge. Here, it is the colour induced by the reddishness of the snow lights by contrast.

LIGHT REFLECTIONS AND COMPLEMENTARY COLOURS

For complementary colours, contrast helps increase saturation. Light reflections of such colours affect each other in the opposite way – reducing saturation of both colours. For example, reflections off a yellow area onto a blue area. The yellow reflection light is reflected off the surface upon incidence on a blue area, and is added to its own blue light. Its yellowness reduces the saturation level of the blue but the blue is turned slightly lighter. The yellow light that has gone under the surface of the blue area has been absorbed. This is actually the biggest loss of reflected light, e.g. in rooms of this colour scheme, when complementary colours are combined. Contrastingly, light reflections off areas the colours of which are close to each other, e.g. yellow and orange, are less affected like this. Similarly to the reflection off a yellow area diminishing the saturation of the blue in the blue area, the blue reflection diminishes the colour saturation of the yellow area.

Colour, Perception of Shapes and Spaces

An image of what we are looking at is projected by the eye's light-refracting system on the retina as a tiny perspective image. This means it is a 2D image. In this sense, eyesight has a special characteristic; the viewed image is before our eyes, large and in 3D. We do not realise the image on the retina like we e.g. sense the radiant heat of sunshine on our skin; we project it in front of ourselves, back to the spot where the light stimuli come from.

Just like an artist's painting is a set of areas of different colours and sizes, the image on the retina is composed of tiny spots of various sizes and colours. The shapes of the spots are derived from their contours; the sizes, positions and distances are derived from the context and inter-comparison of the shapes. This involves the muscles of the eye. The viewing focus of the eye is transferred to various points of the viewed environment by saccades. This allows to verify the dimensions, proportions and mutual distances of the shapes. Even the effort made by the eye muscles in the move helps us estimate the larger dimensions. The eye must exert a bigger effort for larger dimensions.

Seeing by both eyes is also important; the object is simultaneously observed from two places defined by the distance between the eyes. This is more significant for close vision and assessment of plasticity of objects in the horizontal direction, i.e. from the right and left, depending on the mutual position of the two eyes. Assessments of horizontal dimensions in a face-to-face position are easiest for the eyes; bigger height dimensions are more difficult and the most difficult is assessing depth – i.e. distance away from the eyes.

DEPTH ESTIMATION

The eyesight verifies the depth perception by various processing methods. For instance, perspective changes in the size of objects, convergence of the eye axes which have a less sharp angle for close viewing than for distant viewing, and from the accommodation ratios. However, there are many more agents assisting the perception of distance. For instance, when the eye moves, the images of closer objects glide along the retina faster than the images of more distant objects. Looking at the surface of the railway tracks from a train window, the track might seem closer to the windows when the train is moving than when it is stationary. The colour proportions, visual acuity ratios and distinctiveness of shapes as well as colour changes induced through the visual distance are of particular significance for the assessment of distance – these are phenomena under the umbrella term "aerial" or "atmospheric perspective".

ACTUAL AND PERCEIVED PROPORTIONS OF SHAPES

The eyesight renders the viewed image in a form as similar to reality as possible, although the most that can be achieved is more or less approximate image. So, the size of the Moon varies when viewed at moonrise or during culmination although the viewing angle is identical. What we perceive through our eyesight is not a simple and straightforward transcription of the perspective image on our retina but the result of complex realisation processes. For example, a circle (unless positioned face-to-face to us) is reflected on the retina as an ellipsis although the perception processes convert it to our mind as a circle. Similarly, a rectangular frame of a wall-hung picture appears distorted to an irregular trapezium due to perspective but we still know it is of a rectangular shape.

AERIAL PERSPECTIVE

Views of the distance, particularly in large, open landscapes, yield a particularly noticeable illustration of colour changes induced by large viewing distances. Such colour changes are caused by the massive atmospheric layer between the eye and the perceived surroundings and, therefore, this colour perspective is usually called aerial (atmospheric). This is an old term used especially by Leonardo da Vinci who also expressed the individual laws of the perspective.

Light is dispersed in the air both on its molecules and on the vapours and dust distributed in the air. Particularly in its massive layers close to the ground, air is also a semi-transparent environment and adopts its optical properties. Diffuse light in the air is seen as a mist which is most noticeable against dark backdrop in the distance. It is added to and, consequently, changes the colours of the backdrop.

However, changes in distant colours are also caused by the fact that their light, coming to the eye, is poorer due to the partial diffusion in the air. The combined result of all of this, as demonstrated by the changes in distant colours, is included in the "aerial perspective" term. It has three kinds of effect; changes in the lightness level of the colour, in the saturation levels, and transformation into a different colour.

Changes in lightness. Dark colours are lightened by increasing viewing distance – the darker and more distant they are, the more lightening occurs. Very light colours behave differently. They, and white in particular, are robbed of their lightness a bit by the atmospheric mist over long distances. Leonardo da Vinci expressed the phenomena quite aptly: "– out of objects darker than the atmospheric light (i.e. the mist), the most distant one is the least dark; out of objects lighter than the atmospheric light, the most distant one is the least light." This is how the lightness range from darker to lighter colours, namely between the lights and the shadows, becomes softer with increasing distance. For example, in painting, if we intend to emphasise the illusion of distant objects, we adopt this method and reduce the darkness of (especially) the shadows on objects with increasing distance.

Changes in saturation. The atmospheric layer between the eye and a distant colour reduces the saturation of the colour all the more noticeably with increasing distance of the colour and with increasing quantity of mist in the air. Therefore, if the saturation of a colour is gradually reduced with increasing depth in a painting, the impression of the colour being far away is very effectively enhanced (Table IX).

Changes in colour. The light of the setting sun is usually orangey or even red. It passes through the atmospheric layer close to the ground which disperses blue and violet spectral radiations. Red lights pass more easily which makes them prevail in the sunlight – and the Sun appears red.

The blue and violet components of light, diffused by the atmospheric environment, will be manifested more noticeably against darker backdrops, e.g. against dark shadows, forested mountains in a landscape etc.; and the manifestation will also be stronger with increasingly dark and distant background. Long distances are ruled by two colour palettes: orangey or reddish scheme in the very light parts, and bluish scheme in the darker parts.

LINEAR PERSPECTIVE AND AERIAL PERSPECTIVE

The development of colour changes with depth is concurrent with the dimension changes in the linear perspective. The effect of aerial perspective increases with the gradual diminishing of shapes in linear perspective. The aerial perspective is capable of presenting the liveliest appearance of spatial depth if used in its full scope, i.e. within all of its changes – lightness, saturation, colour. The perspectives, both linear and aerial, are the most effective agents in depth perception and depiction. The perspectives allow us to perceive the space and its depth dimensions even when we only watch with one eye. For instance, a photographic image is a one-eye picture and, yet, it gives a clear 3D idea.

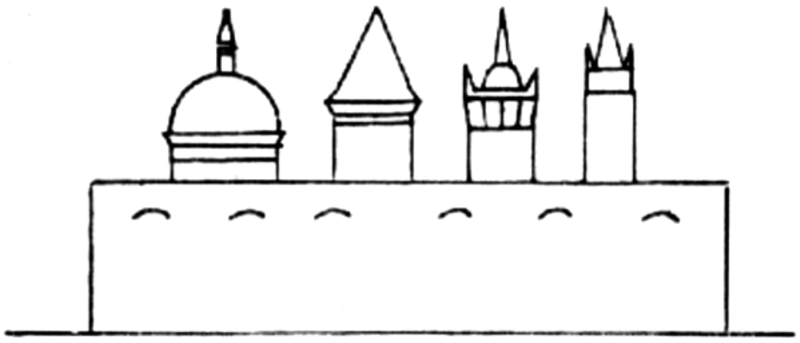


Fig. 65 The aerial perspective would efficiently portray the different distances of the towers from the wall in the foreground.

In his book on painting, Leonardo da Vinci gives an example where the estimated distance rather depends on aerial perspective (fig. 65). The varying distances of the towers behind the wall in the picture are difficult to assess from the linear perspective. According to his instructions, the first tower is rendered in its actual colour scheme. The next tower receives a slightly blue-tinged colour scheme, and a simpler profile of individual details. The remaining towers, even further away, are painted even bluer depending on their dinstance. We should also remind ourselves of what was explained in the previous paragraphs — the closest tower will have the darkest shadows cast and own shadows while the shadows of the most distant tower will be the least dark. The shadows and dark parts of the towers show the tendency towards blue most noticeably — the more distant, the bluer.

Aerial perspective, although fully appreciated already in the renaissance painting (15th to16th centuries) was extremely important to the painting of the19th century. Its application was most significant to impressionism where the concept of colour composition in a painting was largely subordinated to the illustration of the atmosphere and its light-related phenomena.

Some colours make the impression of coming forth out of the area with which they are connected; they seem to be closer while others seemingly recede. Blue is often called a forthcoming colour while red is receding. This is linked to the advice for using red wherever an illusion of even more depth should be created. The phenomena are usually explained by the varying refraction of such colour lights. Blue, whose light refracts more, may create the impression of being closer while red light refracts less and so red might appear more distant (Fig. 66). In contrast to that, some observers have the opposite impression: red appears closer to them while blue seems to recede. This contradiction in observation is explained by varying training of one's eyesight; some people's realization processing might run the other way round.

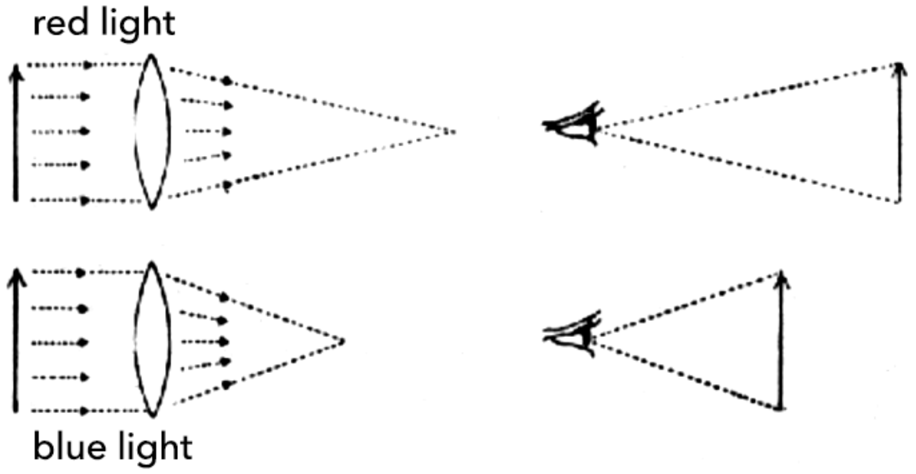


Fig. 66 The physical interpretation of the apparent coming forth and receding of colours based on the differing light refraction values of the individual colours

The impression of blue may be more noticeably receding in less saturated versions, as we are used to connect it with the lighter, less saturated blue tinge of the distant views. Therefore, bluish wall colour is sometimes recommended when a room should seem larger. The illusion of coming forth is more readily delivered by darker blues. One of the observers of this phenomenon states an impression from looking up into the gaps in the supporting structure of the exterior of a gothic cathedral – the blue of the sky shining through the gaps seemed to be right there in the gaps.

What is even more important though is the fact that the impression of coming forth is made by other colours, too, even white or black as long as they form a distinctive, dominating motif in our field of vision. Therefore, psychology does not assign too much significance to the varying light refraction ratios but takes into consideration a different relationship which it believes to be more significant for this phenomenon. It is roughly like this: In close viewing, the field of vision widens slightly; we perceive with a wider angle of viewing. As a distinctive dominant in the field of vision causes a similar widening of the viewing angle, the mind might operate with the impression of it being closer (Table IX).

Therefore, if we wish a certain part of a painting to come forth visibly, we should furnish it with hard, distinctive emphasis dominating the whole picture. It basically conforms to the laws of aerial perspective and texture gradient (shapes lose details of texture with increasing distance). This method is often used in the colour scheme of room decoration. For example, the height of a room may be lowered if the ceiling is painted more saturated colour or a noticeably darker colour. However, such ceiling appears to be heavier, too. The longitudinal characteristic of space can be worked with in a similar manner, e.g. a long corridor may seem shorter if the wall at the end is rich in colour, e.g. more saturated. This can be done in an inconspicuous way, too, the space is seemingly shortened by gradual increasing of saturation towards the depth; the opposite procedure (gradual reduction of colour saturation) creates an impression of a longer space (Table IX).

PERCEPTION OF SHAPES OF OBJECTS

The perception of angular objects, e.g. cube, pyramid, rhombohedron etc., is facilitated by their edges. Light and shadows are most distinctively differentiated on the edges, so it is often enough to depict the objects merely by a linear drawing of the edges which gives a full idea of the shape. Rooms, i.e. the interior of buildings, are usually also angular. In round objects, e.g. a sphere, ellipsoid, cylinder etc., the curves of their shape are usually estimated from the modelling of shadows, i.e. from the soft transitions of light, half-shade and shadow. In other cases, the curves can be presented to the eyesight by a certain drawing or painting attached to the shape. It is basically a grid of lines that illustrates the form of the object through its own perspective. The most effective and the simplest is, in this sense, horizontal and vertical. A spherical shape is appropriately emphasised by a drawing following the style of lines of latitude or longitude on the globe, or both.

Irregular drawing with no appropriate connection to the shape in this sense makes the estimation of the 3D shape difficult, or even seemingly modifies the form.

PERCEPTION OF SHAPE AND COLOUR SATURATION RATIOS

Let us use the saturation scale of shades of a colour with identical saturation level, e.g. green, to assess the behaviour of colour saturation in the perception of 3D nature of objects. The scale consist of shades obtained by mixing saturated green with a grey of identical lightness. Let us paint a simple object, e.g. an angular item, with this saturation scale by putting a more saturated shade on one side while the remaining ones will have less saturated shades – as if we aimed to capture the lights and shades of the object. However, this will not create an impression of the 3D nature of the object portrayed (Table XI). A slight suggestion of the 3D nature is given by the drawing of the interface on the edges but the poor distinctiveness of colour saturation is hardly capable of creating a stronger appearance of a 3D shape. The image looks 2D, as if the object were in a mist. The colour saturation per se, without the contribution of differences in lightness, is not the agent that creates an impression of the object's 3D form in our perception. Similarly, different colours, if adjusted to the same level of lightness, fail to generate a distinctive image of the 3D nature as well.

Colour saturation makes an object seem 3D only through its effect on the depth perception. This is how for instance more saturated patterns may seemingly come out of a less saturated area.

PERCEPTION OF SHAPE AND COLOUR LIGHTNESS RATIOS

If the object as mentioned above is used as an example and given shades of varying lightness levels (Table XI), its 3D nature will be clearly visible. Solely differences in lightness are capable of creating an impression of 3D character of objects. Colour lightness on its own, i.e. with no contribution by saturation and colour differences, is sufficient to give an idea of the shapes in the space. This is the situation of for example dusk or moonlight when we perceive the world around us solely through lightness, not through colour. Even various imaging techniques give an idea of shapes and spaces through a simple scale of lightness degrees, e.g. black-and-white photography, shaded drawings, painting reduced to the shades of a single colour etc.

SHAPE OF OBJECTS AND THEIR COLOUR RENDITION

The aforementioned properties of colour saturation and lightness are of a special significance to various ways of practical use. If a 3D object is given saturation degrees of a certain colour to the same lightness level, or even of different colours of the same lightness levels, we will not interfere (or interfere very little) with its shape defined by the light, i.e. by its own lights and shadows. This is how for example a pottery product can be coloured, if its 3D modelling by lights and shadows should not be overly suppressed by its colour decorations. In this sense, this method can be applied to the colour palette of a building face divided by 3D details.

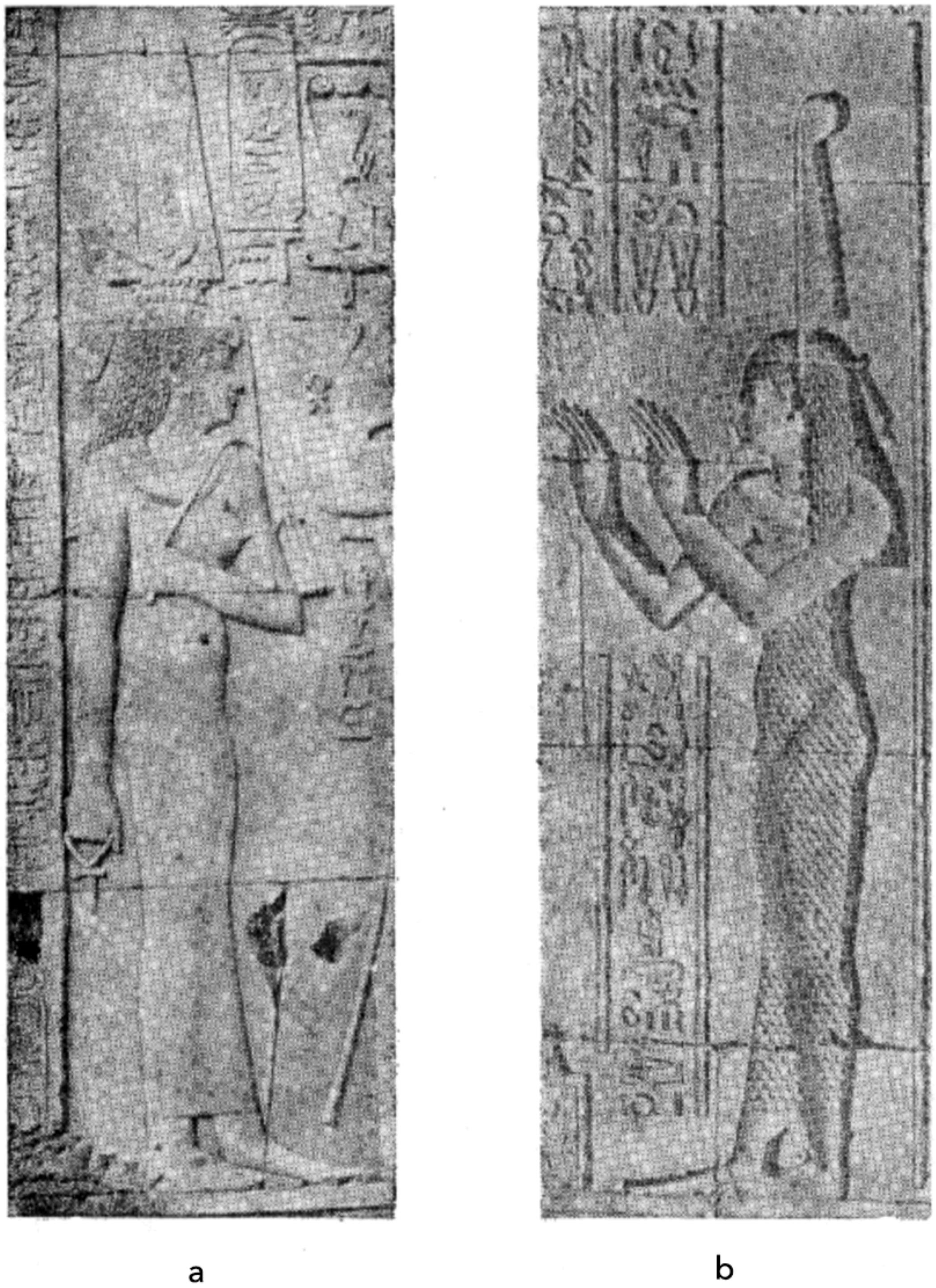
If colours of varying lightness levels are used to colour objects, the natural image of the lights and shadows is affected more significantly. This is how certain schemes of colours of varying lightness levels can hugely distort the impression of the object's form, and it is usually used when the shape of the object should not be recognised easily. For instance light and dark patches break the image of military buildings, particularly to make it difficult to recognise them from above in case of aerial strikes. In a positive sense, the mediaeval wall painting sometimes added colours of varying lightness levels to shapes. For example, shady grooves of building structures were given darker colours while the lit parts were painted a lighter shade. This achieved a more distinctive impression of profiling in the shady areas.

THE POSSIBILITIES OF PAINTING TO EXPRESS 3D NATURE

Leonardo da Vinci called it a miracle when the history of painting first managed to create the impression of a painting coming out of the 2D area, i.e. an illusion of a 3D scene. It is a miracle, all the more because painting does not have all of the means that create the impression of 3D. If we watch an image rendering various proportions of depth, the motion system of our eyes is far less active than in case of watching actual depth of space. The effectiveness of seeing with both eyes, i.e. observing the 3D nature of things from the right and from the left, based on the distance between our eyes, is lacking here. The lens of the eye stays focused on the area of the painting; it does not have to accommodate as if observing actual objects. Similarly, the convergence of both eyes remains inactive although it changes when we look at actual distances. If we consider that when the eye is moving, the images of close objects glide along the retina faster and distant objects more slowly, we can see that such motion-related hints of distance and proximity are eliminated from the perception of a painting as well. All this means a painting puts the motion system of the eyes into rigidity rather than its standard motion activity.

What is left to a painter is just the linear and aerial perspective, depiction of lights and shadows, or possibly also sharp or soft rendition of contours as the most important means of creating the illusion of 3D. The means per se are capable of creating a very lively impression of the depth. A suitable vantage point is a determining factor, too. When viewing a perspective painting, we should be at a viewing distance corresponding to the distance at which the painting was construed. In the case of photographs, this depends on the focal length. If F = 7.5 cm, a ten-fold blow up of the image would require a distance of 7.5 times 10 = 75 cm. Particularly wall paintings in perspective should be adapted to the vantage point in this way.

Relief images where colour is used as an addition to the 3D relief are characterised by livelier depths. This artistic method was popular especially in the ancient times. Besides the relief coming out of the base (Fig. 67b), there were reliefs embedded in the base area where the



contours of the shapes were engraved in it (Fig. 67b). This achieved a distinctive shading of the contours of the relief which acquired additional hard distinctiveness – that was desirable particularly if the piece was placed in a shady environment.

Fig. 67 A raised relief and counter-relief (intaglio)

Painting offers the opposite option, too – reduce, or even eliminate the impression of 3D in an image. We have touched on this point in the discussion of depicting a shape by the saturation scale of a colour alone. A scale where all degrees are of the same lightness level so any contribution of differences in lightness is ruled out.

There are no paintings, whether landscapes, portraits or other 3D facts, rendered merely by the shades of this scale in any gallery or exhibition. And yet, attempting to create such an image is highly recommended as it delivers an important lesson. Although the linear perspective or saturation scheme, if used in the painting in line with the laws of aerial perspective, try to create an impression of depth, the painting remains too soft and, therefore, flat.

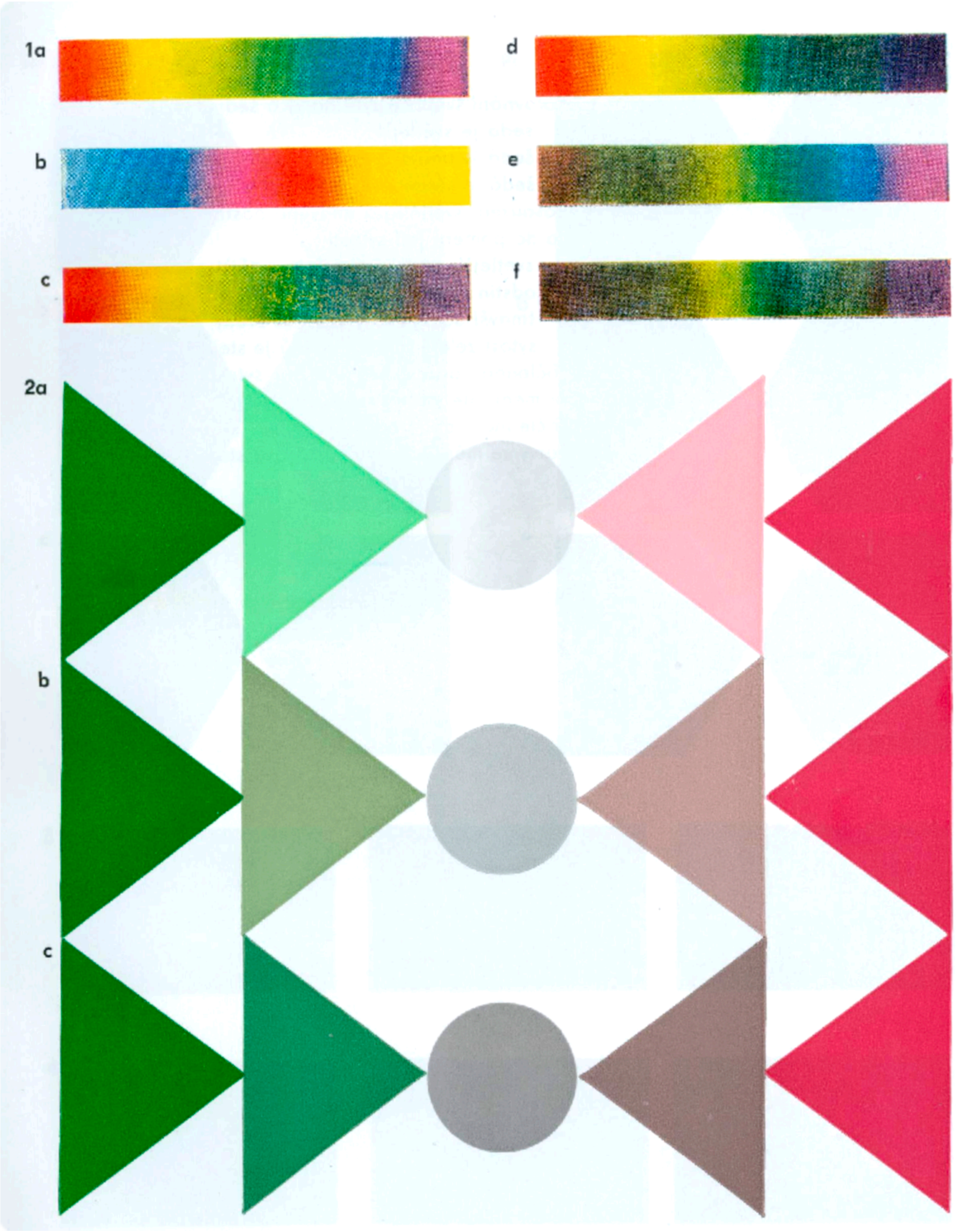
If we test this with the colour difference ratios, by using only colours of the same lightness level, we will also learn about the significance of these levels for both viewing and a painter's rendition of space. There is no need to test the ability of the lightness levels as such as we commonly encounter so many images applying just this scale, particularly in the press, most often with images reproduced by black-and-white photographs.

The aforementioned tests will tell us that from the perspective of perceiving 3D, the lightness levels are the most important factor in vision and, therefore, painting. Perception through colour differences is probably a later stage of eyesight evolution which gave eyesight a great extension of the distinguishing ability. However, the purpose was not to facilitate the perception of space, i.e. 3D — that had been cared for by the lightness level processing already.

Archaeologists put the earliest attempts to create an impression of 3D in an image sometime during the Magdalenian Palaeolithic culture. 3D rendition of shapes and impression of very steep depths were objectives of the baroque painters in particular.

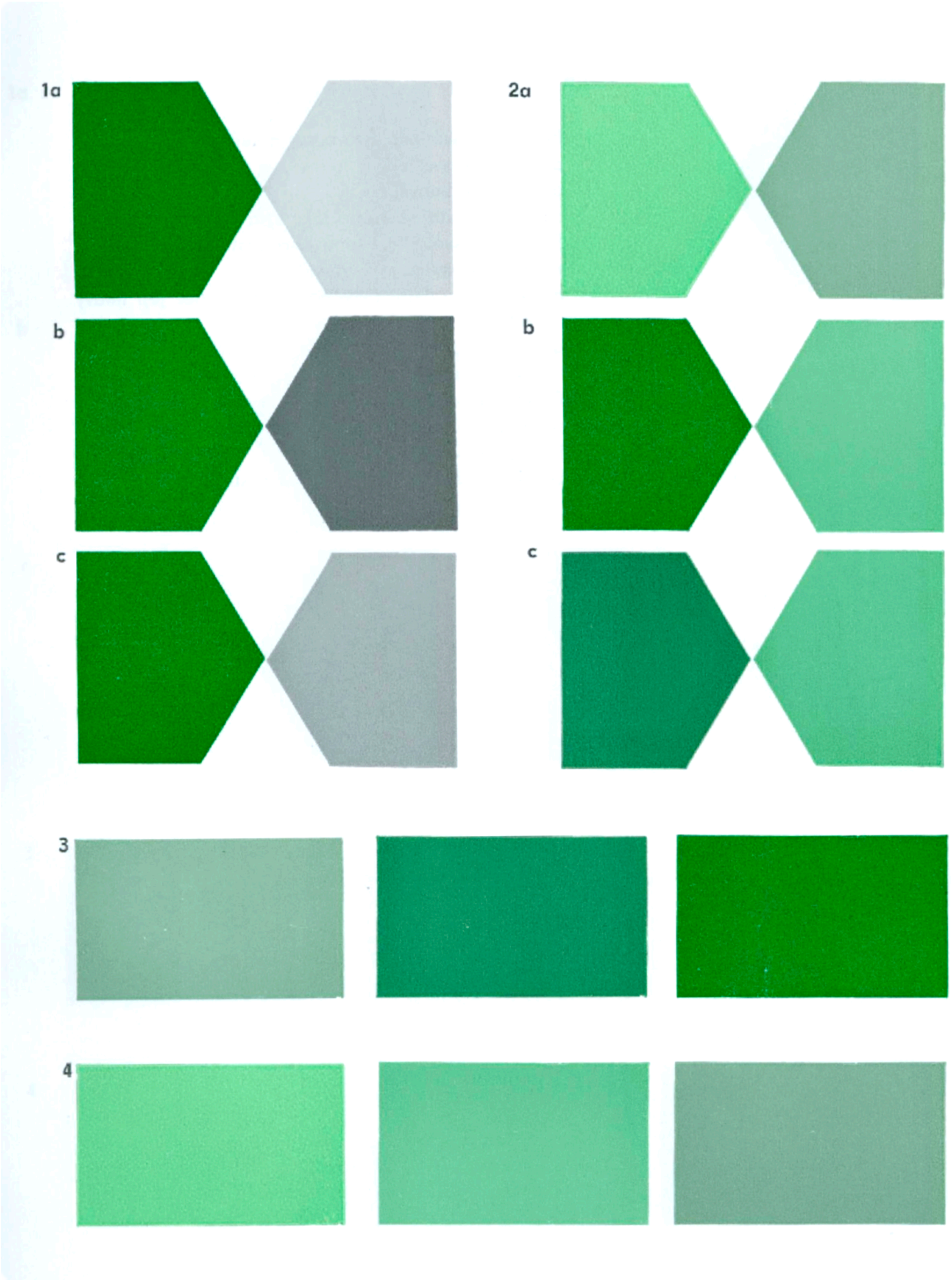
Appendix

I – The basic and extended colour schedule in a circular arrangement (wheel)
The limits of printing do not allow presenting the desired relationships in all their complexity. The reader should follow the instructions in the text to perform the activities which give a better illustration of the relationships.

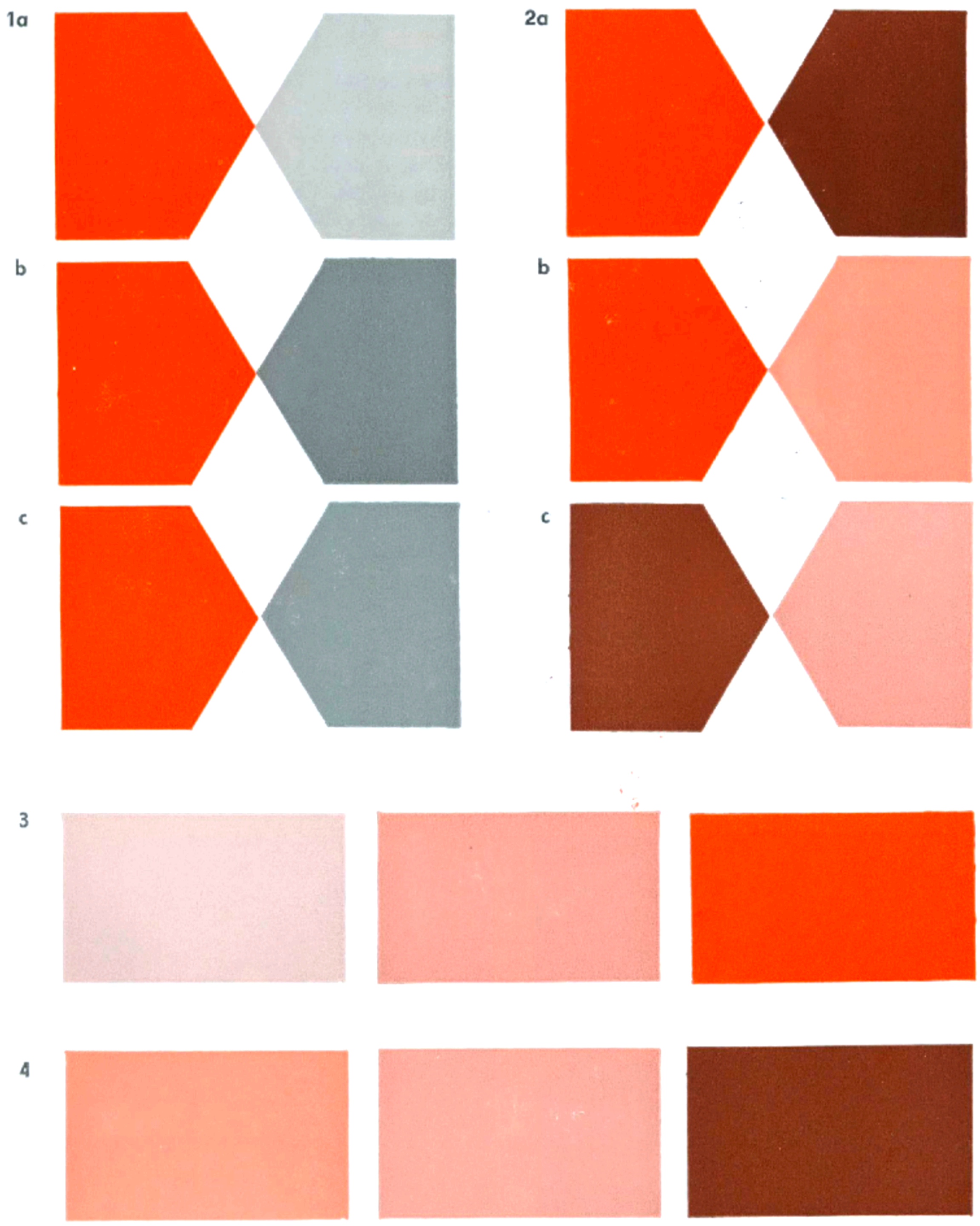


II – 1. Spectra: a) Daylight spectrum, b) Complementary (negative) spectrum, c) Yellowish light spectrum, d) Yellow varnish spectrum, e) Spectrum of yellow varnish applied on top of blue varnish

2. Colour mixing: a) The results of addition of two complementary colour lights, b) The results of a pointillist addition of two complementary colours, c) The diagram of mixing two complementary colours on a palette



III A – 1. Comparison of saturation between saturated colours and grey: a) The grey is lighter, b) The grey is darker, c) The grey is the same degree of lightness as the saturated green
2. Assessment of a light and a dark shade of green in terms of saturation: a) The lighter green is more saturated than the darker shade, b) The darker shade is more saturated than the lighter shade, c) The saturation of both shades is the same
3. A sequence of three shades of varying saturations. The saturation of the colour changes although the lightness level remains the same.
4. A sequence of three shades of varying lightness levels. The lightness of the colour changes although the saturation remains the same.

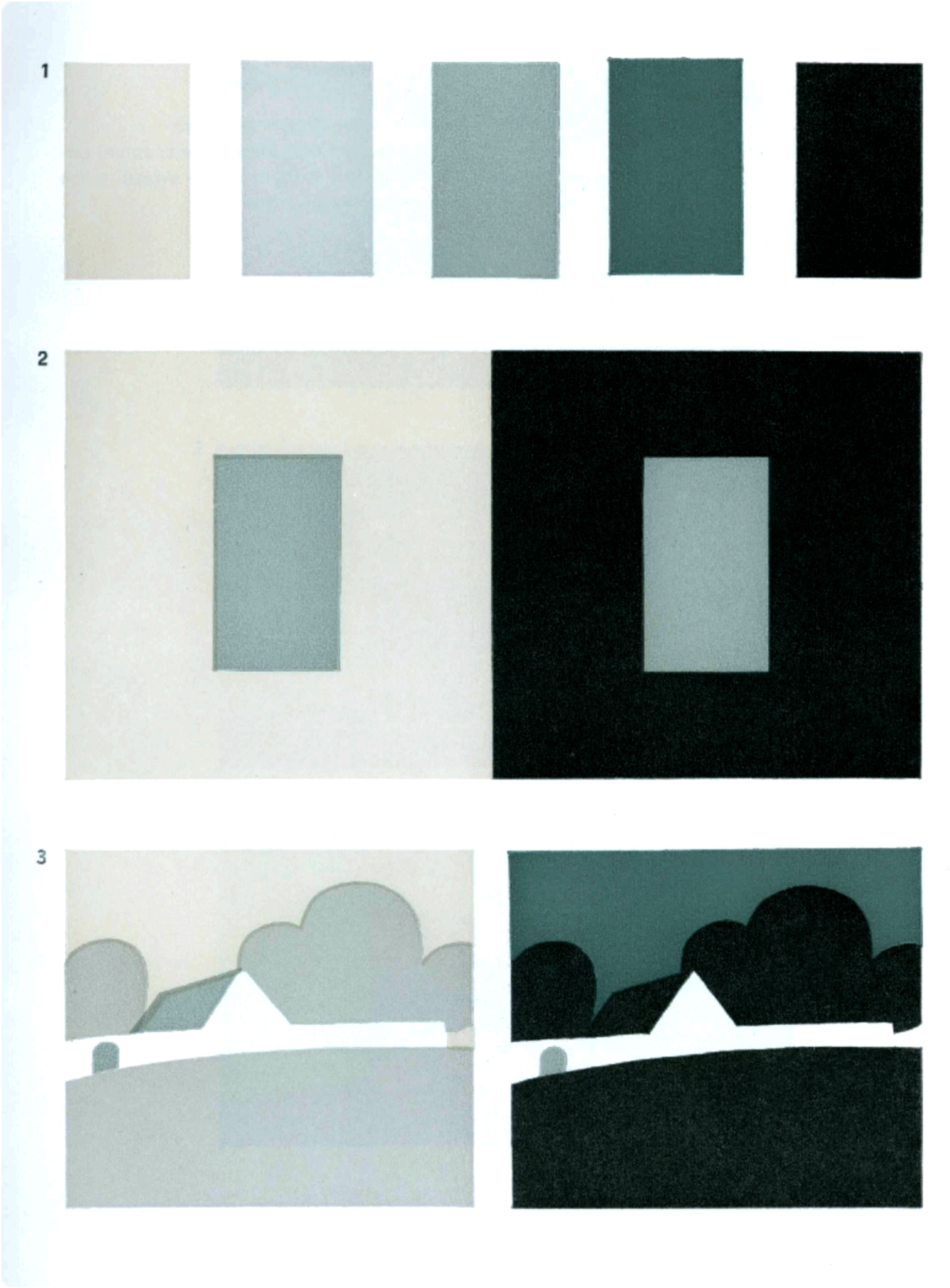


III B – 1. Comparison of lightness between saturated colours and grey: a) The grey is lighter, b) The grey is darker, c) The grey is the same degree of lightness as the saturated red

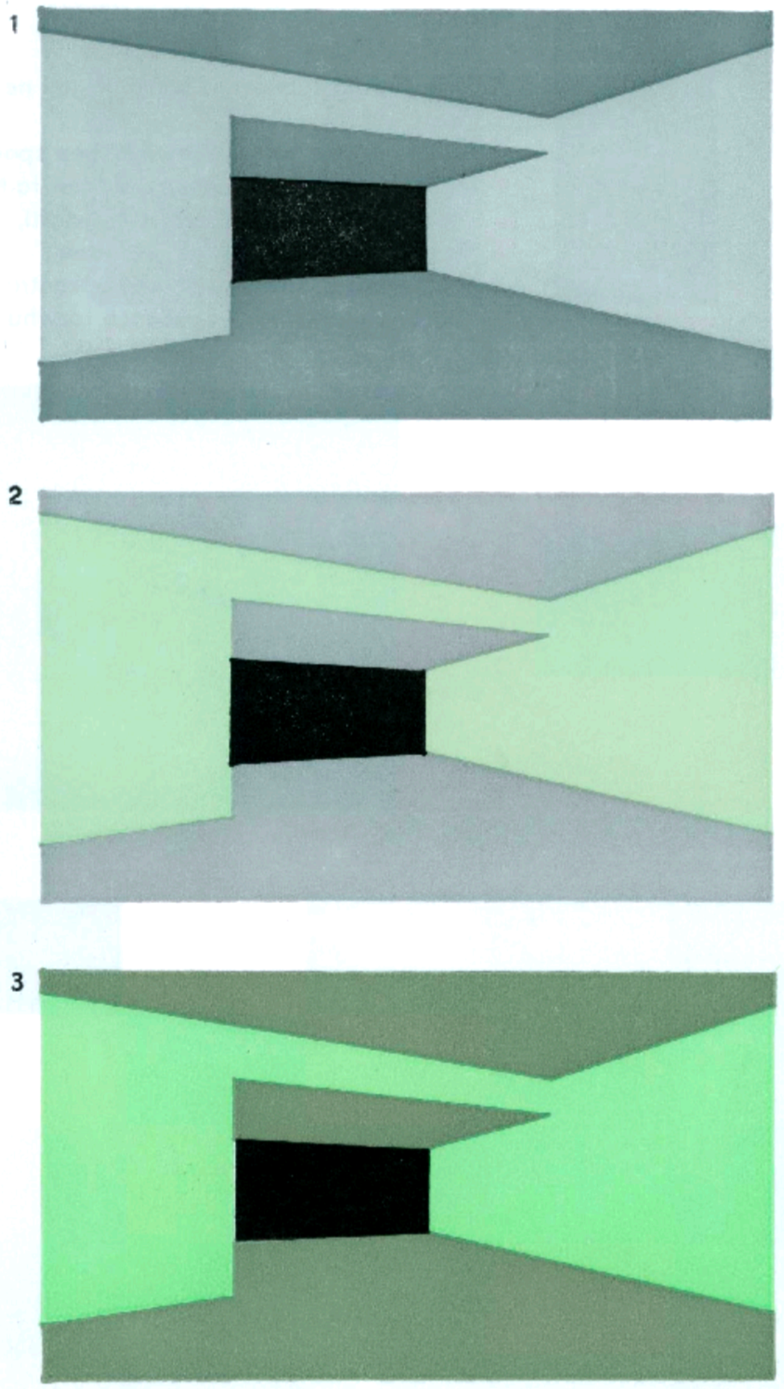
2. Assessment of a light and a dark shade of red in terms of saturation: a) The lighter red is more saturated than the darker shade, b) The darker shade is more saturated than the lighter shade, c) The saturation of both shades is the same

3. A sequence of three shades of varying saturations. The saturation of the colour changes although the lightness level remains the same.

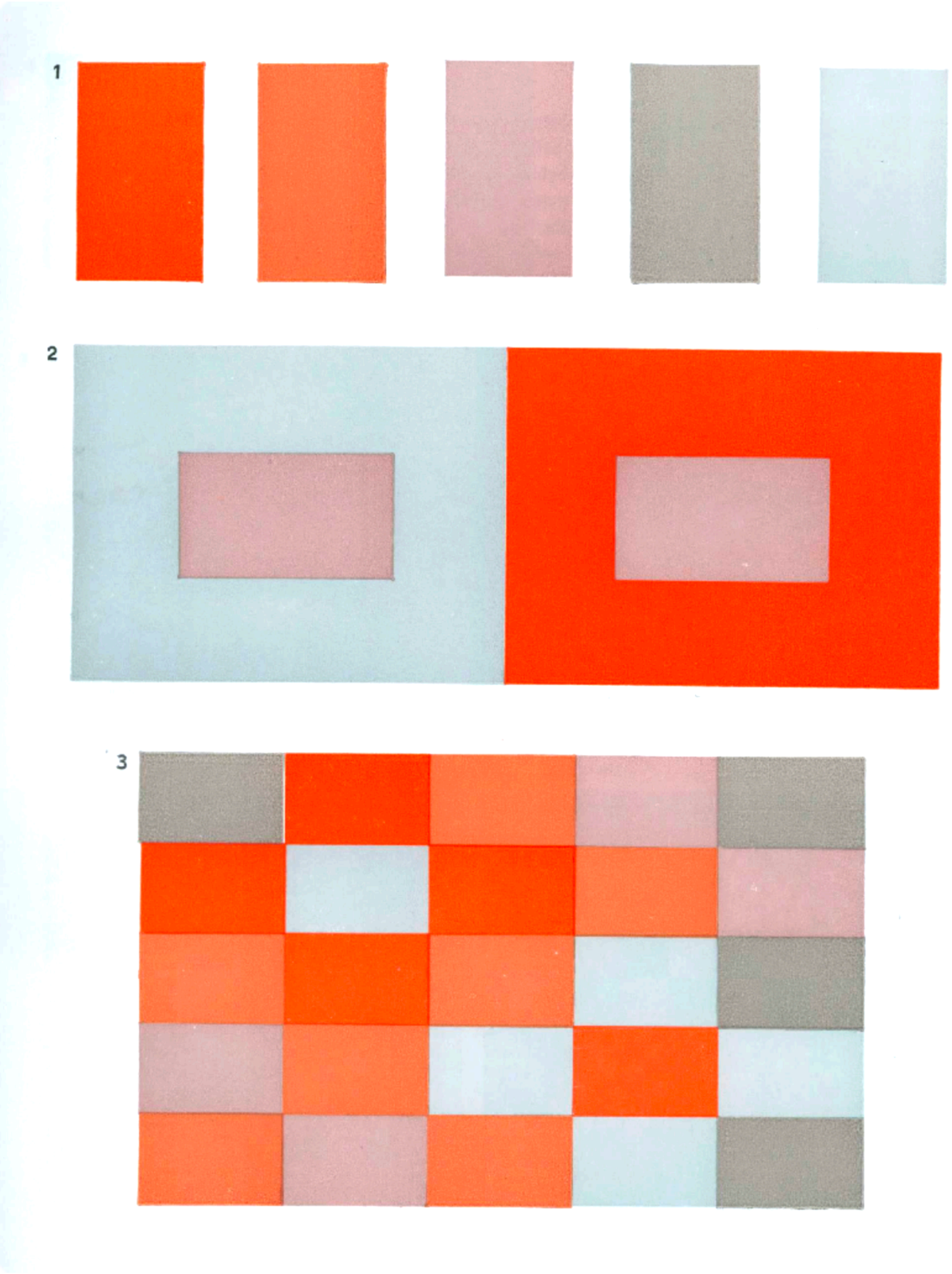
4. A sequence of three shades of varying lightness levels. The lightness of the colour changes although the saturation remains the same.



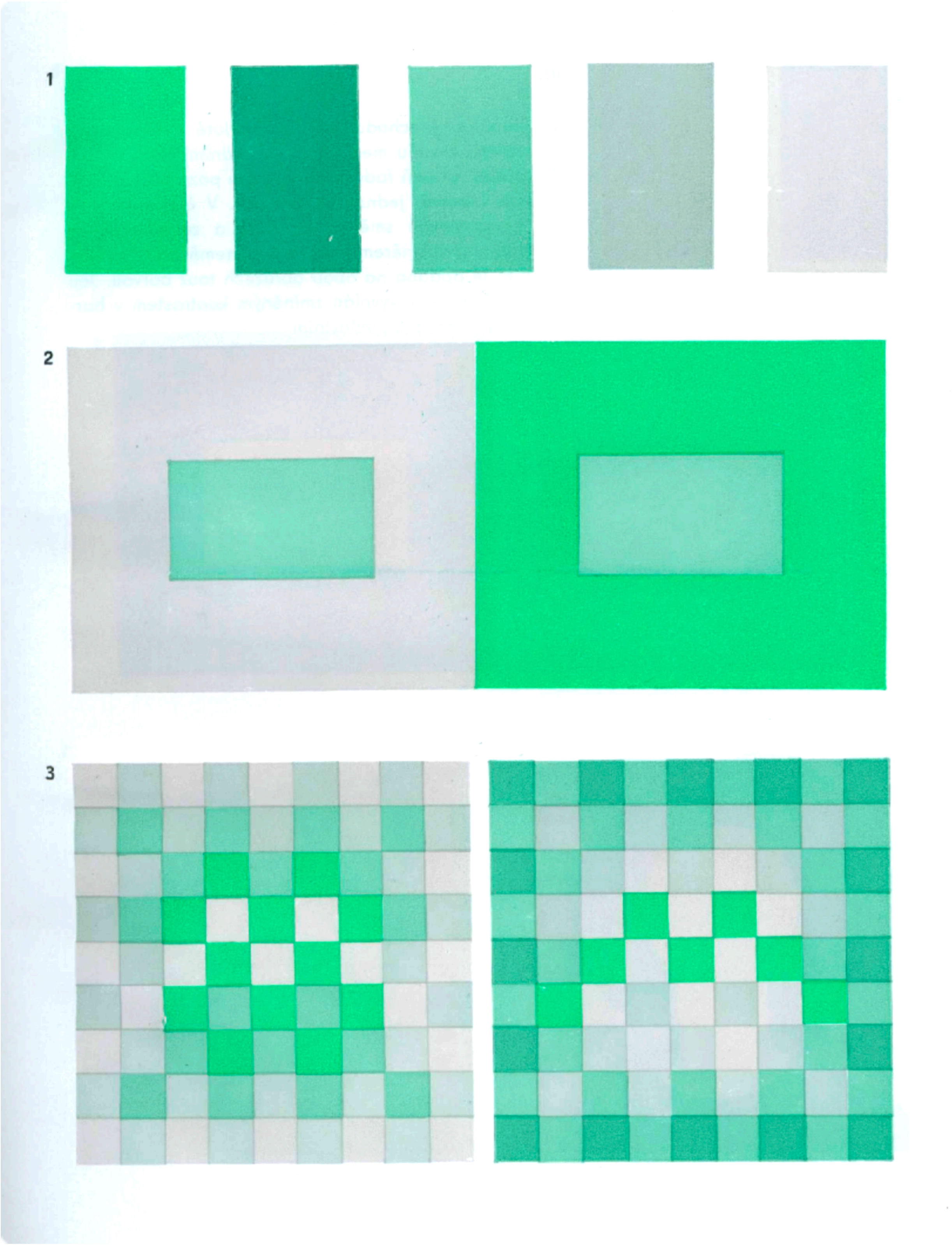
IV — 1. A five-degree scale of grey
2. The contrast effect of the lightest and the darkest greys on medium grey (it appears darkened when framed in a lighter shade, and lightened when framed in a darker shade)
3. Light atmospheres affected by the lightness parameters of the colour. The extreme lightness degrees are not determining (white is the same in both images); only the in-between levels are. If these are light, they create an impression of daylight; if dark, they create an impression of moonlight



V — The lightening effect of increasing colour saturation.
All three images are rendered with the same lightness parameters of the colours. From top to bottom, colour saturation increases which intensifies the impression of the space being filled with light



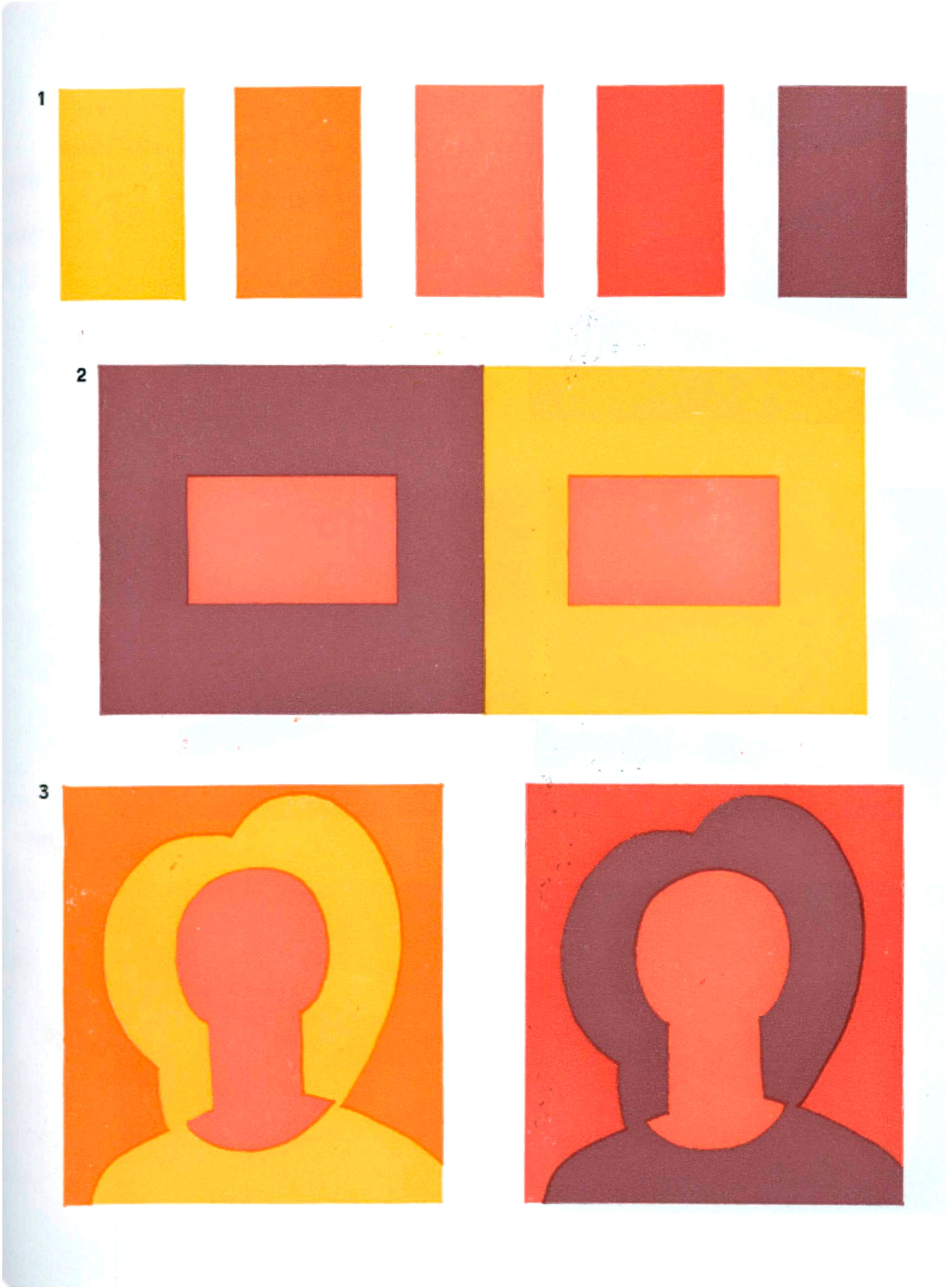
VI A – 1. Degrees of colour saturation while the lightness level remains unchanged
2. The saturation contrast works independently of the lightness contrast. The middle level in the sequence is framed in grey, which emphasises its saturation while in a field of saturated red its saturation is diminished
3. The mosaic pattern suggests the effects of contrast on the individual fields in the arrangement



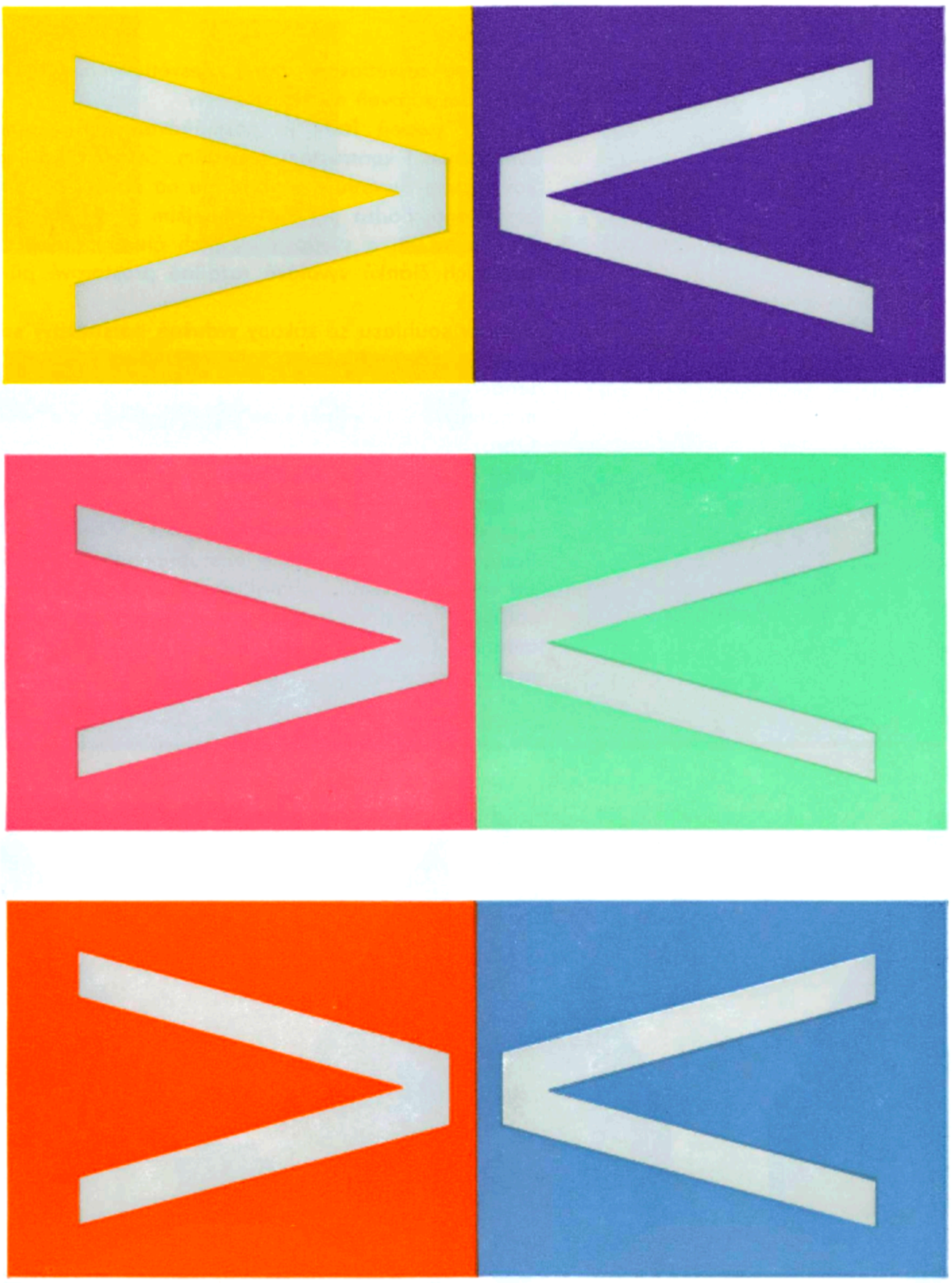
VI B — 1. Degrees of colour saturation while the lightness level remains unchanged

2. The saturation contrast works independently of the lightness contrast. The saturation of the medium green is emphasised by grey, while its saturation is suppressed in a field of saturated green

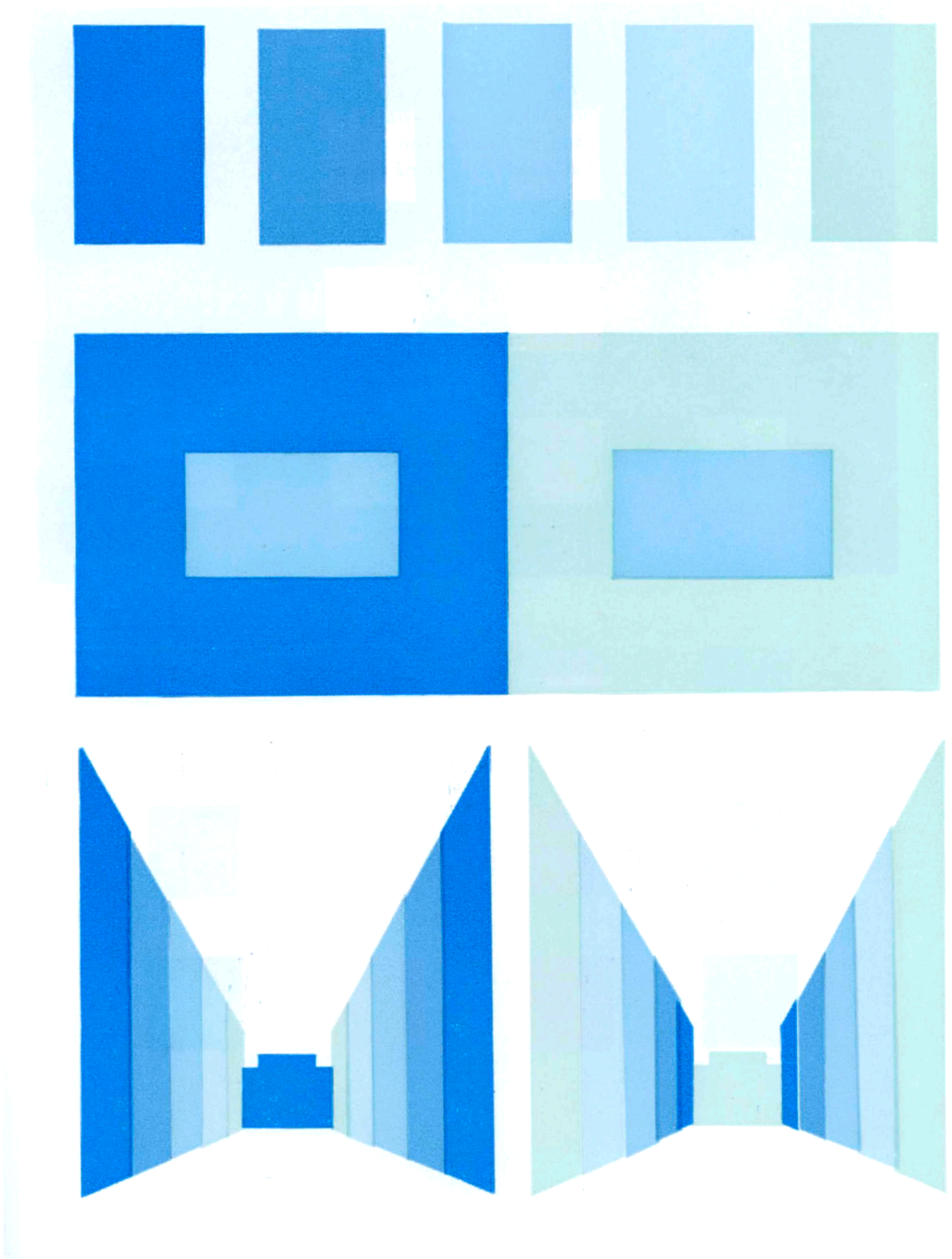
3. The mosaic pattern suggests the effects of contrast on the individual fields in the arrangement



VII – 1. The scale of colour transition from yellow to red (i.e. small differences between the neighbouring members)
2. The middle degree in the sequence is affected by the contrast both in terms of colour and lightness. In a red field, it is pushed towards yellow and lightened; in a yellow field, it is pushed towards red and darkened
3. The skin tone is rendered in the same colour in both images. Its different appearance is caused by the aforementioned contrast in both colour and lightness



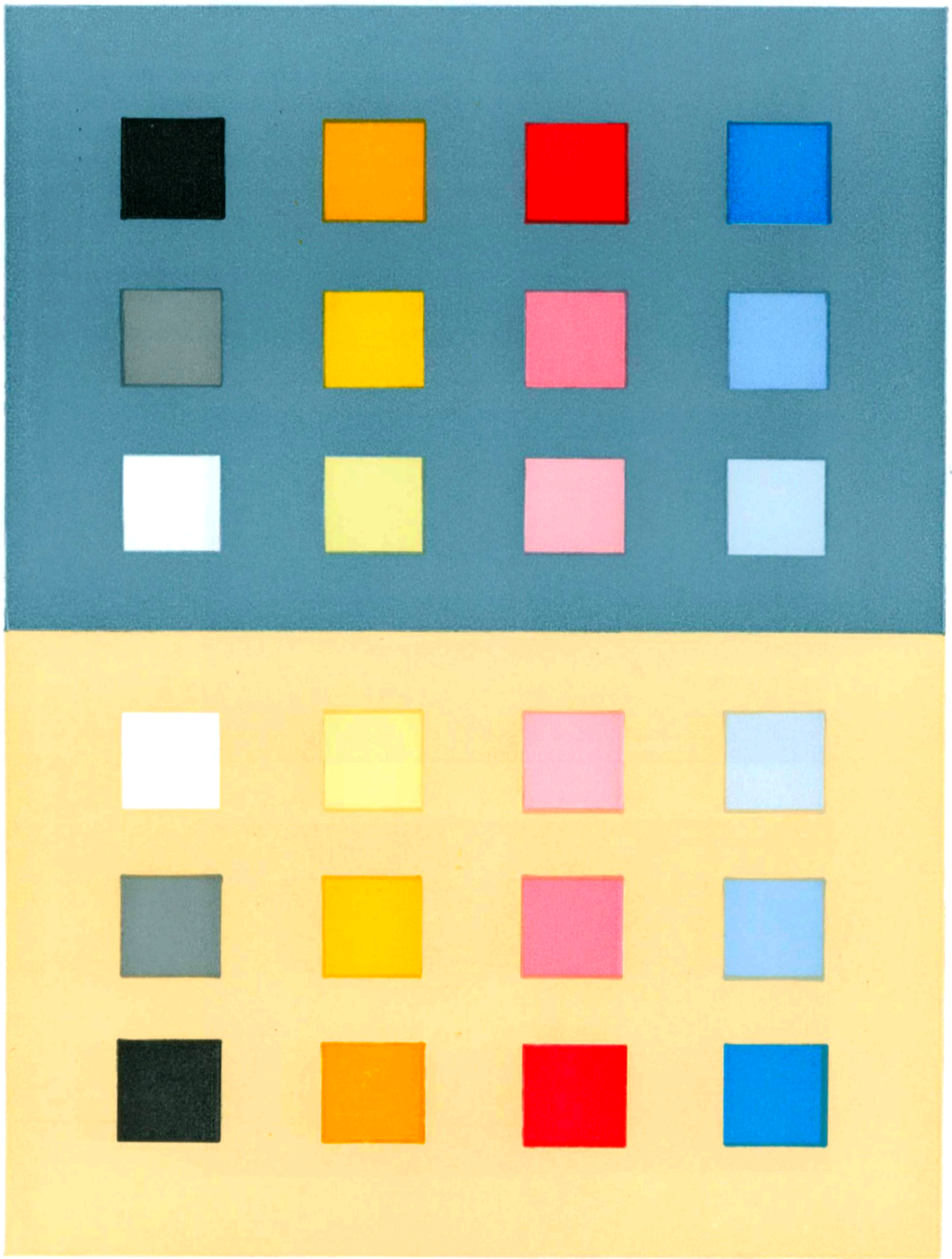
VIII – The V-shaped stripe is rendered in the same grey in all colour fields. However, colour contrast makes it adopt a hint of the colour that is complementary to the background colour



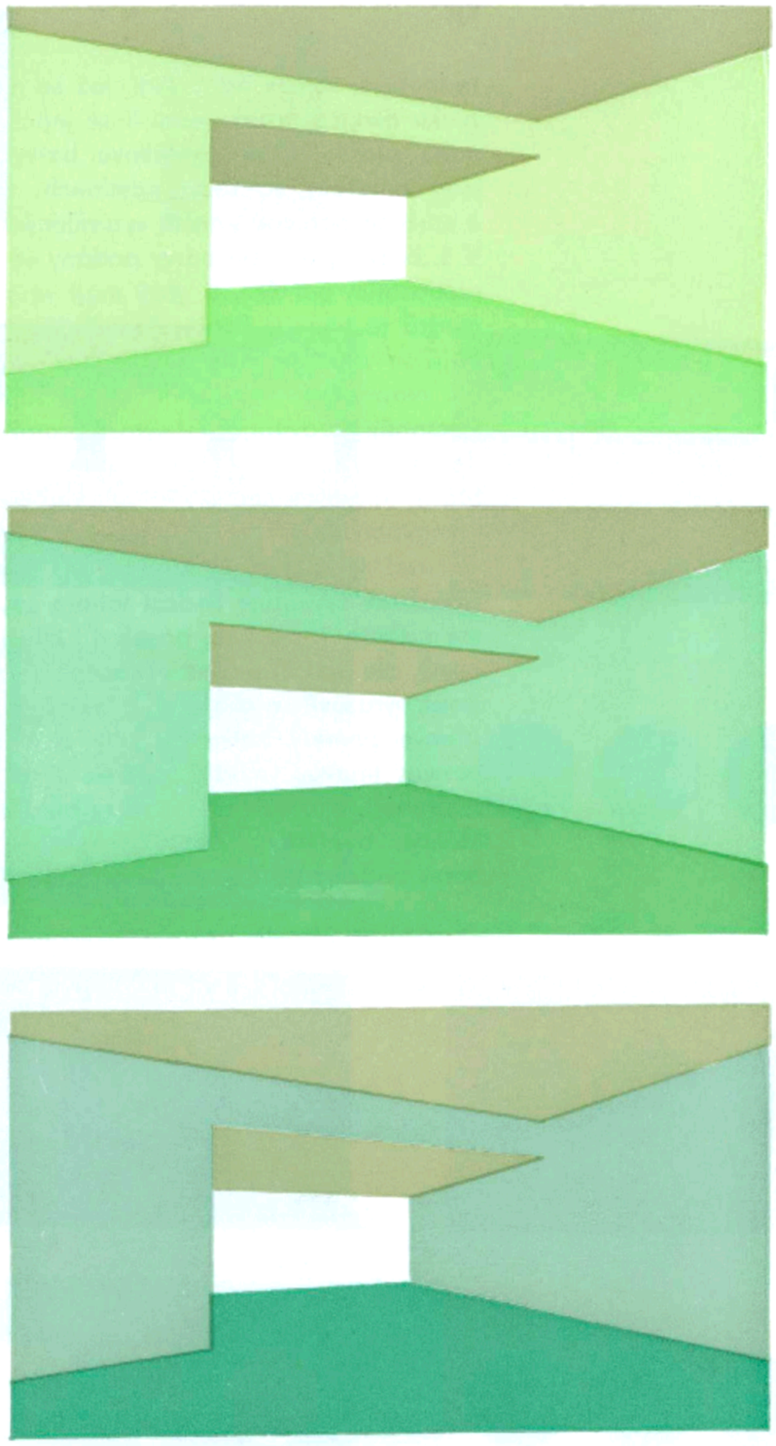
IX – 1. A scale of a lightened colour. Lightening decreases colour saturation of the individual shades at the same time
2. The middle level in the sequence is affected by both lightness and saturation contrast. The saturated blue makes it appear lighter and less saturated by contrast while lightened blue makes it darker and more saturated
3. The changes in saturation and lightness of the extreme parts of the image and of the middle parts create different 3D effects

On the left, in conformity with the laws of aerial perspective, the space appears deeper although the saturated end of the street tends to appear to be in the foreground, which emphasises it as a dominant

A sequence of shades with even differences between one another creates an impressive harmony, if the differences between the individual shades are well chosen. Comparing the two images, we can see how the appearance of the harmony changes when the surface dimensions are swapped



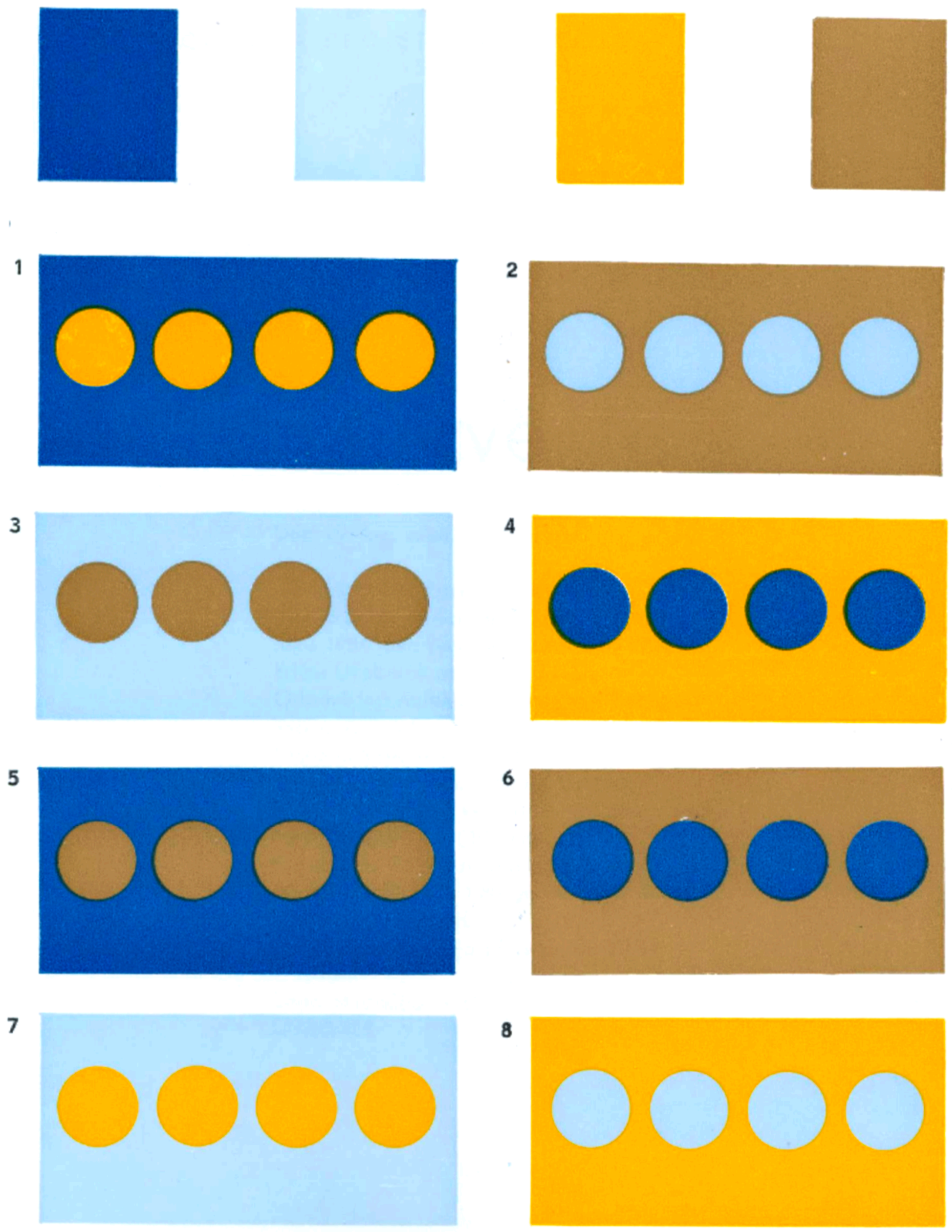
X – Evidence of colours appearing to come forward or recede based on expressiveness. Colours with a heavy difference from their surroundings as to the lightness, as well as more saturated colours seem to come forward in front of the less striking colours



XI – The effect of lightness difference of colours on 3D object perception and representation

The first image from the top is rendered solely through saturation levels of the colour with no differences in lightness. The representation appears flat, colour saturation in itself and any variations therein are incapable of creating a 3D impression. It is also a very soft distinguishing agent

The second image with added lightness differences gives a distinctive hint of 3D arrangements. This distinctiveness increases with increasing differences in lightness in the third image



XII – The individual images illustrate the changes to the appearance of colour pair harmony when the lightness or surface parameters are modified. Both the complementary colours, blue and yellow, are designed in two shades – a dark shade and a light shade with reduced colour saturation as indicated at the top

In the first band, both colours are represented in their natural lightness ratio, i.e. the ratio they have in their saturated state; blue is darker while yellow is lighter. Contrast comes into play in this regard as well, increasing the difference in lightness. It has a more noticeable effect on the yellow which appears shiny and its saturation is emphasised more efficiently because the yellow occupies a tiny area, compared to the blue

If blue were to create a complementary equilibrium with yellow of the same saturation level, it needs roughly twice as much surface than the yellow. The ratio is even higher in this figure; therefore, the hard aspect of the harmony is less disturbing. Let us compare this band to band no. 4 with the same colour ratio while the surface dimensions are swapped

Bands no. 2 and no.3 deliver a different expression; the colour shade parameters are the opposite – the yellow is the dark colour here while the blue is light. These harmonies are more suppressed and more serious than the preceding ones

The pair wherein both colours are rendered with identical lightness (bands nos. 5 to 8) gives a soft, subdued impression.