# WHAT IS COLOUR?

The Goethean approach to a fundamental problem

by

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# AUTHORS PREFACE

Goethe's Theory of Colours was published in 1810. In the eighties it appeared in the Kürschner Edition of Goethe's Works with introductory chapters and annotations by Rudolf Steiner, who was able to characterise and present Goethe's method in a way no one else had done. Nineteenth-century science, however, was set on a different course and Goetheanism in this field had to bide its time. But as modern thought emancipates itself from the naive materialism of last century it will rediscover the soundness of Goethe's approach and the validity of his main argument.

I have based the present essay largely on Goethe's observations of what he calls "physiological colours" and "physical colours" to which I have added several more, particularly on the subject of colour-mixing in which such enormous strides have been made since Goethe's time.

In these, I have tried to apply Goethe's own method. This means in the first place seeking for the "Ur-phenomenon" — Goethe's expression for the ultimate and archetypal phenomenon in each field — the phenomenon which shall be *essential*, *unique* and *indivisible*, *i.e.*, cannot be analysed into constituent phenomena. In the second place, it means avoiding any attempt to "explain" an Ur-phenomenon by means of concepts which go beyond the realm of direct experience. For example, light-waves which we *cannot* experience must never be given as the explanation of colours which we *can* experience. In the third place, it means that where certain important effects can be produced only with a specific experimental set-up, the part played by the apparatus itself in producing the effect must be included in any attempt to formulate the Ur-phenomenon for this particular field.

Finally, it means that where the activity of the observer himself forms part of the effect to be studied sensory and mental processes to the point where they can be included in the "objective" world which he is studying.

I have tried to make the descriptions non-technical and to keep the experimental side within the reach of anyone who is interested in forming from his own direct observation the basic concepts necessary for further study in this field.

Where these simple descriptions need to be further related to present day technical knowledge, I have added short appendix notes.



## PRELUDE

The mountains have emerged from the night fresh and clean in their mantle of deep violet blue, and a liquid light pours across the land calling forth colour as it goes. As the sun climbs and warms the earth, the mountain slopes disclose their form in a play of pink light and purple shadow, while beyond them the distant ranges lie serene and still, cool blue beneath the pale transparent turquoise of the rain-washed sky — a colour changing with infinite smoothness to the deep cobalt overhead. In front of us the wind-swept autumn grass and the dying bracken glow gold and orange-brown in the morning light and even the outcrops of cold grey rock have joined in the scheme of things and show their sunlit faces warm against shadows of soft violet grey. Beyond this the blue of the lake lies back in vivid contrast — a blue embracing all the subtle transitions from clear emerald to deep violet.

We lose ourselves in wonder at the majesty of the perfectly ordered colours and must feel that beauty is not by chance in the world. And yet, we reflect, only yesterday the same landscape was grey — the sky, the mountains, the rocks, the water — all grey with but a hint of dull colour in the grass and bracken. The solid features of the landscape have not changed and the sun gives no more light than yesterday. Where then has this wealth of colour sprung from, and whither will it vanish ? What is the miracle of air and cloud ?

# What Is Colour ?

§ 1

Colour speaks first of all to our feelings. The perception of it is one of the most direct sense impressions that we can have. It needs no interpreter. It creates a mood, gay or grave, riotous or quiet, warm or cold, light or dark. Almost instinctively we contrast the warmth of red colours with the coolness of greens, the lightness of yellow with the depth of blue-violet, the gaiety of orange with the melancholy of blue.

§ 2

Colours lie between Light and Darkness and disappear at both ends of the scale. The landscape is most colourful in morning and evening light. The colours dissolve in the glare of noon and fade away into the blue-grey of twilight.

The intensity or " colouredness " of a colour is not the same thing as the strength of its light. If we hold a yellow glass before our eyes the landscape appears more brilliant and sunny than in its natural white illumination. But the glass has actually darkened the white to yellow. Thus even the lightest of all the colours consists of some darkness as well as light.

§ 3

Our eye must adjust itself to the strength of the surrounding light before it can properly appreciate the colours. If thrown out of balance it will produce its own colours which can be just as brilliant as those outside

A sudden change from a darkened room to brilliant sunshine outside is painful and everything looks pinkish-white. Plunged again into sudden darkness we flounder in a kind of greenish blackness.

The following experiment causes the eye to produce its own series of colours. Gaze for some moments at the intersection of the window-bars seen against a very bright hazy white sky towards the sun. Examine the after-effects (*a*) with the eyes shut and covered by something dark, and (*b*) with the eyes open and gazing at a white surface in the shade of the room. In the case of (*a*) the first impression is a positive echo or after-image, *i.e.*, dark bars and light spaces. These spaces are pale cobalt for the first few seconds, changing rapidly to a strong and slightly yellowish green. Slowly the green becomes dull and more olive, eventually changing to a deep purple. At the same time the dark bars become greenish, and *lighter* than the spaces. The image has now changed from positive to negative, and we are left with purple spaces and light green bars. The purple may become more bluish as it fades away. In (*b*) the after-image is negative from the first moment and is seen as deep violet-grey spaces and light or possibly yellowish bars. The spaces change slowly from violet-grey through emerald green, dull yellow-green, salmon-pink to dull rose-pink, while the bars tend to show something of the opposite colour to the spaces. The final pattern of pink spaces and green bars corresponds exactly to the final stage of (*a*). In both series the image may tend to become lost but can be revived again by opening or shutting the eyes once or twice. Individuals vary somewhat in the colours and changes which they see, but the above description is certainly common to a number of observers.

The polarity of the colours is much more evident when the eyes are open and looking at a neutral surface, but it is at all times the dominating feature of the whole sequence of impressions. Thus we see that the eye is



not a mere passive receiver of external impressions but in its resonance to the stimulation of light it will produce colours in its own rhythm.

## § 4

The eye perceives light and colour very largely in terms of differences and contrasts. Every colour has its own opposite or "complementary" colour.

A simple and well-known observation illustrates this. Gaze fixedly for some moments at a small patch of bright colour against a dark or neutral background and then switch the gaze to a plain surface of light grey or white in subdued illumination. In a few seconds the complementary after-image will be seen, corresponding exactly in shape to the original coloured object. A red or yellow object will produce the effect most readily. Thus a red geranium or poppy will give a brilliant blue-green after-image, a marigold or buttercup will give a blue or blue-violet image.

The quality of these after-images is quite different from our ordinary perception of objects. It is as if the images were made of a substance of light and colour which is quite unmaterial.

This experiment calls our attention to a remarkable fact that is mostly overlooked. We are not aware of the images upon the retina of our eye where the effect undoubtedly originates, but we appear to be able to project them into space where they become strikingly visible on any suitable surface. The further away the surface is from us the larger the area covered by the image. If we think carefully about this phenomenon, we are led to the conclusion that in our normal process of seeing we are continually doing the same thing — fitting images (in perspective of course) on to the objects we are looking at. Normally these images have no more duration than our attention demands, and only when the impression of light or colour is very strong does the optical image leave its mark on the retina and appear in our vision for a short time afterwards unattached to the object which gave rise to it.

§ 5

A preliminary study of these after-images can be made with very simple means. It is only necessary to have a number of strongly coloured sheets of paper or material, some of black, white and one or two neutral greys. These should be cut into a small piece and a large one — the small one as a "stimulating colour" and the larger one for a background.

It is best to start by gazing at a small piece of strong colour against a black background. The after-image can then be seen comfortably on a white or light grey sheet.

The black background of the stimulating colour should then be replaced by a grey or even a white one, and the observations repeated. It will now be found that whereas with the black background the after-images were always darker than their surrounding, with the light background they are mostly lighter, and with the white background they are invariably lighter. What is surprising is that the apparent change in lightness or darkness does not alter the *intensity* of the colour.

If we repeat the experiment using a white patch on a black background we find that the after-image gives us a dark patch on a light ground, and vice versa.

If we now produce the after-image of white and black on to a *black* surface, we find that although the effect may not be so pronounced as before, there is no doubt that the after-image of black, seen on a black surface, is definitely lighter than the surrounding black. In other words, the eye appears to be able to create light where no light was before.

An equally instructive variation of this experiment



is to take a small *grey* patch as a stimulating colour against a strongly coloured background, red for instance. The grey being neutral in character both as regards colour and light-dark, we should expect its after-image to be an equally neutral grey in all circumstances, though the after-image of the red background will of course be blue-green. But the after-image of the grey actually appears bright orange-pink against a background of soft blue-green. If we use a green background to the grey patch the after-image will be a light green patch against a light magenta-pink ground. We can only describe this effect by saying that our whole standard of colour-perception becomes shifted, although we are *concentrating* on a patch of *neutral* colour.

If we reverse the experiment and put a small patch of bright colour on a grey background, the after-image appears as a small patch of the complementary colour against a *neutral* background. This shows that our standard of judgment is influenced by whichever colour preponderates. We shall come back to this point in section 26.

Other forms of this experiment can be devised whereby the after-images can be accurately matched and recorded in relation to any given surroundings and in every case the tendency of the eye to record differences rather than absolute values is outstanding.

A noticeable feature of these colours, called by Goethe "physiological colours" is that the strongest ones are in the green-blue region, and the weakest in the red-orange, whereas in physical colours the reds are the strongest and the green-blues the weakest.

From these observations we see that the eye is always active in relation to its surroundings, and perceives according to the "position" it has taken up between the polarities of light-dark, of warm-cold and of "*colour and no colour.*"

Now let us turn our attention to the way in which colours appear and disappear in our surroundings.

The colours which go to make up our ordinary surroundings are broadly speaking of two kinds. Those which are permanent characteristics of material surfaces, and those which only appear when light interpenetrates with matter in certain conditions. With the former kind we shall not deal in this essay, while to the latter belong the colours of the atmosphere, the rainbow and other haloes, the colours seen in fine cracks of crystals or glass and in fine scratches, and those which appear on very thin films of transparent substance such as oil on water, soap bubbles, etc. Goethe calls these "physical colours." The most common appearance of these colours is where the plain colourless undifferentiated light of day becomes modified through the particular way in which it strikes and mingles with matter. Although it may seem a commonplace assertion it is none the less important to note that light can only give birth to these colours by becoming itself darkened in the process, and moreover this darkening can only be achieved by the influence of matter in some form. We cannot get away from the fact that the colours which we see by ordinary daylight are the result of this light becoming darkened through the influence of matter, and in this way they are quite properly described as the result of the intermingling of light and darkness.

§ 7

This brings us to the next observation which is the "Ur-phenomenon" of Goethe's Colour Theory.

Light seen through a partially transparent medium appears yellowish; darkness seen through such a medium *illuminated*, appears bluish. (Goethe uses the expression "trübes Mittel" for this kind of medium through which objects can be seen sharply but in which at the same time part of the light is simply



scattered, giving the whole medium a cloudy or opalescent effect.)

The archetypal instance of this phenomenon is without doubt the colours of the sun and the sky. Whenever we see the sun shining through a more or less clear atmosphere the colour of its disc has at least a tendency towards yellow, whereas the sky seen away from the sun is always bluish. A moment's consideration is enough to become convinced that the yellow represents a degree of darkening of the sun's white light whereas the blue of the sky occurs where the darkness of outer space is seen through the illuminated atmosphere. When the sun is directly overhead, the darkening influence of the atmosphere is least and the sun's light is fairly white, but around sunrise and sunset its light has to penetrate a much greater thickness of atmosphere and accordingly becomes anything from golden yellow to deep red. When the atmosphere is dry and clear, it puts but little illumination between the darkness of outer space and ourselves, and the sky appears dark — almost violet-blue. At very great altitudes it can appear almost black. As the atmosphere becomes more loaded with moisture and dust particles, so the colour of the sky changes from deep blue through turquoise to pale emerald and eventually to white. This kind of graduation is always to be seen from the zenith to the horizon.

The colours of the landscape change in the same order. The shadows and the deeper colours become filled with a luminous blue with increasing distance, and the exteme highlights tend to become slightly yellower, though this only becomes really noticeable where the intervening atmosphere is not itself illuminated, as for instance in the shadow of a high mountain.

The same tendency for colours to be born in the opposites of blue and yellow can be seen in the case of dry wood-smoke or cigarette smoke seen alternatively against the light or against a dark background. Water made slightly cloudy with soap or gum tincture shows the same tendencies, though these colours never reach the same intensity as do the colours of the sun and sky.

In all the foregoing instances, if the matter which is suspended in the air or the water exceeds a certain degree of coarseness the colours disappear and a grey obscurity takes their place.

§ 8

Quite a different way of making black and white produce blue and yellow is to take a disc which is half black and half white and rotate it just fast enough to prevent the eye from following the alternations exactly but not fast enough to make them merge into a grey. It is usually possible to find critical speeds which will produce primrose and violet, or amber and blue.

§ 9

If we look obliquely through the surface of still water at an object lying under the water, or if we simply look at the object through a wedge-shaped piece of glass or crystal (*i.e.*, one whose front and back surfaces make an appreciable angle with one another) we find that in one direction the edges of the object are no longer sharply defined but have changed into narrow bands of bright colour. It is very noticeable that the colours only appear where there is a boundary between a lighter and a darker part of the object, and never where there is simply a uniform surface. If we examine the simple boundary between two uniform surfaces of black and white we find that it is replaced either by a band of warm colours which is in the order black, red, yellow, white, or by a band of cool colours in the order white, turquoise, deep blue, black, the order depending on the relative positions of the black and white. The contrast between the band of warm yellowish colours and the band of cool bluish colours is an essential characteristic of this phenomenon.



The naked eye will show us the same colours if we half-close our eyes and look at, say, the window-bars out of the extremity of our eye by throwing the head back or forward as far as we can. If we look at a printed page through the edge of a common magnifying glass we shall see the letters fringed with the same blue and yellow.

A simple and very effective way of studying these colours further is by means of a triangular glass prism with sides making an angle of 60 deg. Alternatively a vessel of the same shape can be made of sheets of glass bound together at the edges, the vessel being then filled with water.

§ 10

## THE PRISMATIC COLOURS

In the following descriptions it will be assumed for the sake of convenience that the prism be held in front of the eyes with one 60 deg. edge pointing downwards, and the line of sight passing through the two inclined faces (*i.e.*, the axis of the prism horizontal and at right angles to the line of sight).

At once we notice two things: one is that the edges of all the objects we see appear fringed with brilliant colours, and the other is that the objects appear a long way below where we would expect to see them. If we trace out roughly the path which our looking must take in order to reach the object we are seeing, we have to conclude that our looking is bent upwards through rather less than half a right angle in passing through the prism.

We now take a piece of white paper and lay a piece of black paper upon it (a sloping desk or board is convenient for this) and then look down through the prism so that we can see one of the black-white boundaries. The prism must be held so that its axis is parallel to the black-white boundary. If white is above and black is below we shall see the boundary as a brilliant band of colour with turquoise next to the white and deep blue-violet next to the black. The transition between these colours is deep pure blue. If we reverse the positions of the papers so as to have black above and white below, we find that the band of colours has brilliant red next to the black, and pure yellow below it and next to the white. The transition between these two colours is orange.

Remembering the pairs of complementary opposite colours which we established through the study of coloured after-images, we soon see that the two bands of colour belonging to the two opposite boundaries are complementary to one another in every way: Black opposite to white, violet to yellow, blue to orange, turquoise to red and finally, white to black. The exact oppositeness of these two bands is perhaps the most important thing we can observe at this stage.

We now take a second piece of black paper and lay it upon the white piece near to the boundary we have been looking at, so as to leave a strip of white between two boundaries of black. We shall of course see both the coloured fringes at the same time, separated by an area of white. By moving one of the black papers slowly towards the other we make the yellow of the top band approach the turquoise of the lower band. When the yellow and the turquoise just meet there is of course no white left at that point, and if the two bands approach further, then to the extent to which the yellow and the turquoise can be seen to overlap, *green* appears for the first time. This green will be seen to be always darker than either the yellow or the turquoise which have overlapped to produce it. We must therefore say that these two colours have *darkened* one another and in doing so have produced the new colour, green. Now we arrange the papers in the opposite way, taking two pieces of white and letting them approach one another over a black sheet. This time the order of colours from



top to bottom will be white, turquoise, blue-violet, black (the intervening area) then black, red, yellow, white. By making the two white papers approach one another over the black, we see that the colours which will meet first will be blue-violet above, and red below. This time it is the black that must disappear before the violet and red can meet, and when they do so the new colour that is formed is a luminous magenta pink (called by Goethe sometimes "Purpur" and sometimes "peach-blossom"). There is no doubt that this new magenta colour is *lighter* than either the blue-violet or the red which have overlapped to produce it. We must therefore say that the blue-violet and the red have *lightened* one another and in thus combining have produced magenta.

We now repeat these last two experiments but this time making the boundaries approach until they actually meet. In the first case where the dark boundaries meet over the white we see that after the green has appeared and grown to full strength, no new colour is formed but we are left with a band consisting in the main of red, green and blue which grows darker all over until it finally disappears into blackness. In the second case we bring the two white boundaries together over the black, and after the magenta has been formed no further colour appears but the band which now consists of yellow, magenta, and turquoise grows lighter and paler all over until it finally dissolves into the surrounding white. It is important to remember that the green is formed by a darkening process which ends in blackness whereas the magenta is formed by a lightening process which ends in whiteness.

## § 11

We shall see later on how essential it is to draw a sharp distinction between the mixing of colours by *darkening* and the mixing of colours by *lightening*. What we have to notice at this point is that the green which was produced by darkening is the exact complementary of the magenta which was produced by lightening. Adding these to our list of complementary pairs so far obtained, we get black-white, violet-yellow, blue-orange, turquoise-red, green-magenta. Taking these eight colours in order of similarity we have yellow, orange, red, magenta, violet, blue, turquoise, green, and finally, yellow again — a very fair representation of the whole range of our pure colour sensations. Moreover it would be difficult to imagine these colours in greater purity and brilliance than we have seen in these experiments.

## § 12

In Section 7, dealing with the colours of the landscape, we observed two series of colours — those of the sun itself seen through varying degrees of darkness, which could be anything from pale yellow to deep red, and those of the sky — the illuminated atmosphere seen with dark outer space behind it — which could be anything from violet-blue to pale turquoise. These are of course the same two series that we have been studying through the prism. This may well prompt us to ask whether the prismatic colours are related to light and darkness in the same way that the atmospheric colours are.

If we repeat the prismatic observations and allow our imagination the slightest degree of free play, we shall find that the observation that "light seen through darkness appears yellow-red whereas darkness seen through light appears bluish" does provide a very apt description of what we see in the behaviour of the black and white boundaries. Thus we would say that the yellow-red fringe represents the darkness being spread out over the light, and the blue fringe the light being spread out over the darkness. As the two bands approach,



in the one case the yellow creeps over the turquoise like a transparent film, darkening it to green, whereas in the other case the violet shimmer which seems to float out over the black, spreads like a film of light over the red, lightening it to magenta.

It is moreover very evident that the colours cannot appear out of the white only, but owe their existence to the presence of darkness as well. Whichever way we move the papers or the prism we can never separate the colours from a boundary of light-dark.

These experiments can be varied to an almost unlimited extent by using grey and coloured papers in addition to black and white. Though some of the effects are unexpected, the underlying principles hold good in every case.

We have now seen how the whole range of brilliant colours is produced prismatically out of the simple boundaries of black and white, and that the various colours are produced in characteristically different ways. Thus if yellow represents the first darkening of the light, then red is the final battle of the light to pierce through the increasing darkness. Similarly the deep violet represents the first shimmer of light which dispels the blackness, and turquoise the last vestige of colour as the darkness is finally filled up with light. The warm and cold bands of colour represent the birth of colour out of light and darkness. Green is where the two opposite bands balance one another in darkening the intervening light, whereas the magenta-pink can only occur where the two bands meet in the opposite sense and lighten the intervening darkness. It is remarkable how far these characteristics remain true of the colours in the way they appear in Nature.

## § 13

So far we have been dealing with prismatic appearances which exist only in that we see them through the present when we look for them. By now using a simple projection lantern we can project all these prismatic appearances on to a screen where they will have a more objective character. The black and white papers are now replaced by cardboard or thin sheet metal masks which are inserted in the place of the usual lantern slide or film strip, and one or more prisms are placed immediately in front of the objective lens so that the image is projected out towards one side of the lantern instead of straight in front. The illuminated parts of the screen correspond to the white paper of the previous experiments and when the opaque masks are inserted they produce a black image on the screen which corresponds to the previous black paper.

It is simple enough to bring the edges of the two masks together so as to narrow the beam of light down to nothing, but for reverse experiment the narrow strip of metal which gives an image of a strip of darkness bounded by light on either side, cannot be caused to vanish away to nothing. The best that can be done is to turn the metal strip slowly round until it stands edgewise in the lantern, when its image on the screen will be reduced to a minimum.

The birth, transformation, and extinction of the colours can be followed exactly as in the previous experiments looking through the prism held in the hand.

## § 14

In this form of experiment there is a strong temptation to consider the darkness as mere absence of light and therefore to attribute the colours to a function of the light itself, leaving the darkness out of account altogether.

Isaac Newton's famous experiment, made in 1666 when he was 23, was of this form. He simply used the light of the sun streaming through a hole in his " window-shuts " and thence through a glass prism. It is easy



enough to understand his conclusion that the prism does no more than separate out the colours which are already contained in the white light, although to-day, if we are quite strict with ourselves, we must admit that this does not really conform to the observable facts.*

We shall return to this point later, and will now follow up the consequences of Newton's conclusion that the colours are already contained in the light.

If the prism really does " analyse the light into its component colours " the next step will naturally be to see how far the process of analysing can be carried, and at what point it will be possible to speak of units of " primary " colour which cannot be analysed further. Newton's method was to let a narrow beam of sunlight pass through a prism and then at a distance of some feet, where the colours of the spectrum thus formed were well spread out, to make one of the colours, red for instance, pass through a second prism in order to see if any further new colours were produced. He found that this did not happen, and he therefore called the separated colours of the spectrum " homogeneal lights " *i.e.*, lights in which no differences of colour could be further brought about. He also established experimentally that there is an invariable correspondence between the extent to which the light is bent round by the prism, (he called this its refrangibility) and the colour which it exhibits. He found that this correspondence could be most accurately measured by making the initial beam of white light very narrow, and then spreading it out to the greatest extent by means of one or more prisms, and letting it form the coloured image on a screen as far away as practicable.†

This is exactly the principle embodied in the spectroscope in common use to-day, and the idea of " analysis " of the light has taken firm root in the centuries that have elapsed since Newton first arrived at it.

* See Appendix I    † See Appendix II

From the point of view of our study of colour, this has had three consequences which are of the utmost importance. These are:

1. The exact correspondence between the *positions* of the variously coloured lights within the spectrum and their actual *colours* gives us no clue whatever to the natures of different colours as such.

2. For the purpose of identifying the exact constitution of a light it is found to be much more satisfactory to measure the amounts of light corresponding to all the different wavelengths within the spectrum band than to describe its colour. Modern spectral-analysis is done by means of ordinary black-and-white photographs which record the position and intensity of the spectrum lines and bands without any reference to their colour.

3. This method of analysis which is so extensively used to-day in industrial research gives us much exact and valuable information about identities and quantities of *matter* but practically no information at all *about colour as such.*

In other words, by analysing the light in this way we are led not to the origin of *colour*, but to properties of *matter*. To-day this fact is being increasingly recognised, but only when the myth that "the spectrum is the origin of colour" has been thoroughly exploded shall we feel free to look for the laws of colour in a direction where they are to be found. Had Newton been prepared to show in all his experiments that if light and darkness are interchanged then every colour produced changes to its complementary, this fallacy about the origins of colour might not have misled us for so long.



§ 15

One simple experiment* may serve to illustrate this point. Consider the fact that for the kind of accurate measurement described above, three conditions are essential in the setting up of the apparatus. One is that the edges of the slit through which the light enters the instrument shall be parallel to one another. Another is that the width of the slit, *i.e.*, the width of the beam of light to be analysed, shall be the very least that is consistent with adaquate visibility. The third is that the refracting angle or edge of the prism shall be rigidly parallel to the edges of the slit.

The experiment consists in simply exchanging these three extremely rigid conditions for the maximum of irregularity and mobility. Instead of a narrow parallel slit an open and highly irregular aperture is used, such as a much thickened letter E or W for instance, and instead of keeping this aperture in a fixed relation to the prism or prisms, it is steadily rotated. The resulting spectrum is projected on to a screen using the method of projection already described. The effect is surprising. The two-dimensional figure of the cut-out aperture now appears as a three dimensional figure rotating in space, the third or "depth" dimension consisting of the red-yellow colour band on one side of the figure, and the violet-turquoise band on the other side. Where the projecting or re-entrant limbs of the figure are thin, the colours of one side of the figure will appear to be seen through the colours of the other side, the result of this overlapping being green in the one case and magenta in the other. The colours present themselves in a most definite spatial relation to the light within the figure and to the darkness without, and as the sides of the figure present alternately their inner and outer faces with each

*** For the idea of this I am indebted to Mr. F. H. Julius, of The Free School, The Hague, Holland.**

revolution, so do the colours change to their complementaries and back again. The whole drama of the formation and transformation of the prismatic colours presents itself in one single moving scene, and even if the appearance of colour-space be considered by some to be a mere illusion, the fact that this is the language in which the experiment speaks immediately to every unbiased observer is not likely to be disputed by anyone who has witnessed the experiment.

Thus by the removal of the usual arbitrarily imposed and rigid conditions the phenomenon of the prismatic colours is allowed to show itself in its true stature.

## § 16

## THE RAINBOW

The order and manner in which the prismatic colours appear is a basic phenomenon which underlies many manifestations of colour, and the rainbow gives us this phenomenon in its most natural form.

The following may help in understanding the physical aspect of its formation. If I go out early on a fine morning when the dew is still on the grass, I shall find if I face my own shadow that some of the dewdrops to my left and right reflect the sun's light in bright sparkling colours which change rapidly or disappear as I move. I shall find that the colours only appear in the directions which make an angle of about 42 degrees with the direction of the shadow of my head. If I look carefully at such a dew-drop and move my head slightly I find that the colours change through the range of the rainbow. The dew-drop appears to be acting both as a prism and a mirror. I now look for the boundaries of light and dark which must be there if these colours are produced, and I see that these can only be the



boundaries of the sun's disc itself. Since these are neither parallel nor very close together (the sun's disc has an appreciable width) I am not surprised that the colours of the rainbow are lighter and softer than the brightest colours of the prismatic experiments. As soon as I have grasped the fact that there is an invariable relationship between the colour which I see and the direction in which I see it (*i.e.*, the angle between the direction of the colour and the direction of my own shadow) I then ask myself where the other points lie all of which make the same angle with my shadow, and I soon see that they must lie on a circle with the shadow of my head as the centre of it. This means that wherever the drops of water may be situated, whether on the grass or falling through the air, the places where they can reflect any particular colour for me can only be a circle around the shadow of my own head. Therefore, although the drops of water may be falling through the air at a considerable speed, as in a breaking rain-cloud, the position of the colours is determined only by my own position in relation to the sun — in other words by the direction of my own shadow. If I move, the rainbow moves exactly as I do. Anyone who has watched a rainbow against a dark hillside seen from a moving train at a distance of a few hundred yards will have been struck at the way he takes the rainbow with him. It is, therefore, a universal truth that each person sees only his own individual rainbow.

The fact that the position in which I see the rainbow is completely independent of the actual position of the drops of water although of course dependent on their presence, brings me to the conclusion that in looking at the rainbow I am really seeing an image of the sun's disc transformed into a circle of colours by the magical properties of the surface of a drop of water. Though the rainbow mostly appears as an arc of a circle, from a mountain top one can sometimes see the complete circle.

## § 17

So far we have dealt with phenomena which appear to depend on a simple relationship of boundaries of light and darkness. There are others° which are based on a rythmical series of light-dark alternations and which present characteristic series of colours such as we see in soap-bubbles, in oil on the surface of water, in thin fissures of glass and crystals and also in the multiple rainbows which sometimes appear at the inner edge of the ordinary rainbow.

These light-dark alternations appear as ripples within the light itself, and seem to be an expression of the natural elasticity of the light when it is made to pass through exceeding small spaces between material surfaces. The exact size of these spaces (*i.e.*, width of fissure, thickness of film, size of raindrops, etc.) determines the spacing of the colour-series which may begin with dull yellow and violet or with a more complete spectrum and after a few alternations fades out in several ripples of pink and green. These last two colours are the ones most frequently seen.

## § 18

## THE MIXING OF COLOURS

The apparently naive statement made in Section 2, that Colours lie between Light and Darkness has some important consequences. We must be able to regard colour either as a Lightening of the Darkness or as a Darkening of the Light. Both processes are ones which we can easily bring about and control.

If I go into a completely dark room and then switch on an electic torch, I am lightening the darkness. If I now switch on a second torch, I am adding the light of the second one to that of the first, and no matter what

° Known as Diffraction, Interference, and Polarisation.



the brightness or colour of the second one, it can have no other effect than to make the room lighter than it was before. Under no circumstances can the second torch darken the effect of the first one. If I start again, but this time cover the one torch with a piece of red glass and the other with a piece of blue glass, then the effect of switching on the first one will be to illuminate the room with red light, and when I switch on the blue one I am adding its blue light to the red light that is already in the room. If the two torches are lighting the same part of the room, a patch of white ceiling for instance, then the result of the two lights will be a magenta-pink light that is lighter than either the red light or the blue light separately. If I now start again, this time without the coloured glasses, and simply switch on one torch, then the ceiling will be illuminated with whitish light. Now I put the red glass over the lighted torch, and my action in doing so is to darken the light of the torch from white to red. Whatever material I may put over the lighted torch, it cannot possibly have any other effect than to darken to some extent the light that is already there. If I now put the blue glass over the red lighted torch, I must of course darken its light still further. I am in fact adding the darkening effect of the blue glass to the darkening effect of the red. If the the red and blue are both full intense colours then the result of the combined darkening effects of both will be almost complete darkness. In the first case the red and blue colours combined as *lights* and produced a bright magenta-pink. In the second case the same two colours combined as *darkness* and produced blackness, or at most a very dark dim red. If I now repeat the whole experiment with a yellow glass and a turquoise-blue glass (or a piece of dyed gelatine) a very different thing happens. When I add the yellow light to the turquoise light the result will probably be a rather cool whitish light. But if I put both glasses over the same torch the result will be a strong intense green.

The lack of sharp distinction between these two processes is responsible for more confusion in the teaching of the science of colour than all the other difficulties added together.

§ 19

There is yet a third possibility — one which is often misunderstood. For this we return to the black and white rotating disc described in Section 8, and now cause it to rotate so rapidly (a small electric motor is best for this) that we can no longer distinguish the white half and the black half but see instead a disc which appears light grey all over. This grey is manifestly darker than the white paper and lighter than the black. It is as though the blackness and whiteness had been mixed up and then shared out evenly over the whole area of the disc. We evidently cannot speak of a lightening process alone or of a darkening process alone because we see both happening. A better description would be an " averaging " (though investigation shows that this is not an ordinary arithmetical average, but one that goes by multiplication rather than addition). At all events, it is clear that if we are looking at one place on the revolving disc we hold the succeeding impressions of white and black for longer than it takes for the black paper to take the place of the white, and in this way the alternating impressions seem to accumulate within our eye.

Next we replace the black and white papers by intense blue and red ones. (Papers in the form of a circular disc with a small hole in the centre for the motor spindle, and with one cut made radially from the hole to the circumference enable several such discs to be interleaved so as to show varying amounts of each disc.) When rotated the result is a brilliant magenta-purple which in depth of tone lies between the original blue and red.



The same experiment with a yellow disc and a turquoise-blue disc fails to produce anything like a real green, and only gives a pale greenish grey. Again in this case the depth of tone of the resulting colour lies between the tones of the two original colours. From these observations it becomes clear that this combining of two colours to produce a new one is similar to the *lightening* process as far as the *hue* of the new colour is concerned, but as far as lightness or darkness (depth of tone) is concerned, the result is more like an *averaging* of the two original tones. What is very definite is that the mixing does not at all resemble the process of *darkening*.

From this it is clear that as long as the disc consists of coloured rather than white sectors, the mixture resulting from rotation can under no circumstances be as light as plain white paper. It is therefore bound to appear either coloured or grey. The confusion which has arisen from the fact that Newton considered this kind of grey to be of the same order as white and merely a darker variety of it, still prevails in some most unexpected quarters.

§ 20

We have now seen that quite different things happen when (*a*) the illuminating powers of colours are mixed and (*b*) the darkening powers of the same colours are mixed. We must now find the pattern on which this takes place.

A convenient way of doing this is to obtain a set of small pieces of coloured celluloid or gelatine such as are made for use in stage-lighting. These are available in most of the intense or saturated colours (sometimes called Full Colours) we require, and a useful selection consists of Yellow, Orange, Red, Magenta, Violet, Deep Blue, Prussian Blue (if obtainable), Turquoise Blue, Green, and Yellow-Green. If we look at the light through such a piece of coloured gelatine it is evident that the colour we see is the result of a darkening of the light by means of the gelatine. If we hold a second piece behind the first one, we shall be adding the darkening power of the one to the darkening power of the other. The result will be *mixture by darkening*. We can therefore find out at once which colours are capable of producing new colours by being darkened, and which will merely be darkened without producing a new colour. We soon discover that there are three chief colours out of which no new full colours can be produced, and that they are Red, Deep Blue, and Pure Green. When darkened by other colours or by one another they only change towards black. On the other hand we find another set of three, each of which is capable of being darkened in two directions with the formation of two new full colours. These are :

Yellow, which can be darkened as far as full green in one direction and through orange to full red in the other.

Magenta, which can be darkened to a full red in one direction and to a deep blue in the other.

Turquoise (now known as Cyan in this connection) which can be darkened to either a full green or a full deep blue.

The colours which lie in between can always be darkened to a full colour in one direction and only to a degraded colour in the other. Thus :

Orange can be darkened to a full pure red, but only to a dull olive green.

Purple can be darkened to a full pure blue, but only to a deep dull red.

All the colours between Deep Blue and Leaf Green can be darkened to blue and green in varying proportions as one would expect, for we always describe these colours as greenish blues or bluish greens. The only one which can produce both a full blue *and* a full green is the brilliant turquoise.

Greens which begin to have a yellowish



character can be darkened either to a pure green or to a dull brownish red. The red propensity increases as the colour approaches a full yellow.

Thus there are three lighter colours each of which can produce two other full colours, and which cannot be produced by a darkening mixture of any other two. With respect to the *darkening* process therefore, they must count as primary colours or rather as primary paints or dyes. These are Yellow, Magenta, and Turquoise.

§ 21

For investigating the *lightening* process two enclosed lanterns or projectors are needed, which are capable of throwing a bright and very even patch of light on a white wall or screen. The colours are then tested by holding or fixing one colour over the opening of one lantern, and the other colour over the other lantern and letting them both illuminate the same patch of white screen. Here we find that the same two groups of three are the significient colours, but that their characteristics are reversed. The ones that are *primary* in that they cannot be produced by mixing lights of any other colours are Red, Green, and Blue, but it is just these that can, when mixed in pairs, produce the other three, Yellow, Magenta and Turquoise.. (It usually comes as a surprise to see for the first time that Red light and Green light produce Yellow.) As soon as we try to go beyond this and mix any two of the group Yellow — Magenta — Turquoise, we find that we have left the circle of full saturated colours and are producing paler tints which have all the appearance of being diluted with white. If we mix all three primary lights Red — Green — Blue in the right proportions we get a colourless light which we can justifiably call white.

Out of these two sets of experiments the pattern begins to emerge and it is always a pattern of three. The starting points for the lightening process are Red, Green and Blue, whereas the starting points for the darkening process are Yellow, Magenta and Turquoise. The fact that in either case the three primary colours, taken in varying proportions are between them capable of producing practically every colour sensation is the basis of all such processes as colour-printing, colour photography, colour films and soon, colour-television.

It is however very important to realise that the whole three-colour principle is never more than an approximation which is just good enough to be practically useful, and that the ideal primaries which would be needed to make it a perfect system are colours which simply do not have any physical existence.*

§ 22

One thing needs to be cleared up at this point. It has been taught for generations that for the purpose of painting, the three primary paints are Yellow, Red and Blue, whereas experiment shows that to obtain all colours in full brilliance these must be Yellow, Magenta and Turquoise. The explanation is probably that among the painters' classical and permanent colours, saturated Turquoise and Magenta simply do not exist. The nearest permanent paints are Cobalt or Cyanine Blue on the one hand and Crimson Lake or possibly Rose Madder on the other. These work well enough for the rendering of quiet landscapes, and they can quite reasonably be described as Blue and Red. The colours which must be used for good colour-printing and colour photography however, are very different from what is usually understood by Red and Blue. The loose way in which these terms are used has led to a great deal of confusion.

A simple way of identifying or defining these two sets of Primaries is to return to the prismatic experiments

* See Appendix III



described earlier. The ultimate colours of the spectrum of " light bounded by darkness " are bands of Red, Green, Violet-Blue, and the mean or average colour of each band can be taken as a good standard for the one set. The corresponding spectrum of "darkness bounded by light " consists of bands of Turquoise, Magenta and Yellow, and the mean colours of these three bands are good standards for the other set. From this it will be obvious that the three colours of the one set are complementary to the three of the other set, and that any two colours from one set will always produce one colour of the other set.

The effect of mixing any two complementary colours, however, will be White, Grey or Black, according to whether they are mixed by Lightening, Averaging or Darkening.

§ 23

The two processes of Mixing by Lightening and Mixing by Darkening are usually known as Additive Mixing and Subtractive Mixing though subtraction is not a very accurate description of what happens. This idea of addition and subtraction of colours is the natural consequence of Newton's statement that the prism does no more than separate out the colours which are already contained in the light. His demonstration of the re-combining of the spectral colours into white is convincing only if we are satisfied that the colours are the same thing as the light. Here we are compelled to give an answer to the question " can a colour be present when I actually see that it is absent ? " Newton implied that the colours are all present in the white light, though we do not see them. If we accept this then we must admit of some criterion for the presence of colour *other* than the evidence of our senses. But all other evidence we can produce only indicates the presence of certain *quantities* such as wave-length, or *refrangibility* as Newton called it. The *only* justification for saying that a radiation of wave-length 660 mμ is a red light is the fact that we have always *seen* it to be red. If we discount the evidence of our eyes then the study of colours is meaningless. Modern thinkers are beginning to see loopholes in the Newtonian explanations, but this by itself does not bring us nearer to the real nature of colours.

If we are quite strict we have to admit that colour is a *quality* — a qualitative experience — which is immediate and unique, whereas all the measurements we can make by means of our laboratory technique are only measurements of the physical vehicle of the colour-experience, *i.e.*, the frequency and size of electro-magnetic and chemical disturbances. The *reality* of colour lies only within our immediate experience. Once we can get used to this point of view we can without inconsistency continue to speak of the separation and re-combination of lights or radiations of different wave-lengths, accompanied by the appearance, transformation and disappearance of the colours with all their different and complementary characteristics. We are then free to look for the laws of the behaviour of colours — the Alchemy of Colours — without the materialistic presuppositions which have for so long been a hindrance to the study of the real nature of colour.

Instead of saying "this piece of glass looks yellow *because* it absorbs all the blue and violet of the day-light and transmits only the yellow" we shall say "this glass darkens the white daylight to a brilliant yellow and in so doing robs it of all blue-forming possibility." If to this yellow light we now add blue light from another source we shall not say "yellow light plus blue light makes white light which must therefore contain both the yellow and the blue" but "in adding the two lights together, the blueness of the one, being of opposite quality redeems the yellowness of the other, giving us



the light of both, but no colour." Yellowness and Blueness are more like Debit and Credit, for when we bring them together both disappear. Finally it must be said that the intricacies of colour mixture cannot be learned from theoretical considerations alone. One must live with the colours before one can understand them.

## § 24

There is yet another way of combining colour sensations which is not usually included in the chapter of colour mixing.

A coloured after-image will appear to combine with the colour of the surface on which we are seeing it. This is a very simple experiment which should be tried by anyone who is interested in the problems of colour-mixing and colour-vision.

Using the coloured papers described in Section 5, we place a small scarlet disc on a black background, gaze at it so as to produce a turquoise after-image and now instead of producing the after-image on a grey or white sheet, we produce it on a sheet of strong yellow. We see the after-image as bright green. We can identify the colour of the after-image by placing a small piece of green paper near to it, and we find that it is really saturated green. This combining of turquoise and yellow to produce green is not surprising in itself and at first sight suggests that the mixing is by the darkening (subtractive) process. We put this to the test by using another pair of colours.

We now produce an ultramarine blue after-image by gazing at a yellow disc on a black background. We let the blue after-image appear on a scarlet sheet. If the blue and red combine by darkening we know that they can only produce something approaching black, but to our surprise we see the result is a brilliant magenta-purple, which we can match with a magenta disc next to it. But this colour-change belongs only to the lightening (additive) process! We must therefore find out whether the colours really lighten or darken one another.

It should be a simple matter to decide whether the after-image is lighter or darker than the surrounding coloured sheet on which it appears, but here another factor comes in which we have so far ignored. The black background against which we gazed at the first colour, produces its own after-image which will tend to be whitish, or more simply, light and colourless. Any colour we place on the black background will be lighter than the black, and in consequence the after-image of the colour will appear *darker* than the background on which it appears. We therefore try gazing at the first colour on various backgrounds — white, grey and black — and we find that the coloured after-image can at will be made lighter or darker than its surroundings without altering the purity of its colour.

By this simple method we can test all the colour-combinations we know, and are led to some remarkable conclusions.

1. The colour-change is in no way dependent on the distinction between lightening and darkening which plays such an important part in the mixing of coloured lights and coloured pigments. It seems to transcend this distinction altogether.

2. Conversely the lightening and darkening of the after-image colours can take place without affecting the purity of the hue at all. This again seems to transcend the purely physical laws of colour-mixture.

3. The two mixtures which are the most striking are those that produce intense green and intense magenta. These are two changes that occur



in the prismatic experiments and are the most reliable and effective mixtures in painting and stage lighting respectively.

4. The mixtures which are the *least* effective by this method are:
   (*a*) Green and Red, which will combine to brown but never to yellow.
   (*b*) Turquoise and Magenta, which will combine to a grey-blue but not to a pure saturated blue.

   These are the mixtures which in any three-colour process are the ones most likely to be imperfect.

5. There is really no such thing as the exact specific after-image of one colour by itself. The after-image of the surroundings always plays an important part even when the surroundings are black. It influences the appearance of the after-image as well as the appearance of any neighbouring colour used for matching.

6. A coloured after-image seen on a surface of its own colour (*e.g.*, a green after-image seen on a green surface) gives us a purer and more intense sensation of colour than we can have by any other means.

In face of this evidence we begin to suspect that the behaviour of these non-material colours is both simpler and more magical than that of colours which belong to material substances. We begin to see that the way in which the purely physical colour-changes are tied to the distinction between lightening and darkening is a condition that belongs only to the physical manifestation of the colours, and not to the nature of the colours themselves.

§ 25

It is now necessary to look at another phenomenon which plays a greater part in our perception of colour than we normally realise.*

Taking the small coloured papers used in our after-image experiments we arrange them in order so as to form an approximate colour-circle upon a black or neutral background. Using one of our lanterns in a darkened room we now place a turquoise gelatine sheet in front, thereby darkening the light to a turquoise colour. As we might expect, any redness in any of the paper colours is killed, since the turquoise in the light combines with the colours of the papers in the *darkening* sense, and red is the complementary of turquoise. We know that the yellow papers must darken the turquoise light to green, and that the colour of the green, turquoise and blue papers will be hardly changed at all. What is surprising is that we quickly lose the sense of the turquoise light, and the turquoise papers begin to seem whitish, whereas all the green colours look yellowish. In fact the whole circle seems to consist of blue or violet-blue colours on the one hand and greenish-yellow colours on the other.

If we now replace the turquoise gelatine by a magenta one, the main colours are now blue and yellow-orange. Green has disappeared, magenta looks whitish and red looks orange. With a yellow light the effect is less marked, the colours being red and green, in which the green tends to look bluish and the deep red slightly crimson.

From this we see that where the prevailing light limits the range of possible colours, our seeing tries to expand the limited range so as to make up for the deficiency. Thus when red is absent, as in a turquoise light, our eye seizes on the *difference* between blue and

* Known as Chromatic Adaptation.



green and makes the green more yellow and the blue more violet so as to cover part of the red deficiency.

The same thing happens to a greater or lesser degree with lights of all colours * except pure red, pure green and pure blue which are the three primary lights and exhibit no difference of hue with which the eye can work.

This phenomenon points once more to the way the eye perceives by means of differences and not only by absolute values. Goethe describes it by saying that the eye strives towards Polarity in order to achieve Totality. This again is an Ur-phenomenon of our seeing process.

§ 26

## THE PHENOMENON OF THE COLOURED SHADOWS

For these experiments we need two small lights which can throw fairly sharp shadows, (motor-car or torch bulbs are convenient for small-scale working) some pieces of coloured gelatine or celluloid, a white screen and a vertical rod or pillar for throwing a shadow. (A tall candlestick, a ruler held upright, or a cardboard tube standing on end will serve the purpose.)

We light one lamp and let it throw a shadow of the rod upon the white screen in an otherwise dark room. The shadow is dark and colourless. We then light the second lamp near to the first, and arrange matters so that we get two shadows on the screen with a good distance between them. The first thing we notice is that both shadows are much lighter than the original single shadow was, and it becomes obvious that each lamp is lighting up the shadow thrown by the other. In other words, each shadow is lit by one of the lamps, while the rest of the screen is lit by both lamps.

* not, of course, the " monochromatic " spectrum colours. (See Appendix IV)

Now we take a piece of the coloured gelatine — red for instance — and hold it in front of one of the lamps. Here the surprising thing happens, for one shadow becomes red and the other a very definite light turquoise. The effect is immediate and lasts as long as we look at it. We replace the red gelatine by a deep blue one, and the shadows become blue and yellow. A green gelatine produces green and magenta shadows. It becomes quite evident that the shadow which is thrown by the coloured lamp and which is actually illuminated by the colourless lamp *all the time*, in each case takes on the complementary colour to the coloured light, whereas the shadow thrown by the uncoloured lamp is illuminated only by the coloured lamp and, of course, takes on the full colour of the gelatine. The rest of the screen surrounding the two shadows is illuminated by the coloured light plus the colourless light.

If we can arrange to vary the brightness of the *un*coloured lamp we discover two important things. Firstly, there is always one particular degree of brightness at which the shadow appears most strongly coloured, and this is different for different colours. Secondly, if the colourless light is extinguished altogether, the shadow becomes plain black whatever the colour of the light.

The apparent objectivity of the colour of the shadow is puzzling at first sight, but experiment has always shown that if the observer's field of vision is limited to the shadows *only* and thorough precautions are taken to prevent him seeing any of the coloured light whatsoever, then he sees the shadow always grey, and is unable to tell when the coloured light is changed from one colour to another. The appearance of colour in the shadow is unquestionably due to the appearance of the coloured surroundings, but it is different from the after-images which we have studied in that it is independent of the Time element. The colour appears at once and the effect does not die away.



The key to an understanding of this phenomenon is the careful observation of the surrounding portion of the screen. In every case it is illuminated by coloured light plus white light so that when the coloured light is red for instance, the colour of the shadow is compared not with the pure red surroundings but with a reddish white. As we saw in the foregoing experiments with coloured light (Section 25) this prevailing reddish white becomes the standard which partly takes the place of a true white, and the colourless area within the shadow, being *less red* than the surrounding reddish white, must appear *positively turquoise.*

If we dim down the red light until the shadow from it is only just discernible, we see the prevailing light as colourless and the shadow as pale turquoise. We are aware of the turquoise but *not* of the red. This only happens as long as the area of shadow is small in relation to the area of the surroundings. As soon as the area of shadow becomes the dominant tone and the coloured space smaller and more circumscribed then our colour-judgment holds to the neutrality of the shadow tone rather than that of the surroundings and no colour appears. (Compare Section 5.)

## § 27

A variation of this experiment is useful in giving us further insight into the character of the shadow colours. Instead of using a colourless light for the secondary source, we now make it coloured,* but not complementary to the main source. For example, using red once more for the main source, we make the secondary source yellow. The shadow then appears not turquoise but a full green. If the secondary source be made purple or magenta, the shadow will be blue.

This effect has been described by saying that the

* An alternative method is to use a coloured screen instead of a coloured secondary source. The screen can be opaque or transparent in either form of experiment.

normal colour of the shadow, in this case turquoise — combines with the colour of the secondary source — say yellow — and in this way the green is produced. But in this case the turquoise is never seen, only green appears. It is therefore more correct to say that within the limits of the prevailing yellow light (*i.e.*, absence of blue-possibility) the complementary of red is green, and within the limits of magenta and purple the complementary of red is blue.

If we make the secondary source a strong primary colour such as red, we cannot make the shadow appear any other colour than red. For instance, a yellow main source tends to produce a blue shadow, but with a pure red secondary source there is no appreciable change towards purple in the shadow. Conversely with a blue main source and the same red secondary source, the shadow remains red with no tendency towards orange or yellow.

This introduces a new concept, but a very real one: *complementary in relation to a limited totality*, and brings us to the most important distinguishing factor between the character of the after-images (called by the physicists "successive contrast") and the coloured shadows (called "simultaneous contrast").

The after-images are able to *add* something to the surface on which they appear, whereas the colours of the shadows can only be modified *within* the limits of the colour of the surroundings.

§ 28

From the foregoing experiments certain broad outlines begin to emerge.

1. The Newtonian aspect of the spectrum reveals the relationship of colours to certain definite spatial measurements which we now call *wavelength*. The measurement of the distribution of light through the whole range of wavelengths gives us information about the kind of substance which is either emitting the light in the first instance, or absorbing the light already there, as in the case of transparent material. We can divide the spectrum into as many different wavelengths as we choose to specify, and in the main no wavelength (and therefore no colour) has more significance than any other.



2. The Goethean aspect of the spectrum is essentially twofold in that all colours have a complementary relationship to Light and Darkness. The spectrum does not represent an extreme condition (as does the Newtonian aspect) and is mobile rather than static in that it shows colours born in pairs of opposites and creating a third colour by the meeting of the opposites. This process of transformation gives us two complementary groups of three colours, which are the same as the two sets of primary colours arrived at through the colour-mixing experiments.

   This, therefore, is the realm of the Alchemy of Colours, which always exhibits a system of three.

   (The speculation that the structure of the human retina must also be based on a system of three has occupied scientific minds for a century and a half, but there is still astonishingly little physiological evidence to support it.)

3. Our seeing of the colours, and the reactions of our eye reveal first and foremost the Duality — the Polarity of all colour-experience. Every colour-experience has two equal and opposite aspects in its relation to Light and Darkness, though these are not necessarily visible at the same moment. Goethe characterised these two sides when he described the colours

as being "the Deeds and Sufferings of the Light."

4. This polarity asserts itself increasingly as we learn to separate our experience of colour from our material knowledge of the objects on which the colour appears. This becomes very evident in the study of after-images (which are completely separated from material surfaces) where we see that the *difference* between two colours is preserved although the "degree of colouredness" of the two images tends to find its own equilibrium.

5. The considerable degree of objectivity which can be developed by consistent observation of the colours of after-images and coloured shadows leads us to seek the reality of colour experience, and therefore the nature of colours, on a level which is less circumscribed by material behaviour and measurement than is the usual field of purely physical research.

## § 29

In attempting to approach this realm there are some very simple steps we can take. One of them is an exercise well-known to painters and consists of trying to perceive the actual colour presented to us by different objects and distances in a landscape and by the different facets of an object in the way they take up the colours of surrounding objects.

This can be done by making a small hole (say ½ inch) in a white or light grey card, and holding it at arm's length so that the distant surface in question appears through the hole. Keeping one eye closed, one focusses the other sharply on the hole itself and then imagines that the colour seen through the hole is a patch of paint



on the surface of paper and not a hole at all. It is then possible to judge the colour presented by the distant surface without knowing what object it represents. Another method is to look at the landscape through a steamy window-pane or piece of partially obscured glass. The colours appear somewhat spread and the outlines are lost, and it is much easier to judge the colours of the various patches than those of the objects beyond.

We soon discover that part of our ordinary habitual perception consists of what we are *expecting* to see, and therefore, what we *think* we are seeing. Such preconceptions play a far greater part than we commonly realise and as soon as we begin to free ourselves from them we do in fact perceive far more than we previously thought possible.

This excercise leads us to the next, which is the perception of the way in which the light and the atmosphere interweave in creating and modifying the colours we see. Here a useful excercise is to produce the after-image of a colour upon the original surface which has caused it. If we gaze at a red disc and then shift the centre of our vision slightly to one side of our first fixation point, we are at once aware of the after-image making part of the coloured surface appear degraded in colour, the remainder showing up with unexpected brilliance. In this way we become aware of one colour working over the surface of another as we look normally at any brightly coloured object, and we learn to recognise the different factors which by their interweaving produce the colours we actually see in the landscape.

Another exercise is to make a mental picture of any colour and try to increase its saturation at will, and also to transform it gradually into another colour. Here we learn more about our own individual relationship to the ideas of colour.

A study of the colours of after-images and coloured shadows as already described teaches us not to look on these phenomena of "chromatic adaptation" as failure of our visual mechanism to register correctly the external objective facts, but to see that in our colour-consciousness we ourselves are floating in a sea of light in which we are drawn hither and thither by the manifold currents of colour-experience. It is like a sea of feelings where the colours face us as waves or streams of sympathy and antipathy, of warmth and coolness, of energy and resignation. In such a sea of colour it is evident that the exertion of our own will must have some effect upon our colour-orientation, and anyone who has occupied himself with the perception of these non-physical colours will know that this is indeed the case.

Such study will show us that we are no mere passive receivers of colour impressions but are involved as active beings within a dynamic world of colour. We awaken to perceptions of colour, even on the outward and strictly physical plane, to which we had previously been blind. We begin to recognise the colours as expressions of the manifold interweaving of the creative forces of Light and Darkness and might describe them as follows :

### Whiteness of Light

The experience which comes nearest to the nature of Light which is itself invisible.

### Whiteness of Matter

The purest, lightest and most even appearance which opaque substance can have.

### Yellow

Stands next to whiteness. Has the greatest radiating power and the greatest susceptibility to impurity. As a *Darkness* it has hardening and formative influences and represents the first stage of the darkening of light. Used as a thin transparent wash over a picture it implies a



brighter and more radiant atmosphere. Used as a Light on the stage it accentuates the highlights of a scene both in their form and in their colour. It hardens all other colours into a contrast of red and green. This gives great brilliance.

### Red (Scarlet)

Light is nearly overcome by darkness. Red expresses this battle in its greatest violence. There is maximum energy and maximum obstruction. As a Light it represents violence, wrath, warning. The darkening influence within the light is very strong. It accentuates the forms which it illuminates, and gives maximum contrast between light and dark. It is the most fixed of all colours. A red light shows up no variations of hue. It is the most aggresive colour and produces the strongest after-image.

### Violet-Blue

Stands next to Darkness. It is the most mysterious of all the colours and has the least radiating power. As a Darkness, or a material, it is hard to produce in real purity and has the greatest instability particularly towards the red side. Used as a light on the stage, it has the opposite character to yellow. It wants to fill up the shadows. It appears to creep into them and dissolve them and then take them away, It softens, blends and harmonises the coloured objects upon which it falls.

### Turquoise Blue

Has left the realm of shadow and is no longer mysterious. Darkness has been filled up with quiet cool light and Form has been dissolved away. The infiniteness of sea and sky speaks in these terms. It has endless nuances which are hardly perceptible to the eye. It is the most negative and retiring colour, and produces the feeblest of all after-images.

## GREEN

Is pre-eminently a balance between the activity of yellow and the passivity of turquoise blue. It is produced by the darkening of these two colours. The formlessness of the turquoise is hardened and fixed by the darkening of the yellow. The resulting colour has the character of an *inert surface*. The Earth's green covering expresses this. Green also represents the region in which Life and Growth manifest in elementary form. It is a quality rather than an activity. Green light on the stage is immediately sinister, cruel. Green should normally be a material surface, not a light.

## MAGENTA

Pre-eminently the balance between red and blue, but so that the blue softens, redeems and lightens the fierceness of the red. It represents the result of the lightening process and should be used in its character of bringing light into darkness. Here (as in the spectrum) its character is light and soft and is described by Goethe as "peach-blossom." If used as an extended material surface it is unbearable — over-bacchanalian. Materials dyed with this colour at any depth usually look incredibly vulgar. As a mild source of illumination it can be extremely dignified, intimate and harmonious. It is in every respect the perfect balance of the green of Nature.

## CRIMSON

A difficult colour to describe and to produce. Ideally the colour of deep red roses, also of velvet robes. It is the fire of scarlet tamed and ennobled by the gentle softening influence of blue, but not yet lifted out of the material realm. A deep colour and very apt to be degraded into brown-red.



## BLACK

Not merely the absence of light. A colour whose restraining and strengthening influence on other colours can be very dignified. An idealised black must be invisible in itself. In its very nothingness it becomes a transformation point, a gateway between material and non-material existence.

Its material representative is most commonly carbon (coal, charcoal, lamp-black, black-lead) which can also be the bearer of the greatest light. The diamond is a hard form of carbon, and the carbon arc lamp gives the whitest light that man can produce.

§ 30

# CONCLUSION

The Colours speak a living language. Through them Man can perceive the drama of the world-creative forces of Light and Darkness.

The garments in which the colours appear to Man's physical eyes are found to resemble vibrations. Though the measurement of these can be calculated with accuracy, their real nature still remains a mystery. It has long been the fashion to assume that the vibrations are the cause of the colours. But is this not an arbitrary assumption? Is it not more reasonable to think that the living colours existed before their physical garments — perhaps even created them?

Newton was determined upon a study of these garments, Goethe upon knowing the living colours themselves. Modern technique has enabled Man to make the garments and to conjure up the colours at will. Can he not with modern consciousness learn to meet the living colours in their own realm?

## APPENDIX 1. (§§ 14, 23.)

Where Newton sees the image of the hole elongated and showing colours at the ends with a white space in between, he jumps to the conclusion the tne whole appearance consists of a chain of coloured images which overlap in the centre to an extent that includes all the colours, thus producing white. But the form of the image can *only* be seen where the colours are produced, that is, in immediate juxtaposition to the dark boundaries. We are therefore asked to understand the white as a combination of form and colour neither of which we can, by definition, see.

The falsity of the argument becomes still more patent in the case of the pinhole-camera image. As the hole is made larger we are asked to believe that the resulting unsharpness is really the superposition of a number of images corresponding to the quantity of different "rays" or "pencils" of light passing through the hole. The argument is plausible thus far, but the only possible logical continuation of it is that if we continue widening the pinhole we eventually get not an *image* on the screen, but a plain white space which undergoes no further alteration whatever when the boundaries of the enlarged pinhole are removed altogether leaving nothing but a plain white screen seen by ordinary illumination. If this is to be considered as an infinite number of images of the source of light, then so must everything else in the whole visible world. It is astonishing that we should have swallowed this absurdity for two and a half centuries.

The truer way to describe both experiments is to say that in the one case Colour, and in the other case Form, *only* appear at a boundary of light and darkness. These boundaries must, therefore, be taken into account as an essential part of the phenomenon.

## APPENDIX II. (§ 14.)

When the spectrum band is in this way spread out and seen in dark surroundings, one can readily distinguish more than the three main colours, Red, Green and Blue, and it is customary to use Newton's enumeration of them as Red, Orange, Yellow, Green, Blue, Indigo, Violet. A closer examination of them will convince one that the Yellow is a degraded orange-yellow and not to be compared with the full yellow of the single prismatic fringe. The same applies to the Blue-Green which is now so degraded in comparison to the Turquoise of the single fringe that it is not even named among Newton's seven colours.

This comparison is very striking if the spectrum is made with stepped boundaries which only meet over a portion of their length, beyond which the open fringes can still be seen. Any one whose only acquaintance with the spectrum colours is through a spectroscope should make this observation for himself.

## APPENDIX III. (§ 21.)

The three-colour system is imperfect in that whatever exact colours are chosen for the three primaries, Red, Green, Blue, there are always some hues whose saturation cannot be equalled by mixtures of any of these three. In order to describe such hues in terms of quantities of Red, Green, and Blue primary lights it is necessary to suppose a *negative* quantity of one of them. This is inconvenient and confusing, and therefore three hypothetical primaries have been calculated, called simply X, Y, Z, for which the "tristimulus values" of all known colour sensations are always positive. There are of course no real colours corresponding to X, Y, or Z by themselves, but the system is intended to be no more than a frame of reference, and as such has been accepted internationally since 1931.



## APPENDIX IV. (§§ 22, 25.)

The Turquoise and Yellow of the prismatic fringes or "boundary colours" must not be confused with the blue-green and the yellow regions of the closed spectrum (Newtonian form) (see Appendix II). *All* the colours of this spectrum in its ultimate form are primary or monochromatic in that no further colours can be produced out of them. They therefore represent the last point to which the colours can be darkened towards the realm of number and measure, and should be described as the final skeletons of the colours rather than their point of origin.

In this ultimate form they are not seen in Nature, even in the rainbow. They are, however, increasingly met with in the use of electrical discharge lamps (Mercury, Sodium, Neon) for street lighting and advertising. The spectrum (Newtonian form) of these lights consists for the most part of darkness with a few brilliant lines of light. The modern form of lamp produces this light in great intensity which makes up, as it were, for the greater part of the continuous spectrum which is missing. We can therefore quite accurately describe such lights as containing an overwhelming proportion of darkness in spite of their great brilliance. This darkness shows itself in the fact that these lights are only able to show up a caricature of the real colours of the objects on which they fall. Sodium light for instance, is not able to show up any other colour than yellow, and a very dead kind of yellow at that. A strong red or green object will look dark brown or nearly black.

This concept of *light containing darkness* is difficult to get accustomed to but takes us much further towards understanding the nature of colours.

Finally, it should always be borne in mind that the brilliant colours we see by daylight correspond to at least a quarter of the whole spectrum band (Newtonian form) and in the case of yellow, up to three-quarters.

The proportion of daylight which corresponds to the narrow spectral lines of sodium light is so small that compared to the daylight we would call it darkness.

I. Goethe's Theory of Colour applied.

II. Painting and Imagination.

III. Extracts from Goethe's Scientific Work. (Translation.)
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