AN ACCOUNT

OF SOME

EXPERIMENTS ON COLOURED SHADOWS.

AN ACCOUNT OF SOME EXPERIMENTS ON COLOURED SHADOWS.

WHILE I was employed in the prosecution of my experiments on the intensities of light, I was struck with a very beautiful and what I then considered as a new appearance. Desirous of comparing the intensity of the light of a clear sky, by day, with that of a common wax candle, I darkened my room, and letting the daylight from the north (coming through a hole near the top of the window-shutter) fall at an angle of about 70° upon a sheet of very fine white paper, I placed a burning wax candle in such a position that its rays fell upon the same paper, and, as nearly as I could guess, in the line of reflection of the rays of daylight from without; when, interposing a cylinder of wood, about half an inch in diameter, before the centre of the paper, and at the distance of about two inches from its surface, I was much surprised to find that the two shadows projected by the cylinder upon the paper, instead of being merely shades, *without colour*, as I expected to find them, the one of them — that which, corresponding with the beam of daylight, was illuminated by the candle — was *yellow;* while the other, corresponding to the light of the candle, — and consequently illuminated by the light of the heavens, — was of the most beautiful *blue* that it is possible to imagine.

This appearance, which was not only unexpected, but was really in itself in the highest degree striking and beautiful, I found, upon repeated trials and after varying the experiment in every way I could think of, to be so perfectly permanent that it is absolutely impossible to produce *two shadows* at the same time from the same body, the one answering to a beam of daylight and the other to the light of a candle or lamp, without these shadows being coloured, the one *yellow* and the other *blue*.

The experiment may very easily be made at any time by day, and almost in any place, and even by a person not in the least degree versed in experimental researches. Nothing more is necessary for that purpose than to take a burning candle into a darkened room in the daytime, and open one of the window-shutters a little, about half or three quarters of an inch, for instance; when, the candle being placed upon a table or stand, or given to an assistant to hold, in such a situation that the rays from the candle may meet those of daylight from without at an angle of about 40°, at the surface of a sheet of white paper, held in a proper position to receive them, any solid opaque body, a cylinder, or even a finger held before the paper at the distance of two or three inches, will project two shadows upon the paper, the one blue and the other yellow.

If the candle be brought nearer to the paper, the blue shadow will become of a deeper hue, and the yellow shadow will gradually grow fainter; but, if it be removed farther off, the yellow shadow will become of a deeper colour, and the blue shadow will become fainter; and, the candle remaining stationary in the

same place, the same varieties in the strength of the tints of the coloured shadows may be produced merely by opening the window-shutter a little more or less, and rendering the illumination of the paper by the light from without stronger or weaker. By either of these means the coloured shadows may be made to pass through all the gradations of shade, from the deepest to the lightest, and *vice versa;* and it is not a little amusing to see shadows thus glowing with all the brilliancy of the purest and most intense prismatic colours, then passing suddenly through all the varieties of shade, — preserving in all the most perfect purity of tint, — growing stronger and fainter, and vanishing and returning at command.

With respect to the causes of the colours of these shadows, there is no doubt but they arise from the different qualities of the light by which they are illuminated; but how they are produced does not appear to me so evident.* That the shadow corresponding to

* I ought to inform the reader that when the above was written I had not the smallest recollection of what, many years before, I had read concerning coloured shadows, in Priestley's History of Optics. It may perhaps be thought (by others, as well as by myself) that it was a fortunate circumstance that I had forgotten what I had read; for it left my mind in perfect freedom to pursue, in my own way, the investigation of the causes of the phenomena which presented themselves to my observation, without my being biassed by the opinions of others, who, before me, had attempted to explain them. Had I recollected what others had done, I should not, most probably, have given myself the trouble of engaging in the prosecution of these inquiries.

But although *at the time when this paper was written* I had really no remembrance whatever of what had been written and published before on this subject, yet soon after the paper was finished, and some time before it was sent to England to be laid before the Royal Society, I was, by an accidental circumstance, made to recollect what I had so entirely forgotten. Shall I confess what the motives were which induced me to expose myself to the danger of being thought *ignorant*, or something worse, by suffering my paper to go out of my hands without alteration? When the glow of the sudden blush which I felt on discovering my danger had passed off, and I had taken time to reflect coolly on all the circumstances of the case, I concluded that it might be *useful*

the beam of daylight, which is illuminated by the yellow light of a candle, should be of a yellowish hue, is not surprising; but why is the shadow corresponding to the light of the candle, and which is illuminated by no other light than the apparently white light of the heavens, *blue?* I at first thought that it might arise from the blueness of the sky; but finding that the broad daylight, reflected from the roof of a neighbouring house covered with the whitest new-fallen snow, produced the same blue colour, and if possible of a still more beautiful tint, I was obliged to abandon that opinion.

To ascertain with some degree of precision the *real colour* of the light emitted by a candle, I placed a lighted wax candle, well trimmed, in the open air, at mid-day, at a time when the ground was deeply covered with new-fallen snow, and the heavens were overspread with white clouds; when the flame of the candle, far from being white, as it appears to be when viewed by night, was evidently of a very decided *yellow colour*, not even approaching to whiteness.

The flame of an Argand's lamp, exposed at the same time in the open air, appeared to be of the same yellow hue. But the most striking manner of showing the yellow hue of the light emitted by lamps and candles is by exposing them in the direct rays of a bright meridian sun. In that situation, the flame of an

to permit my paper to go forth into the world in its original state. I conceived that it would show, in a very striking manner, if not the advantages which sometimes result from forgetting what we have read, at least the very great importance of preserving the mind totally unbiassed by the speculative opinions of others when we are in search of truth.

An ardent lover of science will not hesita e to expose himself to *personal danger*, when he perceives that by so doing he has a chance of promoting useful investigation.

Argand's lamp, burning with its greatest brilliancy, appears in the form of a dead yellow semi-transparent smoke. How transcendently pure and inconceivably bright the rays of the sun are, when compared to the light of any of our artificial illuminators, may be gathered from the result of this experiment!

It appearing to me very probable that the *difference in the whiteness of the two kinds of light* which were the subjects of the foregoing experiments might, somehow or other, be the occasion of the *different colours of the shadows*, I attempted to produce the same effects by employing two artificial lights of different colours; and in this I succeeded completely.

In a room previously darkened, the light from two burning wax candles being made to fall upon the white paper at a proper angle in order to form two distinct shadows of the cylinder, these shadows were found not to be in the least coloured; but upon interposing a pane of yellow glass, approaching to a faint orange colour, before one of the candles, one of the shadows immediately became *yellow* and the other *blue*.

When two Argand's lamps were made use of instead of the candles, the result was the same: the shadows were constantly and very deeply coloured, the one yellow approaching to orange, and the other blue approaching to green. I imagined that the greenish cast of this blue colour was owing either to the want of whiteness of the one light, or to the orange hue of the other, which it acquired from the glass.

When equal panes of the same yellow glass were interposed before *both* the lights, the white paper took an orange hue, but the shadows were to all appearance *without the least tinge of colour;* but *two* panes of the

yellow glass being afterwards interposed before *one of the lights*, while only *one* pane remained before the other, the colours of the shadows immediately returned.

The results of these experiments having confirmed my suspicions that the colours of the shadows arose from the *different degrees of whiteness* of the two lights, I now endeavoured, by bringing daylight to be of the same yellow tinge with candlelight, by the interposition of sheets of coloured glass, to prevent the shadows being coloured when daylight and candlelight were together the subjects of the experiment; and in this I succeeded. I was even able to *reverse* the colours of the shadows, by causing the daylight to be of a *deeper yellow* than the candlelight.

In the course of these experiments, I observed that different shades of yellow, given to the daylight, produced very different and often quite unexpected effects: thus one sheet of the yellow glass, interposed before the beam of daylight, changed the yellow shadow to a lively violet colour, and the blue shadow to a light green; two sheets of the same glass nearly destroyed the colours of both the shadows; and three sheets changed the shadow which was originally yellow to blue, and that which was blue to a purplish yellow colour.

When the beam of daylight was made to pass through a sheet of blue glass, the colours of the shadows — the yellow as well as the blue — were improved and rendered in the highest degree clear and brilliant; but, when the blue glass was placed before the candle, the colours of the shadows were very much impaired.

In order to see what would be the consequence of

rendering the candlelight of a still deeper yellow, I interposed before it a sheet of yellow or rather orange-coloured glass, when a very unexpected and most beautiful appearance took place: the colour of the yellow shadow was changed to orange, — the blue shadow remained unchanged, — and the whole surface of the paper not covered by the shadows appeared to be tinged of a most beautiful violet colour, approaching to a light crimson or pink, — almost exactly the same hue as I have often observed the distant snowy mountains and valleys of the Alps to take about sunset.

Is it not more than probable that this hue is, in both cases, produced by nearly the same combinations of coloured light? In the one case, it is the white snow illuminated at the same time by the purest light of the heavens and by the deep yellow rays from the west; and in the other, it is the white paper illuminated by broad daylight and by the rays from a burning candle, rendered still more yellow by being transmitted through the yellow glass.

The beautiful violet colour which spreads itself over the surface of the paper will appear to the greatest advantage, if the pane of orange-coloured glass be held in such a manner before the candle that only a part of the paper — half of it, for instance — be affected by it, the other half of it remaining white.

To make these experiments with more convenience, the paper, which may be about 8 or 10 inches square, should be pasted or glued down upon a flat piece of board, furnished with a ball and socket upon the hinder side of it, and mounted upon a stand; and the cylinder should be fastened to a small arm of wood or of metal, projecting forward from the bottom of the

board for that purpose. A small stand, capable of being made higher or lower, as the occasion requires, should likewise be provided for supporting the candle; and, if the board with the paper fastened upon it be surrounded with a broad black frame, the experiments will be so much the more striking and beautiful. For still greater convenience, I have added two other stands, for holding the coloured glass through which the light is occasionally made to pass, in its way to the white surface upon which the shadows are projected. It will be hardly necessary to add that, in order to the experiments appearing to the greatest advantage, all light which is not absolutely necessary to the experiment must be carefully excluded.

Having fitted up a little apparatus according to the above directions, merely for the purpose of prosecuting these inquiries respecting the coloured shadows, I proceeded to make a great variety of experiments, — some with pointed views, and others quite at random, and merely in hopes of making some accidental discovery that might lead to a knowledge of the causes of appearances, which still seemed to me to be enveloped in much obscurity and uncertainty.

Having found that the shadows corresponding to two like wax candles were coloured, the one blue and the other yellow, by interposing a sheet of yellow glass before one of them, I now tried what the effect would be when *blue* glass was made use of instead of yellow, and I found it to be the same: the shadows were still coloured, the one blue and the other yellow, with this difference however, that the colours of the shadows were *reversed;* that which, with the yellow glass, was before yellow, being now blue, and that which was blue being yellow.

I afterwards tried a glass of a bright amethyst colour, and was surprised to find that the shadows still continued to be coloured blue and yellow. The yellow, it is true, had a dirty purple cast; but the blue, though a little inclining to green, was nevertheless a clean, bright, decided colour.

Having no other coloured glass at hand to push these particular inquiries farther, I now removed the candles, and opening two holes in the upper parts of the window-shutters of two neighbouring windows, I let into the room, from above, two beams of light from different parts of the heavens; and, placing the instrument in such a manner that two distinct shadows were projected by the cylinder upon the paper, I was entertained by a succession of very amusing appearances.

The shadows were tinged with an infinite variety of the most unexpected and often most beautiful colours, which continually varying, sometimes slowly and sometimes with inconceivable rapidity, absolutely fascinated the eyes, and, commanding the most eager attention, afforded an enjoyment as new as it was bewitching.

It was a windy day, with flying clouds, and it seemed as if every cloud that passed brought with it another complete succession of varying hues and most harmonious tints. If any colour could be said to predominate, it was purples; but all the varieties of browns, and almost all the other colours I ever remembered to have seen, appeared in their turns, and there were even colours which seemed to me to be perfectly new.

Reflecting upon the great variety of colours observed in these last experiments, many of which did not appear to have the least relation to the apparent

colours of the light by which they were produced, I began to suspect that the colours of the shadows might in many cases, notwithstanding their apparent brilliancy, be merely an optical deception, owing to contrast or to some effect of the other *real* and neighbouring colours upon the eye.

To determine this fact by a direct experiment, I proceeded in the following manner. Having, by making use of a flat ruler instead of the cylinder, contrived to render the shadows much broader, I shut out of the room every ray of daylight, and prepared to make the experiment with two Argand's lamps, well trimmed, and which were both made to burn with the greatest possible brilliancy; and having assured myself that the light they emitted was precisely of the same colour, by the shadows being pefectly colourless which were projected upon the white paper, I directed a tube of about 12 inches long and near an inch in diameter, lined with black paper, against the centre of one of the broad shadows; and looking through this tube with one eye, while the other was closed, I kept my attention fixed upon the shadow, while an assistant repeatedly interposed a sheet of yellow glass before the lamp whose light corresponded to the shadow I observed, and as often removed it.

The result of the experiment was very striking, and fully confirmed my suspicions with respect to the fallacy of many of the appearances in the foregoing experiments.

So far from being able to observe any change in the shadow upon which my eye was fixed, I was not able even to tell when the yellow glass was before the lamp and when it was not; and, though the assistant often

exclaimed at the striking brilliancy and beauty of the blue colour of the very shadow I was observing, I could not discover in it the least appearance of any colour at all. But as soon as I removed my eye from the tube, and contemplated the shadow with all its neighbouring accompaniments, — the other shadow rendered *really* yellow by the effect of the yellow glass and the white paper, which had likewise from the same cause acquired a yellowish hue, — the shadow in question appeared to me, as it did to my assistant, of a beautiful blue colour.

I afterwards repeated the same experiment with the apparently blue shadow produced in the experiment with daylight and candlelight, and with exactly the same result.

How far these experiments may enable us to account for the apparent blue colour of the sky and the great variety of colours which frequently adorn the clouds, as also what other useful observations may be drawn from them, I leave to philosophers, opticians, and painters to determine. In the mean time I believe it is a new discovery — at least it is undoubtedly a very extraordinary fact — that our eyes are not always to be believed, *even with respect to the presence or absence of colours.*

I cannot finish this paper without mentioning one circumstance, which struck me very forcibly in all these experiments upon coloured shadows, — and that is, the most perfect harmony which always appeared to subsist between the colours — whatever they were — of the two shadows; and this harmony seemed to me to be full as perfect and pleasing when the shadows were of different tints of brown as when one of them was blue and the other yellow. In short, the harmony of

these colours was in all cases not only very striking, but the appearances altogether were quite enchanting; and I never found anybody to whom I showed these experiments whose eyes were not fascinated with them. It is, however, more than probable that a great part of the pleasure which these experiments afforded to the spectators arose from the continual changes of colour, tint, and shade with which the eye was amused and the attention kept awake.

We are used to seeing colours fixed and unalterable, — hard as the solid bodies from which they come, and just as motionless, — consequently *dead*, *uninteresting*, *and tiresome to the eye;* but in these experiments all is *motion*, *life*, and *beauty*.

It appears to me very probable that a further prosecution of these experiments upon coloured shadows may not only lead to a knowledge of the *real nature of the harmony of colours*, or the peculiar circumstances upon which that harmony depends, but that it may also enable us to construct instruments for producing that harmony for the entertainment of the eyes, in a manner similar to that in which the ears are entertained by musical sounds. I know that attempts have already been made for that purpose; but, when I consider the means employed, I am not surprised that they did not succeed. Where the flowing tide, the varying swell, the *crescendo* is wanting, colours must ever remain hard, cold, and inanimate masses.

I am very sorry that my more serious occupations do not at present permit me to pursue these most entertaining inquiries. Perhaps at some future period I may find leisure to resume them.

[This paper is printed from Rumford's Philosophical Papers, Vol. I., pp. 318–332.]

CONJECTURES

RESPECTING THE

PRINCIPLES OF THE HARMONY OF COLOURS.

CONJECTURES RESPECTING THE PRINCIPLES OF THE HARMONY OF COLOURS.

SINCE the foregoing paper was written, I have at different times repeated most of the experiments therein described, and have made a variety of others, with a view to the farther investigation of this curious subject; and from the results of these inquiries I have been enabled to form some conclusions and conjectures which may perhaps be thought not altogether uninteresting.

Whenever a beam of *coloured light* of any species, and a beam of *white* or *colourless light* of equal intensity, arriving in different directions and at equal angles of incidence at a plane white surface, illuminate that surface together, if a solid opaque body of any kind be placed in each of these beams of light, just before the illuminated plane, in such a manner that the two shadows cast on the plane by these opaque bodies may be near each other, the intensities of these shadows will be equal, and they will both appear to be coloured, but of very different hues. That which is illuminated by the *coloured light* will be of the colour of that light,—which is what would naturally be expected to happen by a person who had never seen the experiment,—but that which is illuminated by the *colourless light*, and by that alone, instead of appearing

colourless, will *appear* to be as deeply coloured as the other, but of a different hue.

The two colours exhibited by the two shadows appear in all cases to harmonize in the most perfect manner, or, in other words, to afford the most pleasing contrast to the view.

These two colours are always such that, if they could be intimately mixed together, the result of that mixture would be *perfect whiteness;* and, as whiteness results from the mixture of all the different colours in certain proportions, the two shadows may be considered as containing all the colours in their just proportions, and the colour of the one shadow may with propriety be said to be the *complement* of the other.

Two neighbouring colours are then, and only then, in perfect harmony when the intimate mixture of both would produce perfect whiteness; and hence it appears that, when two colours harmonize, one of them at least must necessarily be a compound colour.

In the experiment of the coloured shadows, the colour exhibited by one of the shadows only is real, that of the other is *imaginary*, being an optical deception, occasioned in some way unknown to us by the colour actually present and by the effects of the different lights and shades. The *imaginary colour*, which may be said to be *called up in the mind* by the other *real colour*, does not, however, appear to be at all inferior to the real colour either in lustre or in the distinctness of its hue.

Any two harmonizing coloured shadows may be produced indifferently, either with one of the given colours, or with the other of them and white light: *pink* and *green*, for instance, are harmonizing colours;

and two shadows of these two colours, equally bright, may be produced either with a beam of pink-coloured light, or with a beam of green light, crossed by a beam of white light, according to the method above described.

A beam of coloured light may readily be produced for making these experiments by causing white light to pass through coloured glass or any other coloured transparent substance.

To every colour without exception, whatever may be its hue or shade, or however it may be compounded, there is another in perfect harmony to it, which is its complement, and may be said to be its companion. It may be *called up* and exhibited to view in the following manner. Let white light be made to pass through the coloured body, or, if it be opaque, let it be reflected from it: with this light so coloured, and with pure white light, make the experiment of the two shadows, and the colour in question will appear *with its companion by its side.*

By experiments of this kind, which might easily be made, ladies may choose ribbons to their gowns; or those who furnish rooms may arrange their colours upon principles of the most perfect harmony and of the purest taste.

The advantages that painters might derive from a knowledge of these principles of the harmony of colours are too obvious to require illustration.

Upon a careful examination of the works of the great masters of the art of colouring, it will appear that they have frequently practised upon these principles, though it is not likely that they were acquainted with the scientific foundation of their practice. They

have certainly produced *appearances* of colours or tints, when their pictures are viewed in a proper light and at a proper distance, which we search for in vain upon the canvas. This may well be called the "*magic of colouring;*" for it is in fact calling up, as by enchantment, and presenting to the mind colours the most pure and vivid, which have no real existence.

As it might very naturally be suspected that the colours called up by means of shadows owe their existence to *something peculiar to shadows*, and that similar effects could not be produced without shadows, by means of coloured pigments, to remove all doubts on that subject, I made the following decisive experiment.

Having found that when a beam of deep red light and a beam of white or colourless light, of equal intensity, arrive in different directions at a plane white surface, and illuminate it, that a blue shadow, nearly approaching to green, is called up by the red shadow, I attempted to imitate this experiment with a coloured pigment.

On the middle of the floor of a spacious room I laid down a very large sheet of black paper, and on the middle of this I placed a circular piece of crayon paper, which, in order that it might supply the place of the illuminated plane surface on which the shadows were projected in my experiments, I covered or coloured it with such a mixture of red lead (*minium*) and pure white lead, both finely powdered and well mixed together as brought it to be of the same tint, as nearly as possible, with the surface illuminated by the red and by the white light. I then took two oblong slips of crayon paper, half an inch wide and two inches long each: then, colouring one of them as highly as possible with red lead, in a dry powder, and covering the

other with a powder composed of white lead and lamp-black, in such proportions that the quantities of light reflected from the two slips so prepared should be equal, I placed these slips in contact with each other, in the middle of the circular piece of paper on the floor; when retiring backwards a few steps, and looking through my hand with one eye, to exclude all other objects, I had the pleasure to perceive that the slip of paper which was covered with a gray powder now appeared to be of a beautiful greenish blue colour, while the other was of the most vivid red.

This experiment was first made at an inn at Florence, in the year 1793; and in order that I might assure myself that my expectations had not deceived me, by imposing upon my senses, I called two of my friends who happened to lodge in the house (Lord and Lady Palmerston) into the room, and without letting them into the secret simply asked them, with a feigned air of indifference, which of the two colours they saw in the centre of the circular piece of paper on the floor they thought the brightest.

After looking at them for some time, and going round to view them from different sides, one of them answered: "I don't know which of them is the brightest. The red is very bright, and so is the blue. But why do you ask us that question?"

When I told them there was no blue there, and that what they took to be blue was merely a deception, they did not believe me; but they were much surprised, and convinced that what I told them was true, when they saw on my removing the red slip that its companion, which was left behind, instantly *faded* and *lost its colour.*

In attempts to call up colours in this way, many precautions are necessary, to which the most scrupulous attention must be paid, otherwise the experiments will not succeed. Care must be taken to exclude all coloured light in illuminating the slips of paper; and, in preparing that slip which is designed for exhibiting the *imaginary* colour, the quantities of black and of white powder that are mixed must be so adjusted to each other that, when the surface of the slip is covered with it, the *quantity* of light reflected from it to the spectator's eye must be precisely equal to that reflected from the surface of the other *coloured slip*, for this equality is essential to the purity and brilliancy of the colour called up. But this equality can only be found by actual trials with several slips of deeper and lighter shades. That slip which takes the clearest and brightest colour is to be chosen.

When experiments of this kind are attempted to be made with oil colours, other and still greater difficulties will occur; for the oil used for fixing the colours diminishes in so great a degree both the brilliancy and the purity of the light reflected from the surfaces of coloured pigments that the light reflected from an oil painting cannot be expected to produce the same brilliant appearances which are exhibited by the mixtures and contrasts of the uncontaminated and brilliant colours of pure light.

But although it may be impossible for painters, with *their imperfect colours*, to produce effects that will bear a close comparison with those magic appearances of which we have been giving an account, yet there can be no doubt but that the knowledge of those facts, and of the theory by which they are explained, may be very useful to them.

The impossibility of producing perfect whiteness by any mixture of painters' colours is a proof of the want of purity of those colours, and of the difficulty of imitating by means of them any of those very striking effects which are exhibited in experiments with the pure prismatic colours.

There is one most important advantage which painters may certainly derive from a knowledge of the principles of the harmony of colours: it will enable them, on sound philosophical principles, to contrast their colours in such a manner as to give to their pictures, or rather to what they choose to make the prominent parts of them, a great degree of force and brilliancy. For, if any and every simple and compound colour has such a power on objects near it as to cause a neighbouring *colourlesss shadow* to assume the appearance of a colour, there can be no doubt but that if, instead of the shadow a *real colour*, nearly of the same tint and shade as that so *called up*, be substituted in its place, *this colour will appear to great advantage*, or will assume an uncommon degree of strength and brightness.

The science of painting is a most curious and interesting subject of philosophical investigation; and until it is more cultivated the art of colouring must continue to be very obscure, uncertain, and imperfect. Genius will be condemned to waste its energy in tedious mechanical experiments, instead of being employed, as it ought to be, in tracing with a rapid pencil the beautiful conception of a sublime imagination.

[This paper is printed from Rumford's Philosophical Papers, Vol. I., pp. 333-340.]