

XVI. *New Experiments on the Ocular Spectra of Light and Colours.* By Robert Waring Darwin, M. D.; communicated by Erasmus Darwin, M. D. F. R. S.

Read March 23, 1786.

WHEN any one has long and attentively looked at a bright object, as at the setting sun, on closing his eyes, or removing them, an image, which resembles in form the object he was attending to, continues some time to be visible: this appearance in the eye we shall call the ocular spectrum of that object.

These ocular spectra are of four kinds: 1st, Such as are owing to a less sensibility of a defined part of the retina; or *spectra from defect of sensibility*. 2d, Such as are owing to a greater sensibility of a defined part of the retina; or *spectra from excess of sensibility*. 3d, Such as resemble their object in its colour as well as form; which may be termed *direct ocular spectra*. 4th, Such as are of a colour contrary to that of their object; which may be termed *reverse ocular spectra*.

The laws of light have been most successfully explained by the great NEWTON, and the perception of visible objects has been ably investigated by the ingenious Dr. BERKELEY and M. MALEBRANCHE; but these minute phænomena of vision have yet been thought reducible to no theory, though many philosophers have employed a considerable degree of attention upon them: among these are Dr. JURIN, at the end of Dr. SMITH'S Optics; M.

VOL. LXXVI.

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ÆPINUS, in the *Nov. Com. Petropol.* V. 10.; M. BEGUELIN, in the *Berlin Memoires*, V. II. 1771; M. D'ARCY, in the *Histoire de l'Acad. des Scienc.* 1765; M. DE LA HIRE; and, lastly, the celebrated M. DE BUFFON, in the *Memoires de l'Acad. des Scien.* who has termed them accidental colours, as if subjected to no established laws, *Ac. Par.* 1743. M. p. 215.

I must here apprise the reader, that it is very difficult for different people to give the same names to various shades of colours; whence, in the following pages, something must be allowed if, on repeating the experiments, the colours here mentioned should not accurately correspond with his own names of them.

I. ACTIVITY OF THE RETINA IN VISION.

From the subsequent experiments it appears, that the retina is in an active not in a passive state during the existence of these ocular spectra; and it is thence to be concluded, that all vision is owing to the activity of this organ.

1. Place a piece of red silk, about an inch in diameter, as in fig. 1. (Tab. IX.) on a sheet of white paper, in a strong light; look steadily upon it from about the distance of half a yard for a minute; then closing your eyelids cover them with your hands, and a green spectrum will be seen in your eyes, resembling in form the piece of red silk: after some time, this spectrum will disappear and shortly re-appear; and this alternately three or four times, if the experiment is well made, till at length it vanishes entirely.

2. Place on a sheet of white paper a circular piece of blue silk, about four inches in diameter, in the sunshine; cover the center of this with a circular piece of yellow silk, about
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three inches in diameter; and the center of the yellow filk with a circle of pink filk, about two inches in diameter; and the center of the pink filk with a circle of green filk, about one inch in diameter; and the center of this with a circle of indigo, about half an inch in diameter; make a small speck with ink in the very center of the whole, as in fig. 2.; look steadily for a minute on this central spot, and then closing your eyes, and applying your hand at about an inch distance before them, so as to prevent too much or too little light from passing through the eyelids, you will see the most beautiful circles of colours that imagination can conceive, which are most resembled by the colours occasioned by pouring a drop or two of oil on a still lake in a bright day; but these circular irises of colours are not only different from the colours of the filks above-mentioned, but are at the same time perpetually changing as long as they exist.

3. When any one in the dark presses either corner of his eye with his finger, and turns his eye away from his finger, he will see a circle of colours like those in a peacock's tail: and a sudden flash of light is excited in the eye by a stroke on it. (NEWTON'S Opt. Qu. 16.)

4. When any one turns round rapidly on one foot, till he becomes dizzy and falls upon the ground, the spectra of the ambient objects continue to present themselves in rotation, or appear to librate, and he seems to behold them for some time still in motion.

From all these experiments it appears, that the spectra in the eye are not owing to the mechanical impulse of light impressed on the retina, nor to its chemical combination with that organ, nor to the absorption and emission of light, as is observed in many bodies: for in all these cases the spectra must

either remain uniformly, or gradually diminish; and neither their alternate presence and evanescence as in the first experiment, nor the perpetual changes of their colours as in the second, nor the flash of light or colours in the pressed eye as in the third, nor the rotation or libration of the spectra as in the fourth, could exist.

It is not absurd to conceive, that the retina may be stimulated into motion, as well as the red and white muscles which form our limbs and vessels; since it consists of fibres, like those, intermixed with its medullary substance. To evince this structure, the retina of an ox's eye was suspended in a glass of warm water, and forcibly torn in a few places; the edges of these parts appeared jagged and hairy, and did not contract, and become smooth like simple mucus, when it is distended till it breaks; which shews that it consists of fibres; and this its fibrous construction became still more distinct to the sight, by adding some caustic alkali to the water, as the adhering mucus was first eroded, and the hair-like fibres remained floating in the vessel. Nor does the degree of transparency of the retina invalidate the evidence of its fibrous structure, since LEEUWENHOEK has shewn that the crystalline humour itself consists of fibres. (*Arcana Naturæ*, V. 1. p. 70.)

Hence it appears, that as the muscles have larger fibres intermixed with a smaller quantity of nervous medulla, the organ of vision has a greater quantity of nervous medulla intermixed with smaller fibres; and it is probable, that the locomotive muscles, as well as the vascular ones, of microscopic animals have much greater tenuity than these of the retina.

And besides the similar laws, which will be shewn in this Paper to govern alike the actions of the retina and of the muscles,

muscles, there are many other analogies which exist between them. They are both originally excited into action by irritations, both act nearly in the same quantity of time, are alike strengthened or fatigued by exertion, are alike painful if excited into action when they are in an inflamed state, are alike liable to paralysis, and to the torpor of old age.

II. OF SPECTRA FROM DEFECT OF SENSIBILITY.

The retina is not so easily excited into action by less irritations after having been lately subjected to greater.

1. When any one passes from the bright daylight into a darkened room, the irises of his eyes expand themselves to their utmost extent in a few seconds of time; but it is very long before the optic nerve, after having been stimulated by the greater light of the day, becomes sensible of the less degree of it in the room; and, if the room is not too obscure, the irises will again contract themselves in some degree, as the sensibility of the retina returns.

2. Place about half an inch square of white paper on a black hat, and looking steadily on the center of it for a minute, remove your eyes to a sheet of white paper; and after a second or two a dark square will be seen on the white paper, which will continue some time. A similar dark square will be seen in the closed eye, if light be admitted through the eye-lids.

So after looking at any luminous object of a small size, as at the sun, for a short time, so as not much to fatigue the eyes, this part of the retina becomes less sensible to smaller quantities of light; hence, when the eyes are turned on other less luminous parts of the sky, a dark spot is seen resembling

the shape of the sun, or other luminous object which we last beheld. This is the source of one kind of the dark coloured *muscæ volitantes*. If this dark spot lies above the center of the eye, we turn our eyes that way, expecting to bring it into the center of the eye, that we may view it more distinctly; and in this case the dark spectrum seems to move upwards. If the dark spectrum is found beneath the center of the eye, we pursue it from the same motive, and it seems to move downwards. This has given rise to various conjectures of something floating in the aqueous humours of the eyes; but whoever, in attending to these spots, keeps his eyes unmoved by looking steadily at the corner of a cloud, at the same time that he observes the dark spectra, will be thoroughly convinced, that they have no motion but what is given to them by the movement of our eyes in pursuit of them. Sometimes the form of the spectrum, when it has been received from a circular luminous body, will become oblong; and sometimes it will be divided into two circular spectra, which is owing to our changing the angle made by the two optic axes, according to the distance of the clouds or other bodies to which the spectrum is supposed to be contiguous. The apparent size of it will also be variable according to its supposed distance; but when such a spectrum is received with only one eye, the other being covered, its form and number are invariable.

As these spectra are more easily observable when our eyes are a little weakened by fatigue, it has frequently happened, that people of delicate constitutions have been much alarmed at them, fearing a beginning decay of their sight, and have thence fallen into the hands of ignorant oculists; but I believe they never are a prelude to any other disease of the eye, and that it is from habit alone, and our want of attention to them,

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that we do not see them on all objects every hour of our lives. But as the nerves of very weak people lose their sensibility, in the same manner as their muscles lose their activity, by a small time of exertion, it frequently happens, that sick people in the extreme debility of fevers are perpetually employed in picking something from the bed-cloaths, occasioned by their mistaking the appearance of these *muscæ volitantes* in their eyes. BENVENUTO CELINI, an Italian artist, a man of strong abilities, relates, that having passed the whole night on a distant mountain with some companions and a conjurer, and performed many ceremonies to raise the devil, on their return in the morning to Rome, and looking up when the sun began to rise, they saw numerous devils run on the tops of the houses, as they passed along; so much were the spectra of their weakened eyes magnified by fear, and made subservient to the purposes of fraud or superstition. (Life of BEN. CELINI.)

3. Place a square inch of white paper on a large piece of straw-coloured silk; look steadily some time on the white paper, and then move the center of your eyes on the silk, and a spectrum of the form of the paper will appear on the silk, of a deeper yellow than the other part of it: for the central part of the retina, having been some time exposed to the stimulus of a greater quantity of white light, is become less sensible to a smaller quantity of it, and therefore sees only the yellow rays in that part of the straw-coloured silk.

Facts similar to these are observable in other parts of our system: thus, if one hand be made warm, and the other exposed to the cold, and then both of them immersed in subtepid water, the water is perceived warm to one hand, and cold to the other; and we are not able to hear weak sounds for some time after we have been exposed to loud ones; and we feel a
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chilliness on coming into an atmosphere of temperate warmth, after having been some time confined in a very warm room : and hence the stomach, and other organs of digestion, of those who have been habituated to the greater stimulus of spirituous liquor, are not excited into their due action by the less stimulus of common food alone ; of which the immediate consequence is indigestion and hypochondriacism.

III. OF SPECTRA FROM EXCESS OF SENSIBILITY.

The retina is more easily excited into action by greater irritation after having been lately subjected to less.

1. If the eyes are closed, and covered perfectly with a hat, for a minute or two, in a bright day ; on removing the hat a red or crimson light is seen through the eye-lids. In this experiment the retina, after being some time kept in the dark, becomes so sensible to a small quantity of light, as to perceive distinctly the greater quantity of red rays than of others which pass through the eye-lids. A similar coloured light is seen to pass through the edges of the fingers, when the open hand is opposed to the flame of a candle.

2. If you look for some minutes steadily on a window in the beginning of the evening twilight, or in a dark day, and then move your eyes a little, so that those parts of the retina, on which the dark frame-work of the window was delineated, may now fall on the glass part of it, many luminous lines, representing the frame-work, will appear to lie across the glass panes : for those parts of the retina, which were before least stimulated by the dark frame-work, are now more sensible to
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light than the other parts of the retina which were exposed to the more luminous parts of the window.

3. Make with ink on white paper a very black spot, about half an inch in diameter, with a tail about an inch in length, so as to represent a tadpole; look steadily for a minute on this spot, and, on moving the eye a little, the figure of the tadpole will be seen on the white part of the paper, which figure of the tadpole will appear whiter or more luminous than the other parts of the white paper; for the part of the retina on which the tadpole was delineated, is now more sensible to light than the other parts of it, which were exposed to the white paper. This experiment is mentioned by Dr. IRWIN, but is not by him ascribed to the true cause, namely, the greater sensibility of that part of the retina which has been exposed to the black spot, than of the other parts which had received the white field of paper, which is put beyond a doubt by the next experiment.

4. On closing the eyes after viewing the black spot on the white paper, as in the foregoing experiment, a red spot is seen of the form of the black spot: for that part of the retina, on which the black spot was delineated, being now more sensible to light than the other parts of it, which were exposed to the white paper, is capable of perceiving the red rays which penetrate the eyelids. If this experiment be made by the light of a tallow candle, the spot will be yellow instead of red; for tallow candles abound much with yellow light, which passes in greater quantity and force through the eyelids than blue light; hence the difficulty of distinguishing blue and green by this kind of candle light. The colour of the spectrum may possibly vary in the day light, according to the different colour of the meridian or the morning or evening light.

M. BEGUELIN, in the Berlin Memoires, V. II. 1771, observes, that, when he held a book so that the sun shone upon his half closed eyelids, the black letters, which he had long inspected, became red, which must have been thus occasioned. Those parts of the retina which had received for some time the black letters, were so much more sensible than those parts which had been opposed to the white paper, that to the former the red light, which passed through the eyelids, was perceptible. There is a similar story told, I think, in M. DE VOLTAIRE'S Historical Works, of a Duke of Tuscany, who was playing at dice with the general of a foreign army, and, believing he saw bloody spots upon the dice, portended dreadful events, and retired in confusion. The observer, after looking for a minute on the black spots of a die, and carelessly closing his eyes, on a bright day, would see the image of a die with red spots upon it, as above explained.

5. On emerging from a dark cavern, where we have long continued, the light of a bright day becomes intolerable to the eye for a considerable time, owing to the excess of sensibility existing in the eye, after having been long exposed to little or no stimulus. This occasions us immediately to contract the iris to its smallest aperture, which becomes again gradually dilated, as the retina becomes accustomed to the greater stimulus of the daylight.

The twinkling of a bright star, or of a distant candle in the night, is perhaps owing to the same cause. While we continue to look upon these luminous objects, their central parts gradually appear paler, owing to the decreasing sensibility of the part of the retina exposed to their light; whilst, at the same time, by the unsteadiness of the eye, the edges of them are perpetually falling on parts of the retina that were just before

before exposed to the darkness of the night, and therefore ten-fold more sensible to light than the part on which the star or candle had been for some time delineated. This pains the eye in a similar manner as when we come suddenly from a dark room into bright daylight, and gives the appearance of bright scintillations. Hence the stars twinkle most when the night is darkest, and do not twinkle through telescopes, as observed by MUSSCHENBROECK; and it will afterwards be seen why this twinkling is sometimes of different colours when the object is very bright, as Mr. MELVILL observed in looking at Sirius. For the opinions of others on this subject, see Dr. PRIESTLEY's valuable History of Light and Colours, p. 494.

Many facts observable in the animal system are similar to these; as the hot glow occasioned by the usual warmth of the air, or our cloaths, on coming out of a cold bath; the pain of the fingers on approaching the fire after having handled snow; and the inflamed heels from walking in snow. Hence those who have been exposed to much cold have died on being brought to a fire, or their limbs have become so much inflamed as to mortify. Hence much food or wine given suddenly to those who have almost perished by hunger has destroyed them; for all the organs of the famished body are now become so much more irritable to the stimulus of food and wine, which they have long been deprived of, that inflammation is excited, which terminates in gangrene or fever.

IV. OF DIRECT OCULAR SPECTRA.

A quantity of stimulus somewhat greater than natural excites the retina into spasmodic action, which ceases in a few seconds.

A certain duration and energy of the stimulus of light and colours excites the perfect action of the retina in vision; for very quick motions are imperceptible to us, as well as very slow ones, as the whirling of a top, or the shadow on a sundial. So perfect darkness does not affect the eye at all; and excess of light produces pain, not vision.

1. When a fire-coal is whirled round in the dark, a lucid circle remains a considerable time in the eye; and that with so much vivacity of light, that it is mistaken for a continuance of the irritation of the object. In the same manner, when a fiery meteor shoots across the night, it appears to leave a long lucid train behind it, part of which, and perhaps sometimes the whole, is owing to the continuance of the action of the retina after having been thus vividly excited. This is beautifully illustrated by the following experiment: fix a paper sail, three or four inches in diameter, and made like that of a smoke jack, in a tube of pasteboard; on looking through the tube at a distant prospect, some disjointed parts of it will be seen through the narrow intervals between the sails; but as the fly begins to revolve, these intervals appear larger; and when it revolves quicker, the whole prospect is seen quite as distinct as if nothing intervened, though less luminous.

2. Look through a dark tube, about half a yard long, at the area of a yellow circle of half an inch diameter, lying upon a blue area of double that diameter, for half a minute;

and on closing your eyes the colours of the spectrum will appear similar to the two areas, as in fig. 3.; but if the eye is kept too long upon them, the colours of the spectrum will be the reverse of those upon the paper, that is, the internal circle will become blue, and the external area yellow; hence some attention is required in making this experiment.

3. Place the bright flame of a spermaceti candle before a black object in the night; look steadily at it for a short time, till it is observed to become somewhat paler; and on closing the eyes, and covering them carefully, but not so as to compress them, the image of the blazing candle will continue distinctly to be visible.

4. Look steadily, for a short time, at a window in a dark day, as in Exp. 2. S. III. and then closing your eyes, and covering them with your hands, an exact delineation of the window remains for some time visible in the eye. This experiment requires a little practice to make it succeed well; since, if the eyes are fatigued by looking too long on the window, or the day be too bright, the luminous parts of the window will appear dark in the spectrum, and the dark parts of the framework will appear luminous, as in Exp. 2. S. III. And it is even difficult for many, who first try this experiment, to perceive the spectrum at all; for any hurry of mind, or even too great attention to the spectrum itself, will disappoint them, till they have had a little experience in attending to such small sensations.

The spectra described in this section, termed direct ocular spectra, are produced without much fatigue of the eye; the irritation of the luminous object being soon withdrawn, or its quantity of light being not so great as to produce any degree of uneasiness in the organ of vision; which distinguishes them from

from the next class of ocular spectra, which are the consequence of fatigue. These direct spectra are best observed in such circumstances that no light, but what comes from the object, can fall upon the eye; as in looking through a tube, of half a yard long, and an inch wide, at a yellow paper on the side of a room, the direct spectrum was easily produced on closing the eye without taking it from the tube: but if the lateral light is admitted through the eye-lids, or by throwing the spectrum on white paper, it becomes a reverse spectrum, as will be explained below.

The other senses also retain for a time the impressions that have been made upon them, or the actions they have been excited into. So if a hard body is pressed upon the palm of the hand, as is practised in tricks of legerdemain, it is not easy to distinguish for a few seconds whether it remains or is removed; and tastes continue long to exist vividly in the mouth, as the smoke of tobacco, or the taste of gentian, after the sapid material is withdrawn.

v. *A quantity of stimulus somewhat greater than the last mentioned excites the retina into spasmodic action, which ceases and recurs alternately.*

1. On looking for a time on the setting sun, so as not greatly to fatigue the sight, a yellow spectrum is seen when the eyes are closed and covered, which continues for a time, and then disappears, and recurs repeatedly before it intirely vanishes. This yellow spectrum of the sun when the eye-lids are opened becomes blue; and if it is made to fall on the green grass, or on other coloured objects, it varies its own colour

colour by an intermixture of theirs, as will be explained in another place.

2. Place a lighted spermaceti candle in the night about one foot from your eye, and look steadily on the center of the flame, till your eye becomes much more fatigued than in S. IV. Exp. 3. ; and on closing your eyes a reddish spectrum will be perceived, which will cease and return alternately.

The action of vomiting in like manner ceases, and is renewed by intervals, although the emetic drug is thrown up with the first effort: so after-pains continue some time after parturition; and the alternate pulsations of the heart of a viper are renewed for some time after it is cleared from its blood.

VI. OF REVERSE OCULAR SPECTRA.

The retina after having been excited into action by a stimulus somewhat greater than the last mentioned falls into opposite spasmodic action.

The actions of every part of animal bodies may be advantageously compared with each other. This strict analogy contributes much to the investigation of truth; while those looser analogies, which compare the phenomena of animal life with those of chemistry or mechanics, only serve to mislead our inquiries.

When any of our larger muscles have been in long or in violent action, and their antagonists have been at the same time extended, as soon as the action of the former ceases, the limb is stretched the contrary way for our ease, and a pardiculation or yawning takes place.

By the following observations it appears, that a similar circumstance obtains in the organ of vision; after it has been fatigued by one kind of action, it spontaneously falls into the opposite kind.

1. Place a piece of coloured silk, about an inch in diameter, on a sheet of white paper, about half a yard from your eyes; look steadily upon it for a minute; then remove your eyes upon another part of the white paper, and a spectrum will be seen of the form of the silk thus inspected, but of a colour opposite to it. A spectrum nearly similar will appear if the eyes are closed, and the eyelids shaded by approaching the hand near them, so as to permit some but to prevent too much light falling on them.

Red silk produced a green spectrum.

Green produced a red one.

Orange produced blue.

Blue produced orange.

Yellow produced violet.

Violet produced yellow.

That in these experiments the colours of the spectra are the reverse of the colours which occasioned them, may be seen by examining the third figure in Sir ISAAC NEWTON'S *Optics*, L. II. p. 1. where those thin laminæ of air, which reflected yellow, transmitted violet; those which reflected red, transmitted a blue-green; and so of the rest, agreeing with the experiments above related.

2. These reverse spectra are similar to a colour, formed by a combination of all the primary colours except that with which the eye has been fatigued in making the experiment: thus the reverse spectrum of red must be such a green as would be produced by a combination of all the other prismatic colours.

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To evince this fact the following satisfactory experiment was made. The prismatic colours were laid on a circular pasteboard wheel, about four inches in diameter, in the proportions described in Dr. PRIESTLEY'S History of Light and Colours, pl. 12. fig. 83. except that the red compartment was intirely left out, and the others proportionably extended so as to complete the circle. Then, as the orange is a mixture of red and yellow, and as the violet is a mixture of red and indigo, it became necessary to put yellow on the wheel instead of orange, and indigo instead of violet, that the experiment might more exactly quadrate with the theory it was designed to establish or confute; because in gaining a green spectrum from a red object, the eye is supposed to have become insensible to red light. This wheel, by means of an axis, was made to whirl like a top; and on its being put in motion, a green colour was produced, corresponding with great exactness to the reverse spectrum of red.

3. In contemplating any one of these reverse spectra in the closed and covered eye, it disappears and re-appears several times successively, till at length it intirely vanishes, like the direct spectra in sect. v.; but with this additional circumstance, that when the spectrum becomes faint or evanescent, it is instantly revived by removing the hand from before the eyelids, so as to admit more light: because then not only the fatigued part of the retina is inclined spontaneously to fall into motions of a contrary direction, but being still sensible to all other rays of light, except that with which it was lately fatigued, is by these rays at the same time stimulated into those motions which form the reverse spectrum.

From these experiments there is reason to conclude, that the fatigued part of the retina throws itself into a contrary mode

of action, like oscitation or pandiculation, as soon as the stimulus which has fatigued it is withdrawn; and that it still remains sensible, that is, liable to be excited into action by any other colours at the same time, except the colour with which it has been fatigued.

VII. *The retina after having been excited into action by a stimulus somewhat greater than the last mentioned falls into various successive spasmodic actions.*

1. On looking at the meridian sun as long as the eyes can well bear its brightness, the disc first becomes pale, with a luminous crescent, which seems to librate from one edge of it to the other, owing to the unsteadiness of the eye; then the whole phasis of the sun becomes blue, surrounded with a white halo; and on closing the eyes, and covering them with the hands, a yellow spectrum is seen, which in a little time changes into a blue one.

M. DE LA HIRE observed, after looking at the bright sun, that the impression in his eye first assumed a yellow appearance, and then green, and then blue; and wishes to ascribe these appearances to some affection of the nerves. (PORTERFIELD on the Eye, Vol. I. p. 343.)

2. After looking steadily on about an inch square of pink silk, placed on white paper, in a bright sunshine, at the distance of a foot from my eyes, and closing and covering my eyelids, the spectrum of the silk was at first a dark green, and the spectrum of the white paper became of a pink. The spectra then both disappeared; and then the internal spectrum was blue; and then, after a second disappearance, became yellow,
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and lastly pink, whilst the spectrum of the field varied into red and green.

These successions of different coloured spectra were not exactly the same in the different experiments, though observed, as near as could be, with the same quantity of light, and other similar circumstances; owing, I suppose, to trying too many experiments at a time; so that the eye was not quite free from the spectra of the colours which were previously attended to.

The alternate exertions of the retina in the preceding section resembled the oscillation or pandiculation of the muscles, as they were performed in directions contrary to each other, and were the consequence of fatigue rather than of pain. And in this they differ from the successive dissimilar exertions of the retina, mentioned in this section, which resemble in miniature the more violent agitations of the limbs in convulsive diseases, as epilepsy, chorea S. Viti, and opisthotonos; all which diseases are perhaps, at first, the consequence of pain, and have their periods afterwards established by habit.

VIII. *The retina, after having been excited into action by a stimulus somewhat greater than the last mentioned, falls into a fixed spasmodic action, which continues for some days.*

1. After having looked long at the meridian sun, in making some of the preceding experiments, till the discs faded into a pale blue, I frequently observed a bright blue spectrum of the sun on other objects all the next and the succeeding day, which constantly occurred when I attended to it, and frequently when I did not previously attend to it. When I closed and covered

my eyes, this appeared of a dull yellow; and at other times mixed with the colours of other objects on which it was thrown. It may be imagined, that this part of the retina was become insensible to white light, and thence a bluish spectrum became visible on all luminous objects; but as a yellowish spectrum was also seen in the closed and covered eye, there can remain no doubt of this being the spectrum of the sun. A similar appearance was observed by M. ÆPINUS, which he acknowledges he could give no account of. (Nov. Com. Petrop. V. 10, p. 2. and 6.)

The locked jaw, and some cataleptic spasms, are resembled by this phenomenon; and from hence we may learn the danger to the eye by inspecting very luminous objects too long a time.

IX. A quantity of stimulus greater than the preceding induces a temporary paralysis of the organ of vision.

1. Place a circular piece of bright red silk, about half an inch in diameter, on the middle of a sheet of white paper; lay them on the floor in a bright sunshine, and fixing your eyes steadily on the center of the red circle, for three or four minutes, at the distance of four or six feet from the object, the red silk will gradually become paler, and finally cease to appear red at all.

2. Similar to these are many other animal facts; as purges, opiates, and even poisons, and contagious matter, cease to stimulate our system, after we have been habituated to their use. So some people sleep undisturbed by a clock, or even by a forge hammer in their neighbourhood: and not only continued irritations, but violent exertions of any kind, are succeeded
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by temporary paralysis. The arm drops down after violent action, and continues for a time useless; and it is probable, that those who have perished suddenly in swimming, or in skating on the ice, have owed their deaths to the paralysis, or extreme fatigue, which succeeds every violent and continued exertion.

X. MISCELLANEOUS REMARKS.

There were some circumstances occurred in making these experiments, which were liable to alter the results of them, and which I shall here mention for the assistance of others, who may wish to repeat them.

1. *Of direct and inverse spectra existing at the same time; of reciprocal direct spectra; of a combination of direct and inverse spectra; of a spectral halo; rules to pre-determine the colours of spectra.*

a. When an area, about six inches square, of bright pink Indian paper, had been viewed on an area, about a foot square, of white writing paper, the internal spectrum in the closed eye was green, being the reverse spectrum of the pink paper; and the external spectrum was pink, being the direct spectrum of the pink paper. The same circumstance happened when the internal area was white, and external one pink; that is, the internal spectrum was pink, and the external one green. All the same appearances occurred when the pink paper was laid on a black hat.

b. When six inches square of deep violet polished paper was viewed on a foot square of white writing paper, the internal spectrum

spectrum was yellow, being the reverse spectrum of the violet paper, and the external one was violet, being the direct spectrum of the violet paper.

c. When six inches square of pink paper was viewed on a foot square of blue paper, the internal spectrum was blue, and the external spectrum was pink; that is, the internal one was the direct spectrum of the external object, and the external one was the direct spectrum of the internal object, instead of their being each the reverse spectrum of the objects they belonged to.

d. When six inches square of blue paper were viewed on a foot square of yellow paper, the interior spectrum became a brilliant yellow, and the exterior one a brilliant blue. The vivacity of the spectra was owing to their being excited both by the stimulus of the interior and exterior objects; so that the interior yellow spectrum was both the reverse spectrum of the blue paper, and the direct one of the yellow paper; and the exterior blue spectrum was both the reverse spectrum of the yellow paper, and the direct one of the blue paper.

e. When the internal area was only a square half-inch of red paper, laid on a square foot of dark violet paper, the internal spectrum was green, with a reddish-blue halo. When the red internal paper was two inches square, the internal spectrum was a deeper green, and the external one redder. When the internal paper was six inches square, the spectrum of it became blue, and the spectrum of the external paper was red.

f. When a square half-inch of blue paper was laid on a six-inch square of yellow paper, the spectrum of the central paper in the closed eye was yellow, incircled with a blue halo. On looking long on the meridian sun, the disc fades into a pale blue surrounded with a whitish halo.

These circumstances, though they very much perplexed the experiments till they were investigated, admit of a satisfactory explanation; for while the rays from the bright internal object in exp. *a.* fall with their full force on the center of the retina, and, by fatiguing that part of it, induce the reverse spectrum, many scattered rays, from the same internal pink paper, fall on the more external parts of the retina, but not in such quantity as to occasion much fatigue, and hence induce the direct spectrum of the pink colour in those parts of the eye. The same reverse and direct spectra occur from the violet paper in exp. *b.*: and in exp. *c.* the scattered rays from the central pink paper produce a direct spectrum of this colour on the external parts of the eye, while the scattered rays from the external blue paper produce a direct spectrum of that colour on the central part of the eye, instead of these parts of the retina falling reciprocally into their reverse spectra. In exp. *d.* the colours being the reverse of each other, the scattered rays from the exterior object falling on the central parts of the eye, and there exciting their direct spectrum, at the same time that the retina was excited into a reverse spectrum by the central object, and this direct and reverse spectrum being of similar colour, the superior brilliancy of this spectrum was produced. In exp. *e.* the effect of various quantities of stimulus on the retina, from the different respective sizes of the internal and external areas, induced a spectrum of the internal area in the center of the eye, combined of the reverse spectrum of that internal area and the direct one of the external area, in various shades of colour, from a pale green to a deep blue, with similar changes in the spectrum of the external area. For the same reasons, when an internal bright object was small, as in exp. *f.* instead of the whole of the spectrum of the external object being

being reverse to the colour of the internal object, only a kind of halo, or radiation of colour, similar to that of the internal object, was spread a little way on the external spectrum. For this internal blue area being so small, the scattered rays from it extended but a little way on the image of the external area of yellow paper, and could therefore produce only a blue halo round the yellow spectrum in the center.

If any one should suspect that the scattered rays from the exterior coloured object do not intermix with the rays from the interior coloured object, and thus affect the central part of the eye, let him look through an opaque tube, about two feet in length, and an inch in diameter, at a coloured wall of a room with one eye, and with the other eye naked; and he will find, that by shutting out the lateral light, the area of the wall seen through a tube appears as if illuminated by the sunshine, compared with the other parts of it; from whence arises the advantage of looking through a dark tube at distant paintings.

Hence we may safely deduce the following rules to determine before-hand the colours of all spectra. 1. *The direct spectrum* without any lateral light is an evanescent representation of its object in the unfatigued eye. 2. With some lateral light it becomes of a colour combined of the direct spectrum of the central object, and of the circumjacent objects, in proportion to their respective quantity and brilliancy. 3. *The reverse spectrum* without lateral light is a representation in the fatigued eye of the form of its objects, with such a colour as would be produced by all the primary colours, except that of the object. 4. With lateral light the colour is compounded of the reverse spectrum of the central object, and the direct spectrum of the circumjacent objects, in proportion to their respective quantity and brilliancy.

II. Variation and vivacity of the spectra occasioned by extraneous light.

The reverse spectrum, as has been before explained, is similar to a colour, formed by a combination of all the primary colours, except that with which the eye has been fatigued in making the experiment: so the reverse spectrum of red is such a green as would be produced by a combination of all the other prismatic colours. Now it must be observed, that this reverse spectrum of red is therefore the direct spectrum of a combination of all the other prismatic colours, except the red; whence, on removing the eye from a piece of red silk to a sheet of white paper, the green spectrum, which is perceived, may either be called the reverse spectrum of the red silk, or the direct spectrum of all the rays from the white paper, except the red; for in truth it is both. Hence we see the reason why it is not easy to gain a direct spectrum of any coloured object in the day-time, where there is much lateral light, except of very bright objects, as of the setting sun, or by looking through an opaque tube; because the lateral external light falling also on the central part of the retina, contributes to induce the reverse spectrum, which is at the same time the direct spectrum of that lateral light, deducting only the colour of the central object which we have been viewing. And for the same reason, it is difficult to gain the reverse spectrum, where there is no lateral light to contribute to its formation. Thus, in looking through an opaque tube on a yellow wall, and closing my eye, without admitting any lateral light, the spectra were all at first yellow; but at length changed into blue. And on looking in the same manner on red paper, I did at length get a

green spectrum; but they were all at first red ones: and the same after looking at a candle in the night.

The reverse spectrum was formed with greater facility when the eye was thrown from the object on a sheet of white paper, or when light was admitted through the closed eyelids; because not only the fatigued part of the retina was inclined spontaneously to fall into motions of a contrary direction; but being still sensible to all other rays of light except that with which it was lately fatigued, was by these rays stimulated at the same time into those motions which form the reverse spectrum. Hence, when the reverse spectrum of any colour became faint, it was wonderfully revived by admitting more light through the eyelids, by removing the hand from before them: and hence, on covering the closed eyelids, the spectrum would often cease for a time, till the retina became sensible to the stimulus of the smaller quantity of light, and then it recurred. Nor was the spectrum only changed in vivacity, or in degree, by this admission of light through the eyelids; but it frequently happened, after having viewed bright objects, that the spectrum in the closed and covered eye was changed into a third spectrum, when light was admitted through the eyelids: which third spectrum was composed of such colours as could pass through the eyelids, except those of the object. Thus, when an area of half an inch diameter of pink paper was viewed on a sheet of white paper in the sunshine, the spectrum with closed and covered eyes was green; but on removing the hands from before the closed eyelids, the spectrum became yellow, and returned instantly again to green, as often as the hands were applied to cover the eyelids, or removed from them: for the retina being now insensible to red light, the yellow rays passing through the eyelids in greater quantity than the other colours, induced a yellow spectrum; whereas if
the

the spectrum was thrown on white paper, with the eyes open, it became only a lighter green.

Though a certain quantity of light facilitates the formation of the reverse spectrum, a greater quantity prevents its formation, as the more powerful stimulus excites even the fatigued parts of the eye into action; otherwise we should see the spectrum of the last viewed object as often as we turn our eyes. Hence the reverse spectra are best seen by gradually approaching the hand near the closed eyelids to a certain distance only, which must be varied with the brightness of the day, or the energy of the spectrum. Add to this, that all dark spectra, as black, blue, or green, if light be admitted through the eyelids, after they have been some time covered, give reddish spectra, for the reasons given in sect. III. exp. 1.

From these circumstances of the extraneous light coinciding with the spontaneous efforts of the fatigued retina to produce a reverse spectrum, as was observed before, it is not easy to gain a direct spectrum, except of objects brighter than the ambient light; such as a candle in the night, the setting sun, or viewing a bright object through an opaque tube; and then the reverse spectrum is instantaneously produced by the admission of some external light; and is as instantly converted again to the direct spectrum by the exclusion of it. Thus, on looking at the setting sun, on closing the eyes, and covering them, a yellow spectrum is seen, which is the direct spectrum of the setting sun; but on opening the eyes on the sky, the yellow spectrum is immediately changed into a blue one, which is the reverse spectrum of the yellow sun, or the direct spectrum of the blue sky, or a combination of both. And this is again transformed into a yellow one on closing the eyes, and so reciprocally, as quick as the motions of the opening and closing eyelids. Hence, when Mr. MELVILL observed

the scintillations of the star Sirius to be sometimes coloured, these were probably the direct spectrum of the blue sky on the parts of the retina fatigued by the white light of the star. (*Essays Physical and Literary*, p. 81. V. 2.)

When a direct spectrum is thrown on colours darker than itself, it mixes with them; as the yellow spectrum of the setting sun, thrown on the green grass, becomes a greener yellow. But when a direct spectrum is thrown on colours brighter than itself, it becomes instantly changed into the reverse spectrum, which mixes with those brighter colours. So the yellow spectrum of the setting sun thrown on the luminous sky becomes blue, and changes with the colour or brightness of the clouds on which it appears. But the reverse spectrum mixes with every kind of colour on which it is thrown, whether brighter than itself or not: thus the reverse spectrum, obtained by viewing a piece of yellow silk, when thrown on white paper was a lucid blue green; when thrown on black Turkey leather becomes a deep violet. And the spectrum of blue silk, thrown on white paper, was a light yellow; on black silk was an obscure orange; and the blue spectrum, obtained from orange-coloured silk, thrown on yellow, became a green.

In these cases the retina is thrown into activity or sensation by the stimulus of external colours, at the same time that it continues the activity or sensation which forms the spectra; in the same manner as the prismatic colours, painted on a whirling top, are seen to mix together. When these colours of external objects are brighter than the direct spectrum which is thrown upon them, they change it into the reverse spectrum, like the admission of external light on a direct spectrum, as explained above. When they are darker than the direct spectrum

trum, they mix with it, their weaker stimulus being insufficient to induce the reverse spectrum.

III. *Variation of spectra in respect to number and figure and remission.*

When we look long and attentively at any object, the eye cannot always be kept intirely motionless; hence, on inspecting a circular area of red silk placed on white paper, a lucid crescent or edge is seen to librate on one side or other of the red circle: for the exterior parts of the retina sometimes falling on the edge of the central silk, and sometimes on the white paper, are less fatigued with red light than the central part of the retina, which is constantly exposed to it; and therefore, when they fall on the edge of the red silk, they perceive it more vividly. Afterwards, when the eye becomes fatigued, a green spectrum in the form of a crescent is seen to librate on one side or other of the central circle, as by the unsteadiness of the eye a part of the fatigued retina falls on the white paper; and as by the increasing fatigue of the eye the central part of the silk appears paler, the edge on which the unfatigued part of the retina occasionally falls will appear of a deeper red than the original silk, because it is compared with the pale internal part of it. M. DE BUFFON in making this experiment observed, that the red edge of the silk was not only deeper coloured than the original silk; but, on his retreating a little from it, it became oblong, and at length divided into two, which must have been owing to a change of the angle of the two optic axes with the new distance he observed it at. Thus, if a pen is held up before a distant candle, when we look intently at the pen two candles are seen behind it; when we look intently at

the candle two pens are seen. If the sight be unsteady at the time of beholding the sun, even though one eye only be used, many images of the sun will appear, or luminous lines, when the eye is closed. And as some parts of these will be more vivid than others, and some parts of them will be produced nearer the center of the eye than others, these will disappear sooner than the others; and hence the number and shape of these spectra of the sun will continually vary, as long as they exist. The cause of some being more vivid than others, is the unsteadiness of the eye of the beholder, so that some parts of the retina have been longer exposed to the sunbeams. That some parts of a complicated spectrum fade and return before other parts of it, the following experiment evinces. Draw three concentric circles; the external one an inch and a half in diameter, the middle one an inch, and the internal one half an inch; colour the external and internal areas blue, and the remaining one yellow, as in fig. 4.; after having looked about a minute on the center of these circles, in a bright light, the spectrum of the external area appears first in the closed eye, then the middle area, and lastly the central one; and then the central one disappears, and the others in inverted order. If concentric circles of more colours are added, it produces the beautiful ever changing spectrum in sect. I. exp. 2.

From hence it would seem, that the center of the eye produces quicker remissions of spectra, owing perhaps to its greater sensibility; that is, to its more energetic exertions. These remissions of spectra bear some analogy to the tremors of the hands, and palpitations of the heart, of weak people: and perhaps a criterion of the strength of any muscle or nerve may be taken from the time it can be continued in exertion.

iv. Variation of spectra in respect to brilliancy; the visibility of the circulation of the blood in the eye..

1. The meridian or evening light makes a difference in the colours of some spectra; for as the sun descends, the red rays, which are less refrangible by the convex atmosphere, abound in great quantity. Whence the spectrum of the light parts of a window at this time, or early in the morning, is red; and becomes blue either a little later or earlier; and white in the meridian day; and is also variable from the colour of the clouds or sky which are opposed to the window.

2. All these experiments are liable to be confounded, if they are made too soon after each other, as the remaining spectrum will mix with the new ones. This is a very troublesome circumstance to painters, who are obliged to look long upon the same colour; and in particular to those whose eyes, from natural debility, cannot long continue the same kind of exertion. For the same reason, in making these experiments, the result becomes much varied if the eyes, after viewing any object, are removed on other objects for but an instant of time, before we close them to view the spectrum; for the light from the object, of which we had only a transient view, in the very time of closing our eyes acts as a stimulus on the fatigued retina; and for a time prevents the desired spectrum from appearing, or mixes its own spectrum with it. Whence, after the eyelids are closed, either a dark field, or some unexpected colours, are beheld for a few seconds, before the desired spectrum becomes distinctly visible.

3. The length of time taken up in viewing an object, of which we are to observe the spectrum, makes a great difference

in the appearance of the spectrum, not only in its vivacity, but in its colour; as the direct spectrum of the central object, or of the circumjacent ones, and also the reverse spectra of both, with their various combinations, as well as the time of their duration in the eye, and of their remissions or alternations, depend upon the degree of fatigue the retina is subjected to. The Chevalier D'ARCY constructed a machine by which a coal of fire was whirled round in the dark, and found, that when a luminous body made a revolution in eight thirds of time, it presented to the eye a complete circle of fire; from whence he concludes, that the impression continues on the organ about the seventh part of a second. (*Mém. de l'Acad. des Sc. 1765.*) This, however, is only to be considered as the shortest time of the duration of these direct spectra; since in the fatigued eye both the direct and reverse spectra, with their intermissions, appear to take up many seconds of time, and seem very variable in proportion to the circumstances of fatigue or energy.

4. It sometimes happens, if the eyeballs have been rubbed hard with the fingers, that lucid sparks are seen in quick motion amidst the spectrum we are attending to. This is similar to the flashes of fire from a stroke on the eye in fighting, and is resembled by the warmth and glow which appear upon the skin after friction, and is probably owing to an acceleration of the arterial blood into the vessels emptied by the previous pressure. By being accustomed to observe such small sensations in the eye, it is easy to see the circulation of the blood in this organ. I have attended to this frequently, when I have observed my eyes more than commonly sensible to other spectra. The circulation may be seen either in both eyes at a time, or only in one of them; for as a certain quantity of light is necessary

to produce this curious phænomenon, if one hand be brought nearer the closed eyelids than the other, the circulation in that eye will for a time disappear. For the easier viewing the circulation, it is sometimes necessary to rub the eyes with a certain degree of force after they are closed, and to hold the breath rather longer than is agreeable, which, by accumulating more blood in the eye, facilitates the experiment; but in general it may be seen distinctly after having examined other spectra with your back to the light, till the eyes become weary; then having covered your closed eyelids for half a minute, till the spectrum is faded away which you were examining, turn your face to the light, and removing your hands from the eyelids, by and by again shade them a little, and the circulation becomes curiously distinct. The streams of blood are however generally seen to unite, which shews it to be the venous circulation, owing, I suppose, to the greater opacity of the colour of the blood in these vessels; for this venous circulation is also much more easily seen by the microscope in the tail of a tadpole.

v. *Variation of spectra in respect to distinctness and size; with a new way of magnifying objects.*

1. It was before observed, that when the two colours viewed together were opposite to each other, as yellow and blue, red and green, &c. according to the table of reflections and transmissions of light in Sir ISAAC NEWTON'S Optics, B. II. fig. 3. the spectra of those colours were of all others the most brilliant, and best defined; because they were combined of the reverse spectrum of one colour, and of the direct spectrum of the other. Hence, in books printed with small types, or in

the minute graduation of thermometers, or of clock-faces, which are to be seen at a distance, if the letters or figures are coloured with orange, and the ground with indigo; or the letters with red, and the ground with green; or any other lucid colour is used for the letters, the spectrum of which is similar to the colour of the ground; such letters will be seen much more distinctly, and with less confusion, than in black or white: for as the spectrum of the letter is the same colour with the ground on which they are seen, the unsteadiness of the eye in long attending to them will not produce coloured lines by the edges of the letters, which is the principal cause of their confusion. The beauty of colours lying in vicinity to each other, whose spectra are thus reciprocally similar to each colour, is owing to this greater ease that the eye experiences in beholding them distinctly; and it is probable, in the organ of hearing a similar circumstance may constitute the pleasure of melody. Sir ISAAC NEWTON observes, that gold and indigo were agreeable when viewed together; and thinks there may be some analogy between the sensations of light and sound. (Optics, Qu. 14.)

In viewing the spectra of bright objects, as of an area of red silk of half an inch diameter on white paper, it is easy to magnify it to tenfold its size: for if, when the spectrum is formed, you still keep your eye fixed on the silk area, and remove it a few inches further from you, a green circle is seen round the red silk: for the angle now subtended by the silk is less than it was when the spectrum was formed, but that of the spectrum continues the same, and our imagination places them at the same distance. Thus when you view a spectrum on a sheet of white paper, if you approach the paper to the eye, you may diminish it to a point; and if the paper is made to recede from

the eye, the spectrum will appear magnified in proportion to the distance.

I was surpris'd, and agreeably amus'd, with the following experiment. I cover'd a paper about four inches square with yellow, and with a pen fill'd with a blue colour wrote upon the middle of it the word BANKS in capitals, as in fig. 5. and, sitting with my back to the sun, fix'd my eyes for a minute exactly on the center of the letter N in the middle of the word; after closing my eyes, and shading them somewhat with my hand, the word was distinctly seen in the spectrum in yellow letters on a blue field; and then, on opening my eyes on a yellowish wall at twenty feet distance, the magnified name of BANKS appeared written on the wall in golden characters.

C O N C L U S I O N.

It was observ'd by the learned M. SAUVAGES (Nosol. method. Cl. VIII. Ord. 1.) that the pulsations of the optic artery might be perceiv'd by looking attentively on a white wall well illuminated. A kind of net-work, darker than the other parts of the wall, appears and vanishes alternately with every pulsation. This change of the colour of the wall he well ascribes to the compression of the retina by the diastole of the artery. The various colours produced in the eye by the pressure of the finger, or by a stroke on it, as mention'd by Sir ISAAC NEWTON, seem likewise to originate from the unequal pressure on various parts of the retina. Now as Sir ISAAC NEWTON has shewn, that all the different colours are reflect'd or transmit'ted by the laminae of soap bubbles, or of air, according to their different thickness or thinness, is it not probable, that the

effect of the activity of the retina may be to alter its thickness or thinness, so as better to adapt it to reflect or transmit the colours which stimulate it into action? May not muscular fibres exist in the retina for this purpose, which may be less minute than the locomotive muscles of microscopic animals? May not these muscular actions of the retina constitute the sensation of lights and colours; and the voluntary repetitions of them, when the object is withdrawn, constitute our memory of them? And lastly, may not the laws of the sensations of light, here investigated, be applicable to all our other senses, and much contribute to elucidate many phænomena of animal bodies both in their healthy and diseased state; and thus render this investigation well worthy the attention of the physician, the metaphysician, and the natural philosopher?

Derby, November 1, 1785.



Fig. 1.

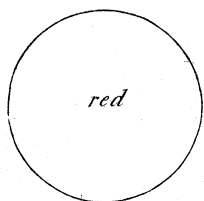


Fig. 3.

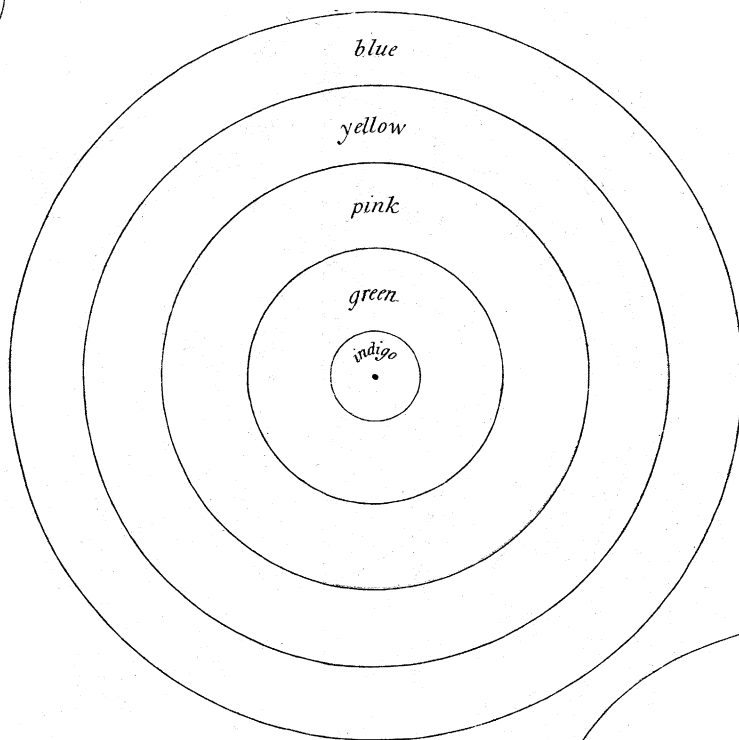


Fig. 2.

Fig. 4.

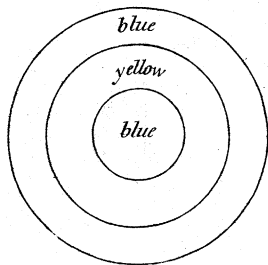


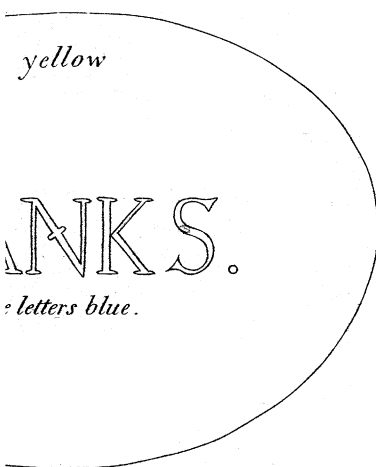
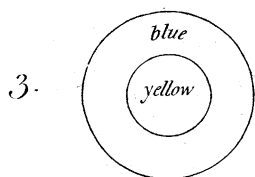
Fig. 5.



yellow

BAN

The letters b.



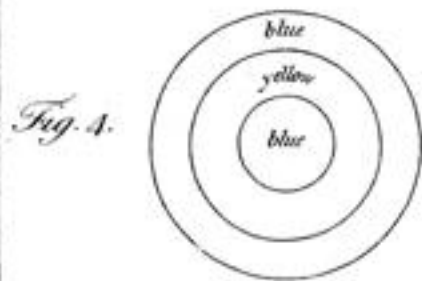
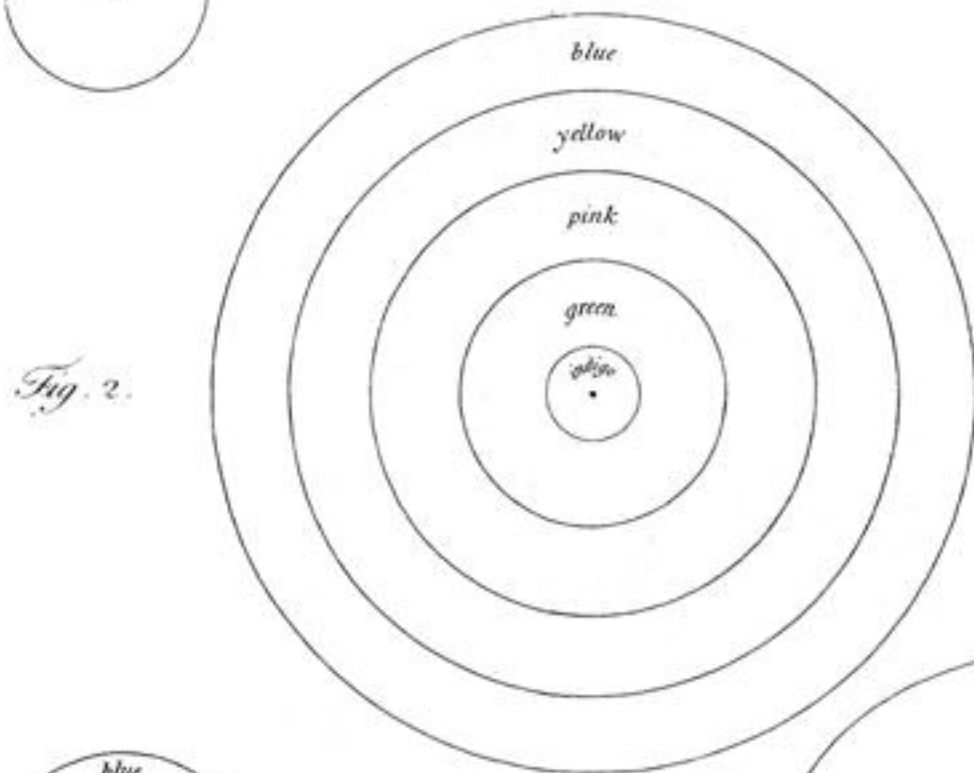
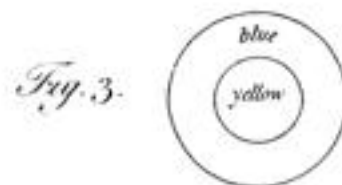
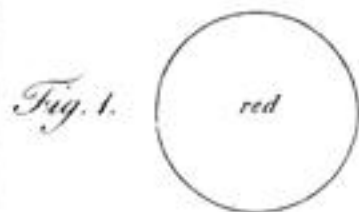


Fig. 5.

