Seeing, then, that in the case of sodic sulphate, which is said to be always present in the air of rooms, and, according to MM. Gernez and Viollette, even in that of the country, the chances are that it is most likely to be present either in the effloresced condition or in solution, and equally non-nuclear in both, I cannot help thinking that too much importance has been given to this part of the subject; for if it be true, we are reduced to the dilemma, pointed out by M. Jeannel*, that there must be floating in the air specimens of all kinds of salts that form supersaturated solutions and crystallize by the introduction of a solid nucleus; whereas there are some such salts which cannot exist in the presence of the oxygen or of the ammonia of the air.

II. "Visible Direction: being an Elementary Contribution to the Study of Monocular and Binocular Vision." By James Jago, M.D. Oxon., A.B. Cantab., F.R.S. Received February 12, 1873.

(Abstract.)

It is a well-known fact that when the eye has been displaced in its socket, as, for instance, by the tip of the finger applied to the eyeball through the eyelid, all objects seen by it deviate from their true directions; and the author's mode of proceeding in this paper is to inquire whether visual deviations that may be observed in arbitrary, but methodically devised, displacements of the eyeball in its socket follow any law, and then to consider how far the results thus derived are conformable with other monocular and binocular experiences, and how far they may be available in the explanation of certain phenomena that have been deemed anomalous in physiological optics.

Having pointed out means by which the ball may be easily displaced in any direction, he draws attention to the fact that, when by such means the apparent directions of objects seen by the eye are made to deviate from their true directions through fully 30°, the orbital muscles so fully retain their command over the movements of the eyeball, that that point in the visual field which was painted on the point of direct sight in the centre of the foramen centrale retinæ still continues to be there painted. He shows this to happen whatever be the direction in which the eyeball is displaced in its orbit.

This fact being a fundamental one in the inquiry he has in hand, he puts it to nicer tests still.

He adjusts the two eyes, when equally displaced so as to cause objects to deviate greatly from their true directions, to look awhile at the top of a high object in the open air, and having obtained a strong *spectrum* of this object in the retinæ, he, with the released eyes, looks at an appro-

* Ann. de Ch. et de Ph. 4th ser. vol. vi. p. 166.

priate mark on a grey wall, and finds that the spectrum really has its margin across the point of direct sight; and he tries other experiments in corroboration.

Also by agitating a pin-hole in a card across the eye when looking at such a high object, he brings the retina into view, and sees that the point of direct sight is visibly within the foramen centrale retinæ, as made visible by the shadow of the wall that bounds the foramen. He indicates other means of proving the same fact.

He gathers from a series of experiments that the mastery of the orbital muscles over such movements of the eyeball as are requisite for pointing the optic axis to its objective point, is practically unimpaired by such shiftings of the eyeball in its socket as have been described.

He then proceeds to show that the regulating duties of the orbital muscles, when the eyeball is displaced in its orbit, are not only fulfilled as to the rotation of the optic axis about a central point, but as to the rotation of the eyeball about this axis. To make experiments to this end, we must have another subjectively visible retinal spot besides the foramen centrale; and this we negatively have in the punctum cæcum, or at the base of the optic nerve.

A diagram is devised by which we may manage that one point of it shall be seen by the direct sight of both eyes, whilst another point is found to fall in the middle of the blind spot of one eye; and the diagram is examined by this eye when this has been pushed from its orbital place upwards, downwards, inwards, and outwards, and in various oblique directions, besides when more or less twisted on its axis; and thus it is demonstrated that what happened with the point of direct sight in the retina happens equally surely for every other retinal point—that under all these displacements the orbital muscles do not forfeit their control of the eyeball, but so regulate its movements that the different points of the field of vision remain constantly painted on the same retinal points.

From these and other methodically continued experiments, he draws the general inference, that if the centre of the foramen centrale retinæ be forced at any instant from its position by any sort of manipulation, and then made to describe a circle round its first position of ease whilst the optic axis has never ceased to remain parallel to its first direction (that is, has generated a cylinder in revolving), the axis of the *seeming* field of vision will have so revolved as to have generated a cone, whose apex is posterior to the retina in the first or undisturbed direction of the optic axis. The like might have been said of any other normal to the retina, the axis of the base of the optic nerve, for instance, were it accessible to light; whilst a twisting retinal movement about a fixed axis twists the *seeming* field of vision.

If the optic axis revolve so as to generate a cone whose apex is in front of the eye, the axis of the *seeming* field may, according to circumstances, generate a cylinder, or a more acute cone enclosing the other.

Conversely, the parallax of the visual field being noted, we can assign the retinal displacements that have produced them.

Should undue contraction of any orbital muscle, or discordant contractions of the orbital muscles, engender visual parallaxes, we may as safely judge from these parallaxes of the retinal displacements that must have been induced, as if they had been due to manipulation of the eyeball.

In these summarized conclusions we have the means of solving highly important problems in physiological optics.

It is found that sensation, or the function of responding to objective light, is exclusively resident in the retinal elements of the bacillar layer, but that the visual functions of the retina extend no further; for it has been evinced in manifold experiments that when the axes of all the pencils of objective light which concur in imaging a picture upon the retina are normals to its surface, any point in the picture may be *perceived* as lying in successive directions, forming very variable angles with and round about its normal. The retina cannot inform us of the visible direction of any point painted on its surface.

This being so, there is no alternative but to seek for a solution of the mystery in the structure out of which the retina proceeds, for the property in question is plainly inherent in the visual nervous apparatus.

The author recalls that he had long ago pointed out that, though the optic nerve in its orbital course and its fibres in their retinal course are obnoxious to mechanical pressure, no visual sensation can be immediately produced by such pressure on nerve-trunks or branches. Sensation can only be produced by pressure through the sclerotic by affecting the rods and cones of the bacillar layer, and then only when the flexure of the retina crowds together the *internal* (as to the eye) ends of the bacillar elements. He cites his former words:—"When we turn in the dark the eyeballs sharply, or even mildly, a couple of white circular rings, brighter at one margin than the other, enclosing a paler area with a central dark spot, flash forth, the diameter extending an angle of several degrees. . . . . . The phenomenon is plainly the result of flexure of the retina where the nerve runs into it, as the eye is pulled round in its socket until it drags upon the nerve; and it is to be noted that it is *again* where the inner retinal elements are squeezed laterally that the phenomenon is disclosed." The absence of the tough and dense sclerotic where the nerve penetrates it, as well as of the choroid, indicates how readily the nerve must yield to the slightest traction.

In these previously recorded facts the author feels assured that he had, unwittingly, provided himself with a key to the secret of visible direction.

For it has been shown by diversified experiments that whenever there is a parallax in visible direction it is accompanied with a displacement of the base of the optic nerve in the same direction, that is to say, with *trac-*

tion upon the nerve-stem, tending to carry its distal extremity that way. The "white circular rings, brighter at one margin than the other," have been instanced as proclaiming that such traction cannot occur without flexure between the nerve-stem and the eye-apple, which displays itself at the junction of the optic disk with the surrounding retinal expansion. In other words, under the concordant action of the orbital muscles, all the movements of the globe are so equably coordinated that the nerve-stem is never subjected to unwonted traction, and consequently always emerges through the ocular tissues to open out into the retina as a normal to their surfaces, in which case no visual parallax appears. But no sooner is there lateral traction than the axis of the emergent nerve-stem, or of the optic disk, deviates from the said normality; and were that disk impressible by objective light, its central point would deviate in the same direction, and an equal deviation in visible direction would be associated with every other point in the visual field.

Hence we are fairly landed upon the conclusion that visible direction, which has already been tracked backwards to the optic nerve, is a function of its terminal direction, being identical with it at the centre of the optic disk, both in the equable use of the eye and in the unequable.

Finally, it is clear that if the eyeball be twisted round the axis of the optic disk the terminal portion of the nerve will be twisted in the same direction; and thus the opposite twisting of the visible field in certain experiments related are explicable by the same hypothesis—an hypothesis that accounts for all the phenomena of visible direction, whether regular or irregular.

Whenever the inverted retinal image, by means of nervous arrangement, is *re*inverted, an erect image is seemingly projected, if not from, by means of the base of the optic nerve.

The principles here arrived at, when applied to binocular vision, lead to the observation of phenomena that have not been before put on record.

Wheatstone, in his classic paper in the Philosophical Transactions, wherein he announces his discovery of the stereoscope and expounds its theory, only speaks of stereoscopic vision from two perspectives, an appropriate one for each eye, when (no instrument being used) the optic axes meet each other beyond them, or have previously intersected, so that each eye sees the other's perspective—that is, in all experiments by him and other subsequent writers on the subject the optic axes have always been supposed to intersect or to lie in one plane.

But as it has been demonstrated that the axes of visible direction need not be coincident with the optic axes, it ought to follow that we may continue to see bodies in relief from a pair of stereoscopic perspectives, though these are not placed transversely to each other.

Two perspectives of a pyramid are drawn, such as, when placed laterally apart as is usual in stereoscopic slides, and looked at by concourse of the

optic axes beyond them, they yield a hollow pyramid, and when looked at by a previous decussation of these axes yield a solid pyramid. But these perspectives are placed so that the one which was at the left has the one that was at the right immediately underneath it, with about half an inch of plain paper between them.

Then it comes to pass that by properly displacing the right eyeball upwards, by means of the tip of the finger placed underneath it, we can put the under perspective immediately upon the upper one seen with the other eye, and thus realize the hollow pyramid; or by placing the finger upon the top of the left eye, we can depress the upper perspective to cover the under one, and thus realize the solid pyramid. The first pyramid depends from the plane of the paper, the second stands upon it.

By means of a finger under one eye and another upon the other, we can obtain either hollow or solid pyramids anywhere between the two perspectives; or by a finger on both eyes, or under both, we can obtain the pyramid and its " converse " below or above both perspective outlines.

In all these cases the optic axes do not intercept each other, but the axes of visible direction (functional of the final directions of the optic nerves) do meet on the paper—that is, the first pair of axes are not, and the second pair are, in such a realization as is herein planned, in one plane.

In all these cases the perspectives fall on similar parts of the two retinæ, as in the modes originally mentioned by Wheatstone.

The author goes on to consider in what way the sensorium refers the sensations it receives notice of from the optic nerves into space, so as to fix the place, size, and form of an object.

The theory of vision in retinal normals being proved to be untenable, it is admitted that there is some such association of the two retinæ as to have fairly suggested the theory of "identical" or "covering" points; but this relation he believes to be subordinate to a law by which the sensorium *projects* or *emits* its perceptions into space, as it were in two imaginary cones of *sight-rays*, which, though not issuing from the ends of the optic nerves, have apices whose positions are functional of the directions of these ends for the instant in question; and that it is by the intersection of the sight-rays in these cones, limited by the law of similar retinal parts, that the places, sizes, and forms of objects are determined. Hence if we conceive that a pair of stereoscopic perspectives, one being imaged on one retina and one on the other, exist as sight affections in miniature in the substance of the optic nerves, the size of the resultant solid form will be greater the greater is the distance from the nerves at which the axes of visible direction intersect, or the optic axes when they are coincident respectively with them.

The paper concludes by exemplifying in sundry ways the modes in which the conclusions in it may be applied in investigating seemingly anomalous phenomena in physiological optics.