Art. XLVII.—*The Stereoscope, and Vision by Optic Divergence*; by W. LeConte Stevens.

During the last twelve years, Professor Joseph LeConte has published in this Journal a series of articles on Binocular Vision, in one of which he refers to a gentleman with normal eyes "who could combine ordinary stereoscopic pictures with the naked eyes beyond the plane of the pictures, even when the distance between the identical points was greater than the distance between the centers of his pupils." He adds, "It would be curious to inquire, at what *distance* and of what *size*, according to the laws of vision, the stereoscopic image ought to seem in this case."*

While conversing with this gentleman,† about three years ago, it was discovered that I possessed the same power; and since that time no stereograph has been found on which identical points were too far apart to secure binocular fusion with the naked eyes. Not until last spring, however, did I begin any careful investigation of these phenomena. Professor LeConte has investigated the phenomena of ocular convergence very fully, and has developed a system of diagrammatic representation far more consistent than any previously published. I have tested all the experiments on this subject that he has described; and my results have been either identical with his, or as closely approximate as could be reasonably expected. To avoid repetition of what has been already sufficiently established I shall assume that the reader is familiar with the contents of Professor LeConte's papers.‡ It will be found convenient to study optic divergence especially in connection with the stereoscope.

In normal binocular vision the two eyes may be regarded as human cameras occupying slightly different positions, from which are obtained simultaneous views of the point upon which the visual axes are converged. The apparent distance of this point is mainly determined by the intersection of these axes, if the optic angle is large enough to be readily appreciable. In reading ordinary print with comfort the optic angle is rarely less than 12°.

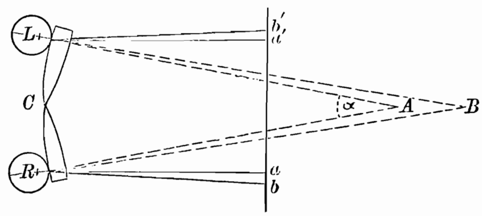
The method of preparing photographs for the stereoscope is too familiar to describe. It is usually assumed that, when these are viewed through the instrument, the lenticular prisms are so adjusted that rays are deviated into the observer's eyes from corresponding points of the stereograph, as if coming from single objects in front; so that he may easily imagine his own

* III, ix, 162–163, March, 1875. † Mr. James Wood Davidson, of New York.

‡ This Journal, II, vol. xlvii, pp. 68 and 153; III, vol. i, p. 33; vol. ii, pp. 1, 315, and 417; vol. ix, p. 159.

eyes to replace the photographer's cameras, and the convergence of his visual axes to replace that of axes from some point in the landscape upon which these cameras have been directed. In fig. 1 let *aa′* be the foreground interval and *bb′* that for the background on the stereograph; then the foreground appears at A and the background at B.

1.



To determine the apparent distance of A, let *i* stand for the observer's interocular distance, RL; *α* for the optic angle, RAL, and D for the apparent distance required. Then, if *a* and *a′* be symmetrical,

$$D = \tfrac{1}{2} i \cot \tfrac{1}{2} \alpha.$$

From this equation it is seen that if *α* be reduced to zero by making the axes parallel, D becomes infinite and there is no intersection. If *α* be made negative by causing the axes to pass from convergence through parallelism into divergence, D becomes negative and the intersection is behind the observer's head. In either of these cases a physiological impossibility is implied, if we accept the theory that the apparent distance of the combined external image is determined by the intersection of the observer's visual axes. If, therefore, distinct binocular vision is attainable with the axes either parallel or divergent, and any judgment of distance is possible, however faulty it may be, this fact is sufficient to prove that the theory is imperfect, and other elements must be sought for the determination of the judgment of distance in vision through the stereoscope.

In normal binocular vision axial convergence is the most important one of several elements which together determine the apparent distance of the point of sight, provided the real distance of this be near the lower limit of distinct vision. In such cases the formula just deduced is applicable with little or no modification. If *i* stand for the distance between two photographer's cameras directed to the same point in a landscape, the formula is also applicable to them, provided there be no lack of uniformity in the media through which the rays pass. In normal vision, moreover, both the focal and axial adjustments of the eyes are consensually adapted to the distance of the object regarded, and the deliverances of the muscular sense from the ciliary and rectus muscles conduce to the same judgment of distance. This judgment is the product of the past experience of the individual, and its accuracy must depend largely upon his acquired skill in interpreting muscular sensations, comparing external relations, and remembering the results of such comparisons. If by any means the axial adjustment can be made to differ considerably from that which usually accompanies a given focal adjustment, binocular vision is to that extent abnormal, and the resulting judgment of distance is correspondingly vitiated. It will be shown that vision through the stereoscope is in nearly all cases abnormal, and that optic divergence is not uncommon among those who use this instrument, especially among young persons whose interocular distance is small, whose eyes are normal, and whose power of accommodation, both focal and axial, is hence large

If an observer, who possesses but a single eye, looks out upon a landscape, the relative distance of the different objects viewed may be roughly estimated in terms of some standard arbitrarily chosen, so long as they are not precisely aligned with his eye. The judgment is less accurate as the angular separation of the objects becomes less, and as there are fewer of them at moderate distances with which to compare the rest. Always, and often unconsciously, he employs one or more of the following elements in judging the distance and form of each object regarded.

I. Near objects subtend larger visual angles than remote objects of equal size.

II. Near objects are seen more distinctly than those that are remote. The illusion of distance may hence be produced by decreasing the brightness of the object viewed, by changing the nature of the medium, or by increasing the contrast between light and shade.

III. Near objects, that are almost aligned with those which are remote, partly cover them. Covering objects are judged nearer than those covered.

IV. Familiarity with the dimensions of known objects when near enables us to compare them when remote and thereby judge their relative distance.

V. By moving from one standpoint to another and comparing the new view with what is retained in memory of the previous one, parallax of motion thus contributes to the formation of a judgment of both distance and form.

The mere synopsis of these elements is all that is necessary; separately they are familiar enough, and to illustrate them would be easy. Every one of them may be employed in the use of each eye, either separately or in conjunction with its companion. For distances of more than 240^{m} the binocular observer has no advantage except that two eyes receive more light than one, and the combined external image hence appears brighter and more distinct. All of them except the last may be imitated in pictures, and some of them, notably the second, may be heightened by the magnifying effect of lenses. In study-ing binocular vision they must be eliminated as far as possible; and all except the first may be nearly eliminated by using only skeleton pictures. In ordinary stereographs their combined effect is usually greater than that due to binocular perspective.

If for convenience we apply the term physical perspective to the combined effect of the elements enumerated, then that of focal and of axial adjustment may be called physiological perspective. The latter might be regarded as mathematical if the theory set forth at the beginning of this paper were strictly applicable in all cases. It is well known that focal adjustment does not vary sensibly for distances of more than 6^m, and that its effect is greatest just beyond the near limit of distinct vision, which is also about the average distance at which a stereoscope card is held when regarded. It is also well known that in normal binocular vision, the convergence of axes does not vary sensibly for distances of more than 240^m. In abnormal vision convergence may be diminished until the limit of parallelism is passed; and the judgment of distance continues to be affected by the relaxation of the interior rectus muscles, or contraction of the exterior rectus, or by both, while the focal adjustment is still adapted to the distance of the object in front held as near as convenient. The judgment of distance which results from the conflict of elements produced by this unusual coördination of muscular actions is necessarily by no means mathematical in accuracy.

While the possibility of securing divergence of axes for normal eyes has been long known, no analysis of the visual phenomena in binocular vision by this method has appeared in print, so far as I am aware. Professor LeConte's diagrams show how to determine the apparent direction of the object viewed, but he says,* "there is no point of sight." There is certainly none determined by intersection of visual axes. In reference to images perceived by abnormal vision, Helmholtz says,† "we judge them according to their nearest resemblance; and in forming this judgment we more easily neglect the parts of the sensation which are imperfect than those which are perfectly apprehended." In combining stereoscope pictures by axial divergence, either with or without the instrument, I secure vision so clear that no defect is appreciable at any point however carefully scrutinized; it does not seem necessary then to assume that any parts of the sensation are neglected. The case was very slightly otherwise during my first experiments in divergence. He makes also the following observation, that I translate from the French edition, which is the latest, of his work on Physiological Optics:‡ "When we compare a stereoscopic

* This Journal, III, vol. ix, p. 163.

† Popular Lectures on Scientific Subjects, 1st series, p. 307.

‡ Optic Physiologique, p. 828, edition 1867.

image, observed by divergence of the visual lines, with very remote real objects visible above the stereoscope, such as a remote chain of mountains, the stereoscopic image appears to us much more remote than real objects the most distant.' The apparent anomaly of binocular vision without convergence of axes he refers, in this connection, to our "comparing the sensation produced with that which resembles it the most, and which is not distinguishable from it but by feebler convergence, that is, with what very remote objects give us." So far as axial divergence alone is effective, I am unable to sustain Helmholtz's observation; nor is it sustained by those whom I have tested, every one of them giving results closely accordant with my own, care having been taken to prevent any previous knowledge of my object in questioning them. All that is essential is to secure axial divergence and compare the binocular effect with the monocular effect of the same picture, if the original landscape be not present. Before me is a stereograph representing Alpine scenery, which I combine binocularly, with from 2° 17′ to 2° 40′ of divergence, as foreground and background are successively regarded. On closing the left eye, the apparent distance of a remote mountain is not perceptibly diminished; indeed on account of the decreased brightness of the monocular image, the mountain seems slightly farther. To eliminate physical perspective as much as possible, this being always strong in pictures of landscapes, a stereograph is now taken, representing a white marble statue against a dark background; the stereographic interval can be varied at will, the card having been cut in two. Placing this in the stereoscope, the two pictures are drawn apart until 5° of axial divergence is attained, the experiment being made at a window from which an extensive landscape can be seen for the purpose of comparison. By no effort of imagination can I estimate the apparent distance of the statue to be more than 10^m. A stereograph representing a skeleton cone is now substituted, but with the same result.

It may be safe to say therefore that if Helmholtz was examining, by axial divergence in the stereoscope, a picture of the same landscape that lay actually before him, the mountains in the picture appeared farther off than those with which they were at once compared by normal vision with both eyes, all the elements of physical perspective being the same in both cases. This is probably what he meant. But his remark is not necessarily or generally applicable when stereograph and landscape are unrelated. Mere divergence of axes is not enough to reverse physical perspective, but may modify it to some extent and introduce special illusions.

[To be continued.]