XLII.—*On the Conversion of Relief by Inverted Vision.* By Sir DAVID BREWSTER, K.H., D.C.L., F.R.S., and V.P.R.S. Edin.

(Read 6th May 1844.)

UNDER the name *Conversion of Relief*, an expression first used by Mr WHEATSTONE, I include all those optical illusions which take place in the vision of cameos and intaglios, of elevations and depressions, whether they are produced with opaque or transparent bodies,—on surfaces with or without shadows,—in reflected or transmitted light,—while using one or both eyes,—or by erect or inverted vision. In these various forms of the phenomenon, the illusion is modified by certain secondary causes, which were regarded both by Mr WHEATSTONE* and myself† as primary causes; so that we were led away, each in a different direction, from the right path of inquiry.

The phenomenon occurs in its most general and simple form, when it is produced by viewing a shadowless depression, or elevation, made in an extended surface, through an inverting microscope, or the inverting eye-piece of a telescope, and at an angle intermediate between 0° and 90° . In so far as I know, the phenomenon has never been thus limited, and, consequently, no explanation of it has ever been given. That which I shall now submit to the Society is capable of the most rigorous demonstration; and when it is once in our possession, we can have no difficulty in recognising the secondary causes which increase or diminish the influence of the primary one, and which, in its absence, are sometimes the immediate cause of the illusion.

Let A, Fig. 1, be a deep spherical concavity, and A', Fig. 2, a high spherical

Fig. 1.

Fig. 2.

convexity in an extended horizontal table MN, M'N', and let them be shadowless, or illuminated by a *quaquaversus* light, like that of the sky. If the observer, placed at a moderate distance, view these objects in the directions EA, E'A', either with

* *Phil. Trans.*, 1838, pp. 383, 384.

† *Edin. Trans.*, Vol. xv. p. 365; *Edin. Journal of Science*, Vol. iv. p. 97; and *Letters on Natural Magic*, p. 98.

one or with both eyes, his accurate appreciation of the distances EA , $E'A'$, will prove to him that A is a *concavity*, and A' a *convexity*; but if EA , $E'A'$ approach to equality, either from the distance of the observer, or from the shallowness of A , or the slight elevation of A' , he will cease to recognise any difference in the distances EA , $E'A'$, and will be unable to tell which is the convexity, and which the concavity. So great, indeed, is this uncertainty, that, from causes which he cannot discover, they will sometimes appear convex and sometimes concave. In this indetermination of the judgment, a touch of A , A' by the finger, or the introduction of a shadow, will remove or confirm the illusion, whatever it may be. The same result will be obtained, if we view A and A' vertically, with an erect or inverting eye-piece. In all these cases, we suppose that the circular, or rather the elliptical, base of the convexity or concavity is distinctly seen.

Let us now look at A , A' , at obliquities varying from 0° to 90° . In Fig. 1 the *concavity* A will have an elliptical section at all obliquities, till, at 90° , it appears a straight line; but in the *convexity* the effect is very different. In passing from 0° to the position E' , Fig. 2, the circular section of A' will appear an ellipse; but in passing from E' to 90° , the appearance of A' will lose all resemblance to A . When the eye is at e' , for example, the summit A' of the convexity will cover the point a of the table, and am will be invisible; and near 90° , the convexity A will eclipse the whole surface of the table mM , however extended it may be, and will rise above it.

Let us now suppose that the eye at E , Fig. 3, views the concavity A through the inverting eye-piece EGH , the horizontal table MN must obviously be inverted as well as the hollow A ; but the *apparent* change, produced by inversion, is very different from the real change. The surface MN , out of which A is excavated, and upon which the observer leans, and rests the lower end H of his inverting eye-piece, appears to remain where it was, and still to look upwards, in place of appearing inverted, and looking downwards. When he strikes the table with the end H of the eye-piece through which he looks, he believes that it is the lower end of the field of view that strikes the table, and rests upon it. With these convictions, he sees what is represented in Fig. 4. The concavity mAn , Fig. 3, appears inverted; and as the visible part of the concavity Am , Fig. 3, is nearest the eye in Fig. 4, and the invisible part An , Fig. 3, farthest from the eye in Fig. 4, mAn must ap-

Fig. 3.

Fig. 4.

pear a concavity in Fig. 4, solely because it seems to rise out of the surface MN, which looks upward, as if it had not been inverted by the eye-piece.

Now, in this experiment, the conversion of the concavity into a convexity depends on two separate illusions, one of which springs from the other. The *first* illusion is the belief that the surface MN is looking upwards, whereas it is really inverted, as shewn in Fig. 5; and the *second* illusion, which arises from the first, is, that the point *n* appears *farthest* from the eye, whereas it is *nearest* to it, as shewn in Fig. 5. All these observations are equally applicable *mutatis mutandis* to the vision of convexities; and hence it follows, that the conversion of relief, occasioned by the use of an inverting eye-piece, is not produced directly by the inversion, but by an illusion, in virtue of which we conceive the remotest side of the convexity or concavity to be nearest our eye when it is not.

In order to demonstrate the correctness of this explanation, let the concavity *m A n* be made in a *narrow stripe* of wood, as in Fig. 5, and let it be viewed, as formerly, through the inverting eye-piece. It will now appear, as in Fig. 5, really inverted, and free from both the illusions which formerly took place. The narrow surface MN being now wholly included in the field of view, and the thickness NO of the stripe of wood distinctly seen, the inversion of the surface MN, which now looks downward, will be at once recognised. The edge *n* of the concavity will appear *nearest* the eye,* as it really is, and *the concavity, though inverted, will still appear a concavity*. The very same reasoning is applicable to a convexity on a narrow stripe of wood.

When, as in Fig. 4, the concavity is seen as a convexity, let it be viewed more and more obliquely. The *elliptical margin of the convexity will always be visible*, which is impossible in a real convexity; and the elevated apex will gradually sink till the elliptical margin becomes a straight line, and *the imaginary convexity completely levelled*. The struggle between truth and error is here so singular, that while one part of the Figure *m A n* has become concave, the other part retains its convexity!

In like manner, when a convexity is seen as a concavity, the concavity loses its true shape, as it is viewed more and more obliquely, till its remote elliptical margin is encroached upon by the apex of the convexity; and, towards an inclination of 90° , the concavity disappears altogether, under circumstances analogous to those already described.

If, in place of using an inverting eye-piece, we invert the concavity *m A n*, by

* The inversion of an object never makes the *nearer* part of an object *more remote*, nor the *remote* part *nearer*.

looking at its image in the focus of a convex lens, it will sometimes appear a convexity, and sometimes not. In this form of the experiment the image of the concavity, and consequently its apparent depth, is greatly diminished. Hence any trivial cause, such as a preconception of the mind, or an approximation to a shadow, or a touch of the hollow by the point of the finger, will either produce a conversion, or prevent it.

In the preceding experiments we have supposed the convexity to be high and the concavity deep and circular, and we have supposed them also to be shadowless, or illuminated by a quaquaversus light, such as that of the sky in the open fields. This was done to get rid of all secondary causes, which interfere with and modify the normal cause when the concavities and convexities are shallow, and have distinct shadows, or when the concavity has the shape of an animal, or any body which we are accustomed to see convex.

Let us now suppose that a strong shadow is thrown upon the concavity. In this case the normal experiment, already explained and shewn in Fig. 5, is much more perfect and satisfactory. The illusion is complete, and invariable when the concavity is in an extended surface; and it as invariably disappears when it is in a narrow stripe.

In the secondary forms of the experiment, the inversion of the shadow becomes the principal cause of the illusion; but, in order that the result may be invariable, or nearly so, the concavities must be shallow, and the convexities a little raised. At great obliquities, however, this cause of the conversion of Form ceases to produce the illusion, and in varying the inclination from 0° to 90° , the cessation takes place sooner with deep than with shallow cavities. The reason of this is, that the shadow of a concavity is very different at great obliquities from the shadow of a similar convexity. The shadow never can emerge out of a cavity so as to darken the surface in which the cavity is made; whereas the shadow of a convexity soon extends beyond the outline of its base, and, finally, throws a long stripe of darkness over the surface on which it rests. Hence it is impossible to mistake a convexity for a concavity, whenever its shadow extends beyond its base.

When the concavity is a horse or a dog upon a seal, it will often rise into a convexity when seen through a single lens which does not invert it; but the illusion disappears at great obliquities. In this case the illusion is favoured, or produced, by two causes: the first is, that the convex form of the horse or dog is the one which the mind is most disposed to seize; and the second is, that we use only one eye, with which we cannot measure depths as well as with two. The illusion, however, still takes place when we employ a lens *three* or more inches wide, so as to admit the use of both eyes, but it is less certain, as the binocular vision enables us to keep in check, to a certain degree, the other causes of illusion.

The influence of these secondary causes is strikingly displayed in the follow-

ing experiment. In the armorial bearings upon a seal, the shield is often more deeply cut than the surrounding parts. With binocular vision the shallow parts rise into a convexity sooner than the shield, or continue so while the shield remains concave; but if we shut one eye, the shield then becomes convex like the rest. In these experiments with a single lens, a slight variation in the position of the seal, or a slight change in the direction or intensity of the illumination, or particular reflections from the interior of the stone, will favour or oppose the illusion. In viewing the shield, or the deepest portion, with a single lens, a slight rotation of the seal round the wrist, backwards and forwards, will remove the illusion, in consequence of the eye perceiving that the change in the perspective is different from what it should be.

In a paper in the *Edinburgh Journal of Science*, already referred to, I have described several other examples of the conversion of form, in which inverted vision is not employed. As seen by the naked eye, hollows in *mother of pearl*, and other semi-transparent bodies, rise into relief; and the same thing happens on surfaces of agate and woods of various kinds, when transparent circular portions are illuminated by refraction, at those parts of their circumference where they would have been illuminated had they been convexities.* But the most interesting cases of conversion of form are those in which *the mind alone* operates, and receives no aid either from inversion, shadow, or monocular vision. “If we take, as I have elsewhere remarked, one of the Intaglio moulds, used in making the bas-reliefs of that able artist Mr HENNING, and direct the eyes to it steadily, without noticing surrounding objects, we may coax ourselves into the belief that the Intaglio is actually a bas-relief. It is difficult at first to produce the deception, but a little practice never fails to accomplish it. We have succeeded in carrying this deception so far as to be able, by the eye alone, to raise a complete hollow mask of the human face into a projecting head. In order to do this we must exclude the vision of other objects; and also the margin or thickness of the cast. This experiment cannot fail to produce a very great degree of surprise in those who succeed in it; and it will, no doubt, be regarded by the sculptor (who can use it) as a great auxiliary in his art.”†

From these observations it will be seen that the conversion of Form, excepting in the normal case, depends upon various causes which are effective only under particular conditions; such as the depth of the hollow or the elevation of the relief—the distance of the object—the sharpness of vision—the use of one or both eyes—the inversion of the shadow—the nature of the object—and the means

* In examining, under the microscope, the shallow fluid cavities *within* the substance of a film of sulphate of lime, described in the *Edinburgh Transactions*, vol. x. p. 35, they frequently appeared as *elevations* on the surface of the plate next the eye.

† *Edinburgh Journal of Science*, No. VIII. p. 109, Jan. 1826.

used by the mind itself to produce the illusion. In the normal case, however, where the cavity or convexity is shadowless, and upon an extended surface, and where inverted vision is used, the conversion of Form depends solely on the illusion, which it is impossible to resist, that the side of the cavity or elevation next the eye is actually farthest from it—an illusion not produced by inversion, but by a false judgment respecting the position of the surface on which the form is placed.

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