

II.—*On the Principle of testing Object-glasses by Miniatures of Illuminated Objects examined under the Microscope, especially of Sun-lit Mercurial Globules; and on the Development of Eidola or False Images.* By Dr. ROYSTON-PIGOTT, M.A., F.R.S., F.R.A.S., F.C.P.S., formerly Fellow of St. Peter's College, Cambridge.

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PLATES XCIX., C., AND CI.

THE method of examining miniatures as a means of testing objectives, as fully described in the 'Transactions of the Royal Society,' offers some intrinsic advantages not attainable by the examination of objects placed immediately upon the stage. For want of this method, it has hitherto been impracticable to develop the splendid interference phenomena of sun-lit mercurial globules, which can only be perfectly seen by the means of magnified miniatures.

Comparison of the enlarged miniature with its original is so facile and self-testing, that the merest tyro can at once declare whether the image shown when highly magnified agrees with the thing itself. For instance, if he detects a kind of white smoke or fog or coloured haloes about the bright points of the miniature, he knows that there must be error somewhere. On the contrary, all doubt as to quality and goodness of definition is completely barred out, when the enlarged image emerges sharp and clear and brilliant in all its details. This can only happen when all the rays, whether *white* or *coloured*, emanating from each single point, are made to converge again into one and the same point in the image. The white rays, if achromatic, but not aplanatic, create a white mist: the coloured rays, prismatic haloes.

And this brings me to the standard principle of perfect definition, viz. that the image of a given point shall not be a confusion of images of that point, but one single point. But to attain this

DESCRIPTION OF PLATES XCIX., C., AND CI.

FIG. 1.—Shows the arrangement for illuminating artificially a mercurial globule by means of a prism: the miniature is formed in the focal plane of the observing object-glass.

- „ 2.—L M the focal plane of vision: aberrating rays intersect in this plane and produce the diffraction phenomena which assume their peculiar forms according to obliquity, kind of correction, and quality of the glasses.
- „ 3-14.—Show the elegant and delicate varieties of diffractions, in different stages of obliquity and correction.
- „ 15, 16, 17.—Display of the conic sections into which the phenomena arrange themselves.
- „ 18.—Apertures forming luminous disks and eidola out of focus.
- „ 19.—An exceedingly minute brilliant disk out of focus.
- „ 20, 21.—Wire gauze and its eidola.

perfection, how much genius, patience, and manipulative skill, knowledge of the various kinds of glass and curvatures required, the makers of such perfection can alone declare. The continual abandonment of old forms and combinations, formerly thought the *ne plus ultra* of art, and the adoption of new, sufficiently vindicate a former declaration that perfect corrections had not then been attained; but that the future is full of hope is shown by recent improvements still made in the face of such refined difficulties.

In my first paper, Dec. 1869, I stated the residuary aberration in the best glasses might be reckoned at the 50,000th of an inch. This small matter seems insignificant; yet in defining a single bead the sixty or even the thirty thousandth of an inch, such an error cannot be despised.

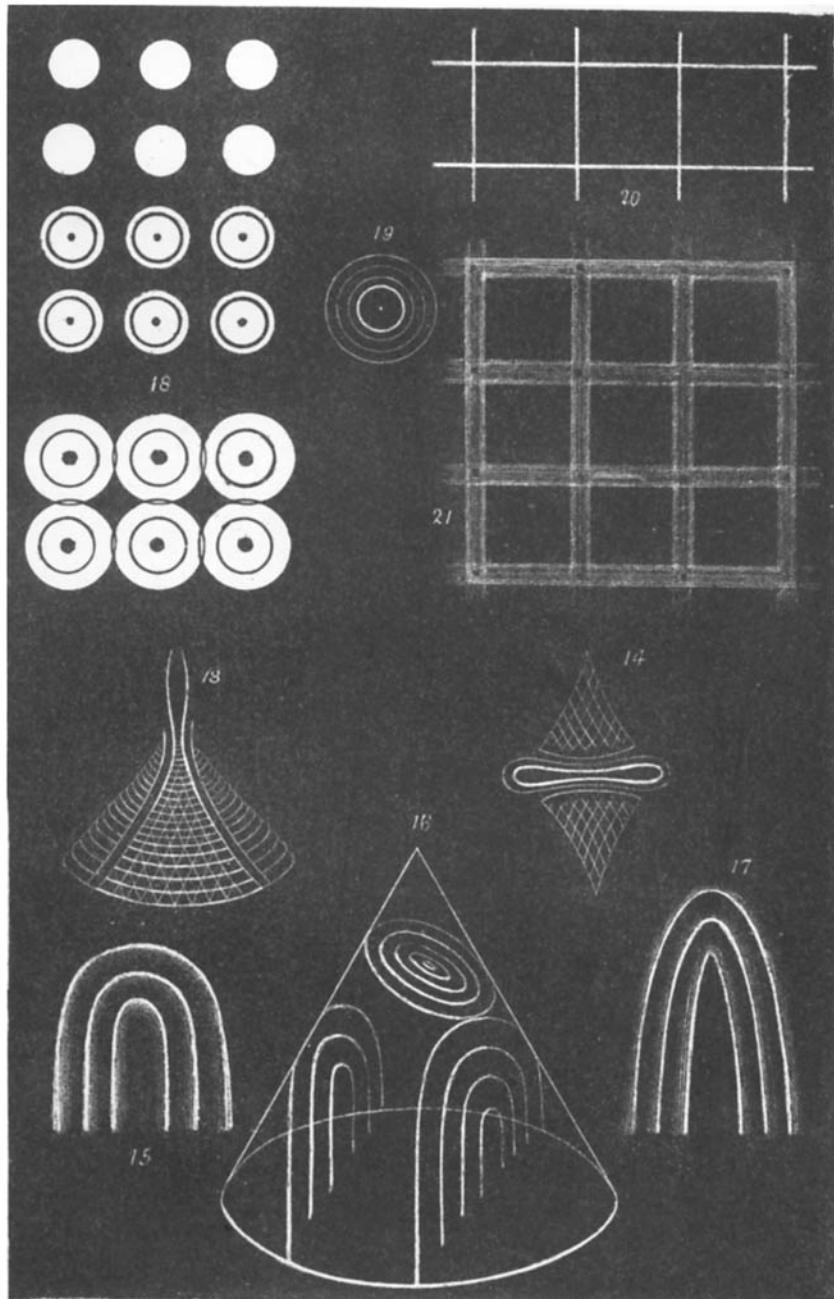
In the older glasses, the effect of this aberration (often much larger than this) was to cause a series of beads to run into each other. I have ever found, as the definition became more and more refined, these objects appeared smaller and smaller with the same magnifying powers. Our Honorary Secretary, Mr. Slack, noticed recently that in Powell and Lealand's new construction (not yet issued) the beading of the *Angulatum* appeared under a power of 4000 with an eighth much smaller than usual: *in short, more "widely divided."*

A bad glass, it may now be stated, unduly enlarges a point: if it be black, it is diluted as it were into a larger and paler area than the truth. In the same way a fine line, which is an assemblage of points, appears thickened and blurred: I have even here noticed dark diffraction rings\* surrounding dark points.

If the point be brilliant, it has special developments as to its appearances as the glasses depart more and more from perfection. And these developments take their own peculiar forms according as the point is itself an origin of light—a reflector or a transmitter of light. They also vary with the directness or indirectness of illumination, and with the position of the line of vision.

If a globule of mercury of exceeding minuteness is placed upon the stage, illuminated as best we may, and then be viewed with a  $\frac{1}{18}$ th, only a very imperfect picture of the illuminating flame is exhibited by the globule, in consequence of the great inconvenience of the closeness of the objective to the stage and the limited range

\* These may often be seen in gold leaf placed between two glasses and illuminated by sunlight by transmitted light. The beautiful malachite green of the film of gold will be seen perforated in many places with apertures of any degree of minuteness, each displaying diffraction rings; the best objectives will show an intensely black border round each aperture, and as the focussing is changed, over the general surface dark points will be seen to swell and shrink, and dark diffraction rings may be noticed correspondingly to expand and contract with great regularity. The behaviour of a good glass may be strikingly contrasted with that of an inferior quality when tried upon this gold-leaf test, which I strongly recommend, especially when transmitting solar light.



of illumination. Those who may have tried this plan will best appreciate the difficulty and trouble attending the experiment.

The method of miniatures is entirely free from this embarrassment.

An object-glass of very fine quality, and in an inverted position, is screwed into the sub-stage.

On black velvet are scattered, from a syringe containing mercury, a number of mercurial globules; then, by means of a Reade's prism, a brilliant light is thrown vertically downwards upon them. The object-glass to be tested is now employed in the usual way, screwed to the nose of the microscope. The two objectives are brought to a central position, so that their axes coincide, and the instrument is then adjusted to form miniatures of the globules for examination. The most beautiful effects are seen under sunlight; and most of those which I shall have to describe are so produced.

These miniatures will develop appearances of marvellous beauty and variety, according to the following circumstances of their employment:

(1) Coincidence of the axes of the observing and miniature-making objective.

(2) Particular corrections, either spherical or chromatic, of either.

(3) (Which is included in the last), the distances at which the original globules are placed from their miniature images.

It is also worth remarking that the aperture of the miniature-making objective should be at least as wide as that of the objective to be tested, and of the finest quality obtainable, and furnished with a screw-collar. Also the choice of powers is a matter of taste and experience. It requires an excellent pair of objectives for diminishing and enlarging, in order to successfully develop the beautiful phenomena caused by the clashing as it were of the waves of light, commonly called *interferences*. As a rule, the observing objective should not be more than double the power of the diminishing objective used to form the miniature.

Some of the most beautiful effects have been produced by a most excellent  $1\frac{1}{2}$ -inch Ross for making the miniatures, and then observed with a  $\frac{1}{4}$ th Wray and a B eye-piece. Occasionally both objectives are used of the same power.

If it be remembered that at 10 inches an eighth diminishes an object 80 times, a power of 800 applied by the microscope will develop too much residuary error: 500 will present a more eligible image for examination.

Various objects may be used for miniatures. A small, brilliantly illuminated opened watch, in motion, is rather a surprising test. Fine glasses show the working parts of the watch, balance, &c., almost as plainly as the naked eye, under a power of 1000 diameters. Inferior glasses spread the miniature over with a *white*

smoke if achromatic, or it appears as through thin horn; but coloured lights play about if the achromatism is at fault.

It may be interesting to quote the 'Philosophical Transactions' here: that if the distance of the image from the original be 100 inches, the miniature, with an eighth, will be 800 times smaller.\*

Again, the sparkle of light on the miniature of a small thermometer as well as the visibility of the divisions on the ivory scale afford highly instructive lessons on residuary spherical or chromatic aberration. At a distance of 100 inches, if the thermometer scale is small, say 30 degrees to the inch, the miniature formed by an eighth 800 times as small will be the 24,000th of an inch; while the *divisions* on the miniature exceed the delicacy of Nobe's minutest lines. At 100 inches the image or miniature formed is in an over-corrected state, and the observing objective should probably be placed at "uncovered," or at least considerably over-corrected. If the miniature be corrected by closing the collar as much as possible, a similar effect should be introduced into the observing objective. Indeed, plying both collars at once will soon discover to the experimenter the peculiar correlations of the observing and miniature-making glasses.

I strongly recommend, however, what I may call the fundamental experiment,—a disk of intense light as small as possible; miniaturized from a distance sufficiently great to develop the test diffraction rings.

The appearance of one thick, broad, dull ring surrounding a planetary disk, I may say, was the first real insight I obtained into the real state of the best glasses I could procure. I then worked in a darkened room and with a shaded lamp; illuminating a minute aperture or pairs of apertures in blackened brass plate. These apertures were about the  $\frac{1}{100}$ th of an inch in diameter. But they were found afterwards to be a poor and insignificant substitute for sun miniatures, at this season so difficult of attainment.

The experimenter on these methods will occasionally be surprised at the very curious results obtained by viewing the same miniature with equal magnifying powers used differently.

For instance:

*Experiment.* A miniature landscape was formed by a small convexo-plane lens  $\frac{1}{30}$ th focal length and a lineal aperture of  $\frac{3}{100}$ ths, 0.03", placed on the stage, the tube of the microscope being directed

\* The formula calculated by the writer is there given:

$$f = \frac{d}{m + 2 + \frac{1}{m}},$$

from which it follows if  $m$  be large,

$$m = \frac{d}{f} - 2,$$

where  $m$  is the minimizing power and  $d$  the distance between object and miniature.

to an open window disclosing a lovely foreground. Eighth O.G. A low eye-piece: power 400.

*Result.* Landscape dark and hazy. *The deficiency of light was most remarkable.* The same power was now got from a half-inch and D eye-piece.

*New result.* An exquisite picture brilliantly lit up, even the glittering foliage twinkling in the sunbeams, and the garden details were marvellously displayed. This difference is truly surprising. *Increased light and superb definition with diminished aperture and same power.*

To those who have not yet tried this method, and are desirous of becoming acquainted with the peculiar effects of over or under correcting their glasses as far as their construction is capable, I may be permitted to recommend the following commencement with these experiments:

A. *Experiment for spherical aberration.* Remove the front glass of the observing objective. Examine the miniatures of the illuminated globules.

B. Remove the internal glasses and replace the front only.

C. Replace all the glasses and close up the screw-collar for the mark "covered" if there be one.

D. Open the collar for "uncovered" position. At the last point for the first time the miniatures will begin to more nearly resemble their original.

The various changes of the appearances of the miniature, to the student of this department of optics, form a most interesting study.

These phenomena, varying from a mild brilliance to a gorgeous splendour, according to the quality of the light, and its mode of exhibition, may be greatly varied by the *reverse process*, viz. changing the lenses of the *miniature-forming* glasses, just as done with the observing. Some of old Pritchard's exquisitely minute lenses mounted by him give very charming miniatures. But these form no test of the quality of the objective in use, because their aperture is extremely limited.

I now may be allowed to describe what has not before appeared before the Society—the singularly beautiful phenomena displayed by *miniatures of sun-lit mercurial globules*.

It is well known that the surface of minute globules of mercury becomes more nearly spherical as they diminish in weight. The law of the curvature of these surfaces, dependent upon the specific attraction of mercury, has been investigated by Professor Bashforth, though not yet published; and according to this law they seem incapable of forming a perfect image by reflexion. But under direct illumination (not that wild bull's-eye side illumination of the globule hitherto employed) a minute spectrum of the sun

may be described. The use of a good prism as a reflector gives a pure beam greatly superior to a quicksilvered plane mirror. On one occasion the subtle delicacy of the interference-waves of light was thus revealed, for the whole of a series of magnificent phenomena was wholly obliterated by substituting a plane ordinary mirror for the prism.\*

In the 'Proceedings of the Royal Society,' the appearances of a minute miniature of the solar disk, republished in this Journal, are so fully described, as dependent upon the quality and condition of the objectives employed, that I may be excused the trouble of recapitulation here. I proceed therefore to treat of the miniatures of illuminated globules of mercury. These may be dismissed with the general statement that the symmetry, beauty, and fineness of the diffraction rings are severe tests of the objective. And finally :

These rings are either wholly above or wholly below the focal point with a bright haze on the other side; or else equal and similar on both sides of the focal point; or altogether ill-defined.

The experimenter will soon ascertain for himself these various appearances. I therefore pass on to the effects of *obliquity*.

If the miniature-forming objective be slightly inclined, so that its axis has a few degrees of obliquity, a new order of effects display themselves of extraordinary beauty and complexity. Sun-lit globules suffice; but of course a minute focal disk of the sun in miniature gives more brilliant effects.

The conditions of over or under correction are beautifully seen, and the best possible adjustments still give very peculiar forms, some of which are shown in the accompanying drawings.

The most extraordinary of all is the curiously winged butterfly form: the cometary, double vase, and conical diffractions are well worth development. These very beautiful solar phenomena, as shown by a miniature of the illuminated globule, vary their exquisite forms according to the quality of the glasses, and according as they are over or under 'corrected, and according to

\* The same destruction of beauty and symmetry occurs with a badly constructed screw-collar, whose movements decentre the component lenses: a very little error in this mechanical adjustment produces huge derangement. Better is a glass of lower aperture without such source of error, than a large aperture and loose adjustment. Indeed, a trifling difference of thickness in the glass cover introduces much milder error than the shake of the adjusting screw causing central displacements. Besides, if the glass be a little thicker than before, a slight extension of the draw-tube will compensate for thickness with extreme nicety. Lengthening the tube "over corrects," whilst a thicker glass introduces "under correction." In the case of telescopes with *fixed glasses*, I have never been able to persuade an optician to clean old glasses and reset them: it is almost always a total failure: nothing is more delicate and difficult than exactly centring the lenses of a telescope, an instrument which seldom magnifies more than 500 times. How much more difficult then must be a *movable* construction of the many lenses of a microscopic object-glass, which is used for much higher powers!

the obliquity at which the miniature is formed in the field of view by inclining the sub-stage. The surpassing beauty and perfection of these figures thus obtained by the magnified miniature of the mercurial solar star, render it probable that the obliquely illumined mercurial globule, viewed *directly* in close proximity to the front of the object-glass of the microscope, and placed upon the stage, is a very imperfect test; and the methods here described are submitted as possessing very superior delicacy and convenience. The perfection of the diffraction lines cannot be displayed at all by the old method.

*Eidola.* With such instances of wonderful variation of the spectra formed by the miniature of a sun-lit mercurial globule, we may well suspect that innumerable diffraction images may be developed :

- (1) By obliquity of illumination.
- (2) By erroneous correction of the glasses.
- (3) By erroneous focussing.

I. An absolute knowledge of structure cannot be probably obtained by obliquity of illumination. Those structures which can only be thus seen are liable to distortion and misrepresentation.

*Example (1).* Display very fine gauze by oblique light and a low power a little out of focus, a complex structure is seen bearing very little resemblance to the reality.

*Example (2).* Treat the transparently-mounted eyes of an insect in the same way. The eidolic forms of delusion are endless. The diffraction effects are the most exaggerated when the illumination is most oblique.

II. *Example (1).* Illuminate perforated metal from behind in a darkened room; view an exquisite miniature of these perforations. The holes will appear enlarged; black dots take the place of apertures; haloes join haloes, and the images are altogether disguised and transformed according to the correction of the observing objective and the focal plane of vision employed.

*Example (2).* Fine copper wire gauze thus treated loses its apparent solidity. The meshes appear chequered with black dots, sharply defined, and the wires appear translucent. Thus in an unknown structure these false eidola might readily be mistaken for the true images. In this way a variety of forms having no reality start occasionally into almost tangible form and existence.

### III. Erroneous focussing.

Microscopists are not always agreed in viewing an unknown object which is the correct focal plane. And it is just possible that different observers with the same instrument and adjustment view a different focal picture.



The most peculiar difficulty of all is the existence of two sets of false images, viz. the one above and the other below the focal reality.

This is seen beautifully in miniaturizing (by the method now advocated) two distinct structures placed the one behind the other. In the case of the perforated metal the false images or *eidola* were made to exist in front of the true image. If therefore another structure were placed behind the first, the eidolic images of the one, as it were, will be mixed and confused with the real image of the other, and *vice versâ*.

The earnest microscopist, remembering the results he has obtained from miniatures of the sun-lit or lamp-lit globule, that the false image lies wholly above or below the best focal point according as the object-glass is over or under corrected, can have no difficulty in perceiving that also when viewing a duller object, a false image will similarly lie wholly above or below the real according to the corrections.

A corollary may be drawn from these principles, viz. that in duplex structures *the upper may be best seen by throwing the false image wholly below*, for then the *eidola* of the lower structure does not mingle with the true image of the upper. And conversely the lower structure is best seen when the false images are wholly above, for then the *eidola* of the upper does not mingle with the true image of the lower. In such cases under-correction best displays the upper and over-correction the details of the lower structure immediately subjacent.

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I now search among the *Quadrata* diatoms, and with a half-inch by Wray, of three lenses, I just discover a waviness like the early stage of *Podura* definition, of somewhat irregular pattern, two of these objects lying exactly over each other at right angles. Another half-inch by the same maker, with a C eye-piece, sharply defines these dark waves, and upon entering with a D the peculiar structure of these markings becomes delicately visible. A Ross  $\frac{1}{4}$ , 1851, resolves them; but the 1870 water-lens of Powell and Lealand's  $\frac{1}{8}$ th now exhibits a more remarkable pattern than the *Angulata*. On applying the finest powers of definition I possess, these markings disappear almost entirely, and the view is wholly confined to the upper surface; then alone clearly beaded.

I have just seen a beautiful example of illusion. On examining this evening a fine specimen of Möller's *Angulata pleurosigma*, I succeeded in finding\* several instances where two diatoms overlay each other at a favourable angle. On carefully illuminating with a small achromatic pencil of direct rays, with a blue shade, I dis-

\* With Powell and Lealand's dry eighth and C eye-piece about 800 diameters.

cerned very beautiful well-defined dark bars nearly parallel, with four rows of beads between each. The pattern is exquisite, and *varies with a change of the screw-collar*, but they look quite as real as the other structure. Here is a remarkable case of eidola. The images of the lower structure mix with those of the upper. These false images are best seen when the objects are overlaid at a slight obliquity. If they cross each other at a large angle, then these eidola change to large bright beading twice the natural size.

The transformation of appearances under the microscope by the application of a series of powers in order of power and merit, is a subject now worthy of special interest and development. For instance, the various plates and engravings of objects still extant, accumulated within the last fifty years, would upon patient investigation yield instructive results as to the causes of these optical misrepresentations, for such, with the extraordinary advances made in the goodness of modern glasses, we are now compelled to pronounce them.

I have the pleasure of recording here that just about four years ago I had the honour of first exhibiting to Mr. Slack many examples of eidola at my house.

The diagrams accompanying this paper represent various forms of interference phenomena developed by sun-lit mercurial globules, miniaturised either by a  $1\frac{1}{2}$ -inch Ross or a  $\frac{1}{2}$  Ross. The sub-stage of the microscope employed has several movements, made by the writer about ten years ago, which enable the operator to manage the miniature as easily as an object on the stage, and also to give great obliquity. The examination of oblique pencils coming from the miniature, as to their conditions of achromatism or aplanatism, whether well or ill corrected, is thus rendered particularly easy and interesting. The figures given represent some of the many forms developed by different conditions of correction and obliquity.

I should state that the Figures 3-14 were copied from sun-lit globules at my house by Mr. Hollick, of 135, Tufnell Park Road, Holloway, N.