XXV. *On a Searcher for Aplanatic Images applied to Microscopes, and its effects in increasing Power and improving Definition.* *By* G. W. Royston-Pigott, *M.A., M.D. Cantab., M.R.C.P., F.C.P.S., F.R.A.S., formerly Fellow of St. Peter's College, Cambridge. Communicated by Professor* Stokes, *Sec. R.S.*

Received March 31,—Read April 28, 1870.

In the observations which I have the honour to submit to the Royal Society, I purpose at present* to describe as briefly as possible—

I. Some experiments which suggested an inquiry into a method of raising microscopic power consistent with a corresponding improvement in the precision of definition, so generally destroyed by excessive amplification.

II. I next purpose to give some account of the inquiries by which the construction of an aplanatic-image searcher was gradually arrived at; the object of which was to search for aplanatic foci, to compensate residuary errors by new spherical and chromatic corrections whilst amplifying power, and to increase the small interval existing between a deep objective and its object, whilst the focal perspective or depth was also increased.

Such an inquiry,—in the present elaborated delicacy of adjustment accomplished in microscopes of the highest quality, especially when armed with "immersion sixteenths" which have alone succeeded in resolving Nobert's most delicate bands, embracing lines 112000 to the English inch,—would seem either superfluous or futile.

The research was originally suggested by the accidental resolution of the Podura scale. This exquisite object, so justly prized by the optician for the trial of microscopes, affords peculiar markings resembling notes of admiration, of sufficient delicacy to put even the defining-power of objectives of one-fiftieth of an inch to a severe ordeal. I had observed these markings to disappear and be resolved into black beads. The objective employed had nearly one-seventh of an inch focal length, and an aperture of 50°. The object was illuminated by solar rays reflected obliquely by a plane mirror. Having related this effect to eminent opticians, I was informed that no objectives (at that time 1862) could resolve this test. I prevailed on them, however, to construct a "very fine" one-eighth

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* The writer may here perhaps be allowed to offer an explanation of the delay in presenting this Memoir, notwithstanding the substance had been verbally communicated to Professor Stokes so early as the summer session of 1869.

It had been intended to give a much more extended account of the results obtained, and for this purpose, during the following autumn and winter, an extended paper was being prepared. In 1870 further delay seemed undesirable, and accordingly a new and brief memoir was drawn up of which the present paper forms a portion.

expressly for this resolution; as this totally failed, a one-sixteenth was carefully constructed with no better success, and finally a one-fourth of very large aperture; all these failed to exhibit the Podura beading*. Some unsuspected cause of this failure evidently remained to be investigated. The evidently delusive character of the standard test, so much relied upon for the construction of microscopic object-glasses, suggested the necessity of a search for other less uncertain methods of testing. The principle of proceeding from the known to the unknown appeared to offer the only sound basis of inquiry.

Simple objects were now examined. The finest glass threads presented linear images of any conceivable degree of proximity, whilst their fused extremities, when selected as forming refracting spherules one-thousandth of an inch in diameter, presented miniature landscapes and points of light of remarkable precision, the spherical aberration of which could be easily calculated to be of insignificant amount for limited apertures. Even a plano-convex lens of one-thirtieth of an inch focal length and three-hundredths aperture displayed, though uncorrected, miniature pictures of marvellous beauty, bearing considerable amplification; whilst a combination of achromatic lenses corrected with all the resources of modern art, seemed capable of forming an exquisitely small image of any given object placed at a distance from it, the appearance of which, when examined by the microscope to be tested, could at once be verified by the object producing the miniature test. When suitable precautions are taken—such as (1) axial coincidence of the objectives; (2) proper corrections for an "uncovered" or aërial, or for an aqueous image when immersion lenses are employed, and for the distance of the object from the image-forming objective,—these miniature test-images bear an extraordinary amount of amplification by the microscope, displaying at once the erroneous corrections. I have found it convenient in general to use the image or *miniature*-forming objective of a deeper focus than the observing, generally one-half.

The following experiments, as elucidating the operation of this testing, will, it is hoped, explain its critical powers. The mechanical arrangements are shown by diagrams, figs. 1, 1 *a*, Plate LII.

Experiment 1.—Miniature of a small thermometer, the ivory scale being graduated 24° to the inch. A power of 300 diameters, gained by a low eyepiece "A" and the objective of one-eighth focal length (made expressly for Podura beading-test), was applied to view the miniature formed by a one-sixteenth objective of excellent quality; and the following appearances were carefully noted at the time of observation.

Result.—The sparkle of light on the bulb of the instrument, the graduation, and the metallic thread within the glass tube are invisible, obscured by a nebulous yellow fog which no objective adjustments are able to dissipate. Fig. 3, Plate LII. (fig. 5 shows improving definition).

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* Messrs. POWELL and LEALAND spared neither skill nor time in endeavouring to assist my inquiry; but with these glasses I signally failed to exhibit to them the new test (1864).

In consequence of this unexpected discovery, regarding the quality of a "very fine" one-eighth, it was returned to the opticians to their surprise for better compensation. It was then, after more accurate compensation by them, again submitted to precisely the same testing conditions.

New results.—Appearance of a slight nebulous yellow cloud through which could be distinctly seen the ivory scale finely graduated, the bulb sparkle, and even minute separated mercurial particles scattered within the glass stem (fig. 7).

The definition had been therefore decidedly reformed. Previously, however, to the alteration, experiments had been tried for the purpose of ascertaining whether a defective glass would still form a fine miniature. It might be reasonably expected that such slight errors as had escaped the notice of eminent opticians would not materially injure a miniature image in which the aberration would probably be reduced in the miniature itself. The image of the thermometer now formed with the imperfect eighth was viewed with a fine sixteenth (at about 800 diameters), when it was gratifying to observe a very beautiful display of the picture well defined in all respects (fig. 4).

These and other experiments appeared to warrant an important conclusion—that an image-test miniature formed by an objective of fair quality enjoyed sufficient accuracy of definition in miniature (even when the object was placed at varying distances from the stage or focal point of vision) to form a trustworthy test of microscopical definition, provided the aperture of the miniature-forming objective was equal to that of the objective to be tested.

To estimate the size of a miniature (α) of a given object (θ) placed at a considerable distance (d) from the miniature (fig. 1 a), it is necessary to consider that the conventional focal length F of an objective may be defined to be 10 inches divided by the micrometric ratio of amplification (m) when the image is thrown on a screen 10 inches from the object, so that

$$\mathrm{F}=\frac{10}{m}, \text{ when } d=10,$$

or

$$m=\frac{10}{\mathrm{F}},$$

$$\propto\frac{1}{\mathrm{F}}, \text{ when } d \text{ is constant.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

When very deep objectives are used (fig. 1) the position of the plane of focal vision varies very slightly for a considerable increase of the length of the microscope, so that if the draw tube be graduated, the increase of power is nearly proportionate to the increased length or reading, because the focal plane being nearly fixed, the image will appear upon a screen enlarged proportionally as its distance (d) increases. On reversing the rays, the miniature diminishes in proportion as a given object is removed further from it: from which it follows that approximately, and sufficiently near for the purpose in hand,

$$m \propto d \text{ when F is constant.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Compounding these expressions (1) and (2),

$$m \propto \frac{d}{\mathrm{F}} = p \cdot \frac{d}{\mathrm{F}}.$$

The constant $p=1$; for if m be made equal 160, the conventional focus $\mathrm{F}=\frac{1}{16}$, when $d=10$, and hence (d being large and F small) approximately,

$$m=\frac{d}{\mathrm{F}} \quad \ldots\ldots \quad (3)$$

If (f) be the focal length of a small lens whose thickness is neglected, a very similar approximate result can readily be obtained from the optical formula

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}.$$

For by construction

$$u+v=d,$$

and by similar triangles

$$mv=u.$$

Eliminating the unmeasured distances u and v of the object and image from the "centre" of the lens, it will be found that

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

and m being very large in these experiments,

$$f=\frac{d}{m+2} \text{ nearly*}, \quad \ldots\ldots \quad (4)$$

or

$$m=\frac{d}{f}-2. \quad \ldots\ldots \quad (5)$$

But in the case of the miniature images employed, m is so large that (-2) may be neglected, so that $m=\frac{d}{f}$ is sufficiently near for their measurement.

The thermometer was now placed 100 inches distance from the microscopical focus; the one-sixteenth being employed to form the image, $f=\frac{1}{16}$, $d=100$; hence

$$m=100 \div \tfrac{1}{16}=1600 \text{ very nearly.}$$

The divisions on the thermometer would be therefore reduced in the image to a miniature 1600 times less than the original, or about 40,000 to the inch, whilst the breadth of a single line would be only the 400,000th.

The means being thus obtained of readily estimating the size of images of known objects at known distances, the examination of immersion objectives next occupied my attention. Double stars were artificially produced in thin brass ($\frac{3}{100}$ of an inch thick) by placing minute apertures ($\frac{12}{1000}$ in diameter) in front of a brilliant flame, at the

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* This method also gives the focal length of a minute lens, to determine which accurately is attended with no little difficulty.

distance of 100 inches from the focal point of observation (fig. 9, Plate LII.). The apertures were so arranged as to gradually exhibit closer double disks (as shown roughly in fig. 9), which were carefully drawn on brass under the microscope and then accurately pierced. The miniature effect of the star-doublets is represented in the following Table, the immersion one-sixteenth objective being converted into one-twentieth*, so that f here$=\frac{1}{20}$, $m=2000$ at 100 inches distance (nearly).

Doublet.	Size of disks.	Calculated size of images nearly.	Distance between their centres.
No. 2.	$\frac{12}{1000}$	$\frac{1}{166000}$	$\frac{1}{40000}$
No. 3.	$\frac{12}{1000}$	$\frac{1}{166000}$	$\frac{1}{20000}$

It will be readily seen from the diagram (fig. 8) that, in No. 2 the disks being $\frac{12}{1000}$ and the separating interval between centres being $\frac{1}{20}$, the actual dividing interval is $\frac{38}{1000}$, or above three times the real diameter of each disk.

Experiment 2.—A drop of distilled water being suspended between the objectives, both of which were fitted with single front "immersion lenses," I was astonished to find that the separating interval (accurately measuring $\frac{38}{1000}$ of an inch) between the centres of the disks had totally disappeared in the miniature image. The disks now resembled a finely divided double star just separated by a black line, yet this minute interval should have appeared above three times the diameter of a disk, as at B in fig. 6 & BC fig. 8. Apparently, therefore, in the eyepiece, spurious disks had been formed four times and one-sixth larger than a true aplanatic representation by the microscope†.

It follows from this experiment that if the disks be supposed to gradually diminish to points, the limiting value of the residuary spurious disks would give nearly $\frac{1}{52000}$ of an inch for the diameter of the least circle of confusion, representing the actual amount of residuary lateral aberration.

This appears from a diagram, where in the limit (fig. 8) $EF=4AE$, when AB, CD both vanish in the case of the disks being reduced to points.

The phenomena presented by these artificial doublet-image tests, gave fine evidence of the skill employed in the construction of the glasses, and of the accuracy with which the axes of the optical parts had been made to coincide in this delicate experiment.

All the disks appeared sharply cut and planetary (fig. 10), surrounded with a black ring supplemented by accurately formed diffraction rings, which enlarged and glowed with

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* By the adaptation of a "water-lens" one-thirtieth inch focus.

† It will be observed in this experiment that the standard distance of 9 inches at which the object should be placed from the objective was increased to 100. It was found that only a very slight adjustment of the screw collar of the image-objective was necessary to compensate for this great increase of defining distance. It is hardly necessary to remark further that in a minute miniature image the aberration is insignificant compared with that taking place in a greatly magnified image of an object placed in the focus. This distinction is inseparable from this experiment, as already explained.

The minute apertures, made accurately with Swiss watchmaking-tools, were carefully blackened, to prevent internal reflexion, with a solution of perchloride of platinum.

prismatic colours, both within and without the sharpest focal point or image, forming concentric intersections, displaying coloured pencils passing either to or from their finest point of focal combination where colour should be destroyed (fig. 6).

Experiment 3.—The disks (λ) shown by the apertures $\frac{12}{1000}$ of an inch in diameter, and separated between centres $\frac{1}{20}$, were now brought nearer to the objective O'. It was then observed that the image-disks (of above four times their proper size) began to separate; and since the spurious disk retains its false *annular* expansion independent of the true magnitude, it became evident that the exact distance at which the test doublet was first divided, gave for other objectives a comparative measure of their aberration; the very slight aberration in the image (of the sixteenth) being scarcely appreciable, especially when favoured by the advantage of the water-film to enhance the precision of definition on the immersion system.

By such experiments, with the finest glasses obtainable, the existence of an aberration of material and measurable amount being thus established, the next question to be settled assumed the following character, viz.

What was the nature of the aberration produced by displacement of the final focal image viewed by the eye-lens; and whether better effects could be produced by a different distribution of the magnifying-powers.

It was now found that increasing the distance between the eye-lenses and the objective, gained power indeed, but caused the aberration to increase faster than the power gained.

Intermediate Huyghenian eyepieces, inverted, were found to increase power but sacrifice definition; the apparent aberrations seemed incorrigible, so that this plan was finally abandoned in 1864. Although by this means the *Pleurosigma rhomboides* was fairly shown to Messrs. POWELL and LEALAND, with their one-sixteenth objective (dated 1862), they stated this method had been tried long before and relinquished as useless to improve definition.

Sliding-tubes (made by them at my request) were now furnished with a "universal screw," in order to admit a great variety of single and compound cemented lenses (more or less chromatically and spherically corrected) being inserted within the draw tube midway between the eyepiece and the objective. So, also, whole or parts of objectives were similarly applied, thus forming a microscope within a microscope admitting endless combinations of compensations.

It now seemed perfectly clear that any attempt to improve high-power definition must be preceded by the attainment of a ready and decisive method of ascertaining whether the balance of compensations was equal, or, on the other hand, over- or undercorrected. The *Image-test* already described appeared to effect this object in the following manner. The finest glasses, it is well known, are constructed upon the principle of balancing compensations, the effect of the posterior combinations when overcorrected compensating that of the anterior glasses which are undercorrected. To ascertain therefore the indications of the character of a given correction (still employing the exquisite images formed by " the sixteenth") wire gauze, forty meshes to the inch, was placed in front of a brilliant light; the image of the gauze was distinctly visible under the one-quarter objective (×250 diameters) finely corrected for an uncoverd object.

To ascertain the appearances due to *overcorrection*, the front glasses were removed; whilst to examine those of undercorrection the front set alone was employed, the inner glasses being removed.

First result.—The image no longer appeared like gauze, but displayed (unless the aperture was reduced) extraordinary patterns, prismatic, translucent, and, as it were, chequered or plaid-like; all of which were situated entirely *above* the best focal point, and nothing but a confused nebulous field *below it.*

Second effect.—The employment of the front lenses alone now reversed the position of these appearances.

Readjusting all the glasses, it was then discovered that the false images were developed principally below the best focal image (ascertained by reducing the aperture of the microscope*) when the objective was undercorrected, and above it when overcorrected. Brilliant images of glittering particles of mercury scattered on black cloth *nearly vertically* illuminated, fine gauze 80 meshes to the inch, perforated metal, gold-leaf displaying against a brilliant light immeasurably small perforations exposed on a rich malachite green ground†, were submitted to be examined in miniature as test-objects. From a variety of experiments of this kind the following data were arrived at, to guide preliminary observations:—

That when any well-defined structure is viewed by the best microscopes, there exist *eidōla*‡ or false images on each side of the best focal point.

That they are placed principally above or principally below the focal point of centrical pencils, according as the glasses are over or undercorrected; and that for a *single* stratum sufficiently thin, these eidola are nearly symmetrically exhibited on both side, of the best focal point only when the compensations are perfectly balanced.

It follows from these results that when a structure consists of two superimposed strata, in such close contiguity as to come within the optical limits of the *eidola*, the false images of the lower stratum are liable to be confused and commingled with the true image of the upper stratum when the objective is overcorrected, and when it is undercorrected the false images of the upper are confused with the true of the lower stratum.

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* The true image is at once seen by reducing the aperture; for this purpose a system of circular stops was applied to the microscope at the part where the objective is attached, admitting an instantaneous change in the aperture, and showing remarkable effects produced by change in the excentric aberration. Its mode of attachment is shown at β, fig. 1, Plate LII., where it is marked *aberrameter*.

† The gold-leaf is mounted on a slide in the ordinary way, and exhibits interesting and instructive phenomena.

‡ Εἴδωλον.

These coincidences of eidola with true focal images may in both cases equally delude the observer.

The next question was the most favourable distribution of the elements of magnifying-power. According to a well-known optical principle, it seemed desirable to bend the rays by less sudden refractions. It is a peculiar result that when the incident and emergent pencils are equally bent so as to be equally inclined to the axis of an equiconvex lens, that then only is the aberration a minimum.

The effects of different distribution of power are well shown by the following experiments, in both of which the same amplification was employed of 400 diameters.

Experiment 4.—A miniature landscape formed by a convexo-plane lens $\frac{1}{30}$ focal length and $\frac{3}{100}$ aperture was examined with the one-eighth and an "A" eyepiece: axis horizontal and window open.

Result.—Landscape dark and hazy, as seen in the microscope.

The deficiency of light was most remarkable.

The same power (400) was now obtained with the half-inch objective and a D eyepiece.

Experiment 5.—The miniature being formed as before by the small lens, the microscope was now again brought into operation on the minute image horizontally.

Result.—Exquisite picture brilliantly lit up; even the foliage glittering in the sunlight was sharp, clear, and decisive, so that the details of the garden picture were marvellously displayed.

The difference appeared truly surprising as regards the two methods of obtaining the same magnifying-power, especially the increased light *with diminished aperture.*

In both these cases the greatest pains were taken to properly adjust the index collars of the objectives for the finest possible definition of an uncovered object.

A new fact had appeared highly suggestive of further inquiry. Accordingly, distribution of power was now varied by employing differently constructed eye-lenses, especially "crossed lenses"[*], and *inserting, midway between the objective and eyepiece, convex lenses* of great variety. It was now seen that these lenses, intermediately placed, developed an entirely new aberration of a negative kind[†]. It became important to decide

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[*] Crossed lenses, well known to give a minimum aberration having the radii of their curved surfaces as 6:1.

[†] It is convenient to define the aberration to be positive or negative, or the lens to be *over-* or *undercorrected,* by the simple fact that a convex lens causes the excentrical rays to cross the axis at a point nearer the centre of the lens than the centrical rays, in which case, and in all analogous cases, it may be said that the lens is undercorrected and afflicted with a negative aberration. English objectives are now constructed on the principle of having the posterior sets overcorrected and the anterior undercorrected so skilfully as to destroy, by opposite errors nearly, the residuary aberration; but the opinion may be hazarded that future combinations will yet be found which will completely throw into the shade the present powers of the microscope, when perhaps we shall be in a better position to attempt to determine the microscopical features of molecular life, at present probably beyond its grasp, as no single particle so small as the *sixty-thousandth* of an inch in diameter can be clearly defined if isolated, until residuary error is very much reduced.

It is to be regretted that the precise nature of the marvellous combinations invented by Professor AMICI for whether compensations of aberration could be effected by attending to some definite principle or law.

The previously ascertained properties of *eidola* enabled many experiments to be made with rapidity and certainty. The following principles were, in short, patiently arrived at by experiments extending over several years:—

I. Displacement of the final focal image towards the eye-lenses, provided the front lens or facet of the object-glass is kept at the same distance from the object under observation, is caused by approximating even slightly the component adjusting lenses of the objective, and this movement causes a negative aberration, and *vice versâ.*

II. With test-images, both observing and miniature or image-forming objective follow the same law of compensation. If one be overcorrected the other must be similarly adjusted, and *vice versâ.*

III. Using additional compensating lenses to gain increase of power, intermediately placed between eyepiece and objective, the finest definition is obtained when each of the three sets, viz. lenses, observing and image-objective, are similarly though slightly overcorrected, as compared with a standard defining distance of 9 inches.

Although a fine definition seemed now attainable by means of supplementary compensating lenses, if judiciously introducing balancing compensations, yet their practical adjustments were innumerable and tediously accomplished*. At this stage of the research, frequent consideration of the well-known optical equations for a vanishing aberration fortunately suggested to me the idea of searching the axis, mechanically, for aplanatic foci. In reference to these equations, which would be out of place here, it has been observed by Dr. PARKINSON, F.R.S.†, "If the aberration for rays parallel at incidence of a compound lens of given focal length—consisting of several thin lenses in contact—be examined, it will consist of a series of terms similar to that in Art. (129), one term for each lens, and the condition that the aberration shall vanish will lead to an equation involving more than one unknown quantity, and consequently admitting an unlimited number of solutions."

In the distribution of the power-lenses, and in the application of a traversing searcher, it was indispensable that the object should be kept distinctly visible in the

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objectives remain unknown. As one of the Jurors in the Paris Exposition, his microscope necessarily remained both uncelebrated and unelucidated in the Reports.

* During 1865–1869 many experiments were tried with complete objectives and various parts of them, either over- or undercorrected by means of a sliding-tube carrying them and fitting into the "draw tube."

Professor LISTING of Göttingen has confirmed the value of this method of amplification quite independently in two papers published in 1869. Nachr. d. kgl. Gesell. der Wissensch. 1869, No. 1, and Poggend. Annalen, 1869, vol. xvi. p. 467 ('Nature,' Jan. 27, 1870).

In the first he recommended an inverted Huyghenian eyepiece, and in the second intermediate achromatic lenses.

As regards intermediate lenses, the writer has ascertained (Nov. 1870) that Dr. GORING (Micrographia, ed. 1837) has anticipated both these methods.—Note added Nov. 1870.

† GRIFFIN's 'Optics,' by PARKINSON, p. 122, 2nd ed. 1866.

field of view, by a proper selection of lenses whilst the optical compensations were being adjusted. The form finally adopted is simply this:—

A pair of slightly overcorrected achromatic lenses, admitting of further correction by a separating adjustment, are mounted midway between a low eyepiece and the objective, so as to admit of a traverse of 2 or 3 inches by means of a graduated milled head. These lenses are conveniently traversed within the draw tube; and can be brought to bear within 4 inches of the objective, or at a distance of 10 inches.

The focal length of the combination forming the aplanatic image-searcher may vary from $1\frac{1}{2}$ inch to $\frac{3}{4}$ of an inch. The latter applies more effectively to low objectives when it is desirable to obtain extraordinary depth of focal penetration, and vision through very thick glass*—as with a half inch giving 700 diameters with a C eyepiece. I possess a WRAY half-inch objective† which bears an E eyepiece and searcher. It should now be stated that the searcher may be employed with very different intentions. Thus—

When it is desirable to view an object through a very thick refracting medium, the searcher is brought as close as possible to the objective, which action lengthens the focus of the objective; and the same thing is necessary when the observer wishes to throw the *eidola* of an upper structure above and away from the true image of the lower but contiguous stratum—as when the lower beads of the Podura are required, or when it is required to give additional negative aberration to an objective too positively corrected in which the front glasses are already forced into a dangerous proximity.

On the contrary, when the searcher is traversed the opposite way, the *objective lenses* require to be brought nearer together; the instrument is then more adapted for viewing objects or particles lying in the upper plane of a complex structure, throwing the *eidola* of the lower layer below that layer itself, and so leaving the upper stratum less disguised by the false images of the lower.

In intermediate cases, where greater penetration or focal perspective is required, with a thin glass cover, the objective lenses must be proportionately separated by an increased interval, the searcher being traversed towards the objective; and in general confused images of both upper and lower strata can be obtained by opposite arrangements‡.

A very interesting refinement upon the corrections for chromatic effects may be accomplished by gradually traversing either way both searching and objective lenses and closely watching the effect.

The most brilliant definition is generally obtained when the searcher (a little more overcorrected) is used as close to the objective as possible.

The overcorrection of the searcher is increased by separating its component lenses according to the divisions upon the sliding tubes of the searcher.

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* Nearly one-fourth of an inch thick.

† With a "Kelner" two-thirds of an inch focal length, a very clear, very large, and flat field is presented to the eye, notwithstanding the increased power with the searcher. A one-and-a-half-inch objective by Ross was used generally for a condensing illuminating apparatus more or less stopped off.

‡ Such as separating the objective lenses and traversing the searcher further from them.

It will be seen that an exceedingly small pencil engages the surface of the searcher diverging from a point in the image $p_{\prime} q_{\prime}$, which is inverted again at $p_{\prime\prime} q_{\prime\prime}$. As the searcher is traversed nearer the eye the pencils become less divergent, and the effect of the searcher is diminished. On the contrary, as it approaches the objective, $p_{\prime} q_{\prime}$ being formed nearer to the latter after refocusing, a *more* divergent pencil engages a greater aperture of the searcher, and this now automatically causes a stronger overcorrection than before. The essential action of the searcher is to apply a rapid variable correction by a traversing movement (fig. 2, Plate LII.).

The use of this instrument will be facilitated by first setting the microscope for ordinary use without the searcher, adjusting an eyepiece, the focus, and screw-collar to the most distinct vision, and then applying the draw tube containing the searcher placed at a point nearest to the eyepiece E. As the searcher is traversed towards the objective, the lenses of the objective may *require separation.*

The change in the general aberration is shown by the divided index of the milled head actuating the movement of the searcher (M, fig. 1).

The power obtained is in general from two and a half to four times greater than that given with the third eyepiece C of 1 inch focal length: with a very fine eighth of Messrs. POWELL and LEALAND'S *new* construction, a clear and satisfactory definition of the beading of the *Pleurosigma formosum* was exhibited to them, by means of the aplanatic searcher, at a power *estimated* at 4000 diameters*. Several inferior objectives have acquired a fine definition by the application of the searcher.

This paper perhaps will hardly be complete if I omit to add, that the instrument will be most effectively employed by considering it as a conjugate portion or integral part of the objective itself, in which the minute traversing adjustment of the objective lenses finds its counterpart in the more extended and therefore more delicate adjusting traverse of the searcher itself. So that, in short, during minute microscopical research each adjustment should be intelligently applied, according to the nature of the research in hand. The indications of the one adjustment should be employed to verify those of the other. Correlative movements by the aid of the searcher may introduce aplanatic images, whilst a violation of their correlation will exhibit deformity.

I ought also to state that I have found in every case, either an extra thickness of glass cover or a deeper immersion of a given object in the film of Canada balsam (or other fluid used for mounting it) to require for a precise definition additional adjustment; the searcher should be made in this case to traverse towards the object to attain the new correction requisite. The same remark is applicable to immersion lenses. Further slight improvement can be effected in the precision of definition by separating more or less the component glasses of the Huyghenian eyepiece (the power of which is preferred as low as 3-inch focal length for the $\frac{1}{20}$ "immersion") or by substituting for it a single

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* The usual power of the one-eighth with a C eyepiece is 800; a power of 4000 is given by an eyepiece of one-fifth of an inch focal length.

achromatic combination slightly overcorrected for spherical aberration of 2 inches focal length, or less according to the power required*.

An additional cap containing a supplementary achromatic lens is sometimes advantageously fixed upon the lenses of the searcher, when (for instance) a power of 700 diameters is desired to be developed by a half-inch objective (for test *Podura* beading).

In conclusion, the experiments detailed in this paper, selected from a great number made within the last few years, it is hoped will induce more able observers to repeat them in a more general form; but, so far as they are detailed, they appear satisfactorily to demonstrate the detection of residuary aberration of considerable amount in the very finest microscopes, and enable one to measure it and to suggest means of diminishing the errors of the glasses whilst greatly increasing the power. Whether a similar method can be applied also to telescopes has been some time under the author's consideration, with results which he hopes on a future occasion to have the honour of communicating to the Society.

APPENDIX.

The law of displacement followed by the final focal image corresponding to a minute displacement of the internal lenses of a complex objective, the front lenses or facet *remaining fixed*, possesses some interest and may thus be expressed:—

Let F be the distance of the final focal image when the objective lenses are closed together.

$F+\delta F$ its distance when the front sets of the objective are displaced by a quantity δx.

Then it will be found if f_1 be the distance of the virtual image conjugate with the *object* as formed by the front set of lenses,

$$\delta F : \delta x :: -F^2 : f_1^2;$$

and consequently every slight change of the screw-collar of an adjusting objective produces comparatively a very large displacement in the final focal image, and therefore of the traversing image-searcher; so that the searcher-traverse represents a movement conjugate with the objective index. Again, since this traverse towards the objective encounters rays of increasing divergence, an increasing breadth of pencil is encountered by the lenses of the searcher, and its own peculiar aberration receives an instantaneous increase, which introduces an important new element in definition, it having been observed that the glasses must be very gradually overcorrected as the image is formed nearer the objective, within the tube of the microscope.

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* I may be permitted to add a note here (Nov. 7, 1870), that a WRAY one-fifth, made expressly, admitted of as great amplification as an ordinary one-twelfth. In fact these researches appear to point decisively to greater advantages to be expected from raising the quality of the lower objectives rather than deepening focal length. Observers are more numerous every year who prefer the ooe-eighth to the one-twenty-fifth and one-fiftieth.

EXPLANATION OF THE PLATES.

PLATE LI.

Plate LI. is intended to represent the working powers gained by the use of the Aplanatic Searcher by means of comparative outline drawings of a given "scale" taken by Mr. ALDOUS with the Camera under the magnifying-powers and objectives indicated.

Fig. 1. The standard appearance of the Podura under the $\frac{1}{50}$, $\frac{1}{25}$, and $\frac{1}{8}$ POWELL and LEALAND objectives.

Fig. 2. Resolution of the lower beads of Podura.

Fig. 3. The beads of the upper stratum.

Fig. 4. Comparative magnifying-power of the $\frac{1}{8}$ objective with the searcher, and also in the ordinary way with a "third" eyepiece, C, of 1 inch focal length.

Fig. 5. General appearance of the wavy markings of the Podura, consisting of beaded ribbing faintly visible here with a pocket-lens.

Fig. 6. Both sets of beading exhibited at once.

Figs. 7, 8. Ordinary and extraordinary appearance of Lepisma.

PLATE LII.

This Plate shows the image-test arrangements of the objectives and object of which a miniature is desired, and also the construction of the searcher.

M. The divided milled head of the traversing aplanatic searcher, consisting of separable lenses, A, B, having a variable interval, x', between them. The searcher traverses the draw tube, into which is fixed the eyepiece E. R, M are adjusting milled heads of the stage supporting the image objective O′ (fig. 1 *a*).

O, O′, fig. 1, fig. 1 *a*, are the objective to be tested and the miniature-forming $\frac{1}{16}$ immersion objective, giving an image α of the object θ, or double disks λ, illuminated by a lamp, δ.

γ represents the focal adjustment, and

β the aberrameter inserted into the nose of the microscope containing two revolving disks forming central and peripheral stops.

Fig. 2 represents the course of the rays from the object Q to the last focal image $q_{\prime\prime}p_{\prime\prime}$ erected.

Fig 7

Lepisma

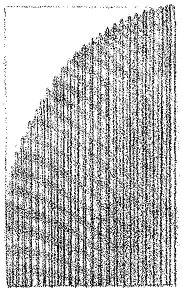
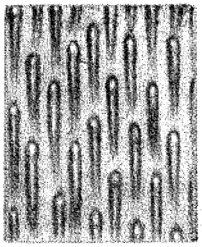


Fig. 1 *2500 diameters.* Fig. 2



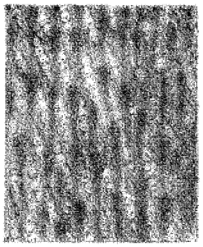
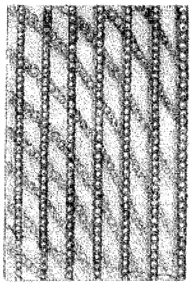
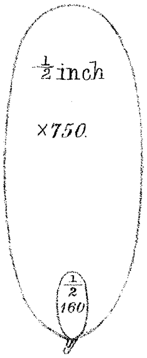


Fig 8

Lepisma





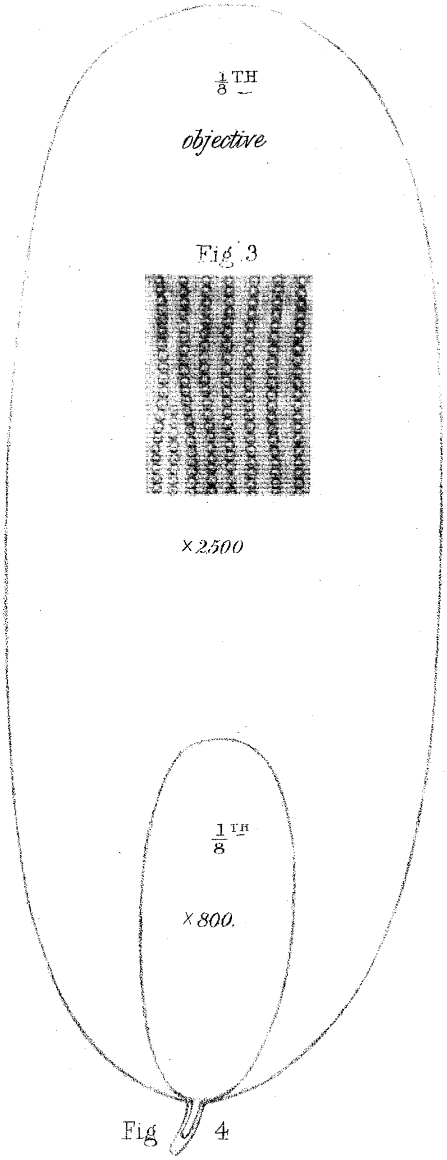
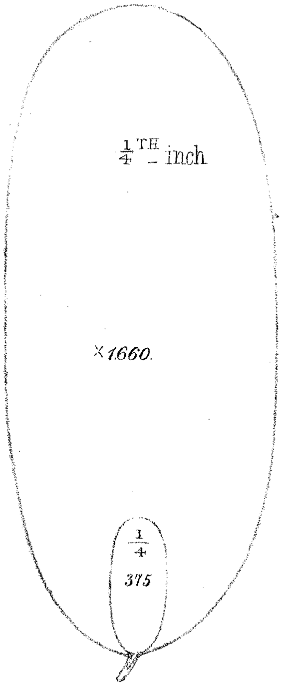


Fig 4



×900.

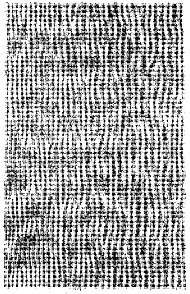


Fig. 5

×1800.

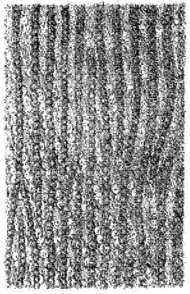


Fig. 6

Structure of the Podura Scale.

Lens Aldous del. et lith. ad Nat with Camera Lucida.

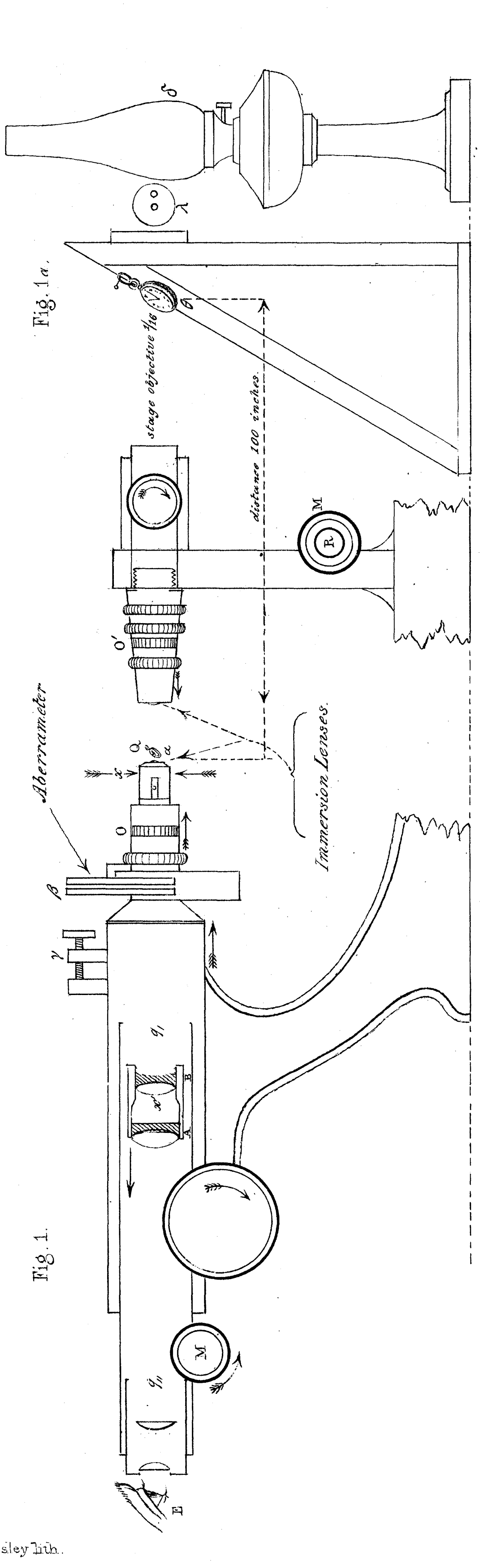
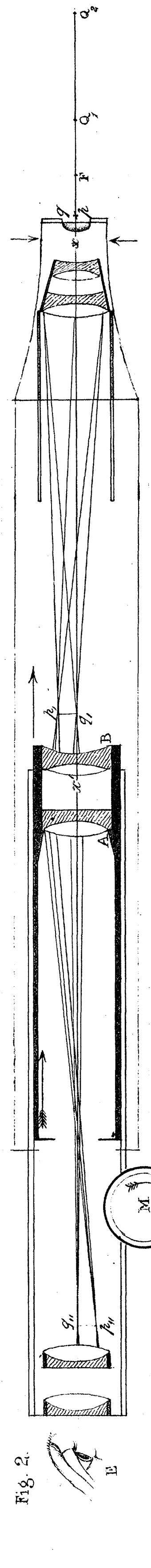


Fig. 1.

Fig. 1 a.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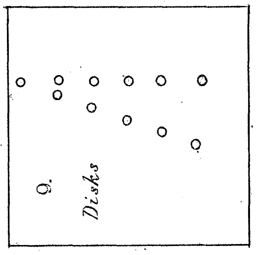
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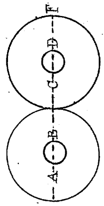
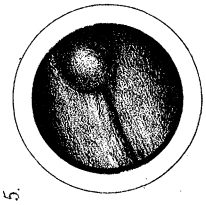
Disks


8.


10.

Planetary disks.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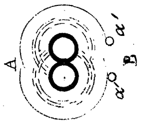
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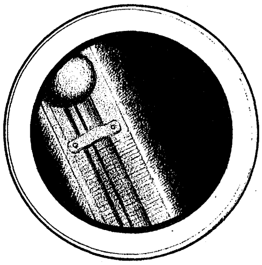
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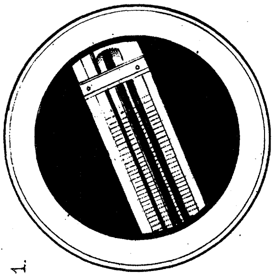
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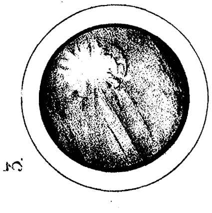
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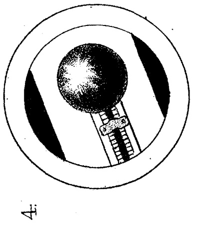
4.