ON EYE-PIECES

FOR

TELESCOPES AND MICROSCOPES.

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WHEN I invented the graphic telescope (described in Vol. L. of the Society's Transactions), the chief obstacle was in the eye-piece; the usual achromatic eye-pieces shewing the image beautifully distinct, but with all the lateral lines so curved as to become useless for any purpose of art: and, as perfect truth of form in every part of the image is the chief requisite for a drawing instrument, I was obliged to give up the perfect correction of colour to obtain truth of form; but as low powers are the most useful in drawing from nature, the loss from imperfect correction is not so much felt as I at first feared.

Although the compound microscope, as well as the astronomical telescope, requires truth of form along with the most accurately defining power, these two qualities have not, to the present time, been well reconciled, so as to be found in the same eye-piece. Yet there are resources in optical science which, I believe, are fully able to effect this union in the most satisfactory manner.

I therefore propose giving a full view of the three principal eye-pieces: namely, the achromatic, which is used both in the astronomical telescope and the compound microscope; the micrometer eye-piece, used by Ramsden; and a variation of it which I use for my graphic telescope and microscope: in order to shew every effect produced by their lenses on the pencils of light, and so lead to the perfecting them; and also to enable persons who use these instruments to know how to alter or adopt them to suit any particular purpose, without causing that deterioration which otherwise is so liable to occur.

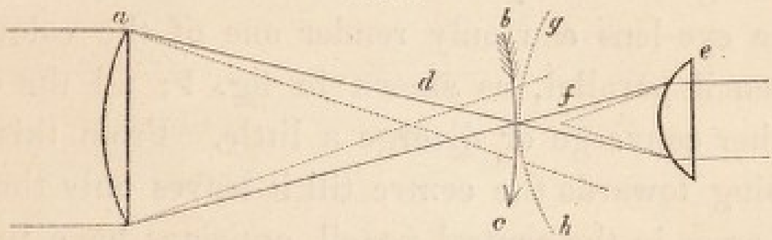
Great magnifying powers must evidently be first obtained by the object-glasses or specula, and to them, accordingly, workmen have directed their chief attention; but many who have succeeded in this difficult task, and have produced really excellent object-glasses, have quite neglected the eye-pieces, and have in consequence greatly impaired the performance of their object-glasses.

As eye-pieces are never used alone, and are not intended to receive every sort of light, but to act on particular pencils presented to them from an object-glass, it will be requisite first to consider what sort of light it is that is so presented, and to know how it may be altered to suit the purpose. We may, therefore, begin with a single lens for an object-glass with a single eye-lens, and take only the central pencil of rays.

A pencil of rays consists of that portion of the rays of light which enters an object-glass from any point of an object; consequently, there are as many pencils as there are points in the object. The lens causes all these to converge to their separate foci, in a curve of which itself is the centre; therefore, all the pencils that we use begin as cones, having the object-lens for their base, and may be considered as originating there, because it limits their diameter.

It is well known, that when light passes through a single lens it is separated into the different colours, and that red rays are the least, and blue rays the most refrangible. Therefore, an object-glass like *a*, fig. 1, will have three foci; the longest one will be red, the next yellow, and the shortest blue: if we place the arrow *b c* on the red focus, then the dotted lines may represent the blue rays meeting together in a shorter focus at *d*. Let *e* be an eye-lens, so placed that its red focus meets that of the object-glass at the arrow *b c*; it will then refract the red

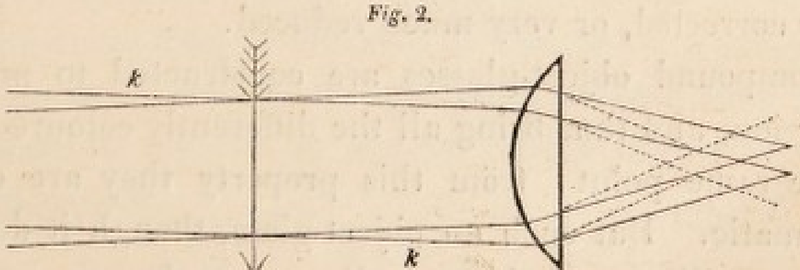
Fig. 1.



rays into a parallel pencil, a condition requisite to give distinct vision; but the blue rays having crossed at *d*, they will be dispersed to right and left of the red pencil, and, instead of helping to give vision, they will only confuse the image by causing coloured margins; in addition to this evil, the eye-lens also has its focus for blue parallel rays shorter as at *f*. So the two foci *f* and *d* must meet to enable the blue rays to give distinct vision, which, of course, would put the red out of focus and cause as much confusion.

Having traced the course of the central pencils, let us examine the lateral pencils, and we shall find another evil, increasing with the diameter of the eye-lens. Fig. 2

Fig. 2.



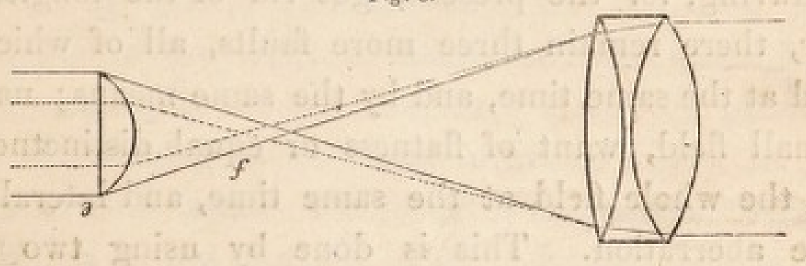
shews two lateral pencils *k k* arriving at the eye-lens with the imperfections just stated; this lens, besides rendering them parallel, deflects them towards the axis, so that the eye receives them at the same time with the central pencils; but the eye-lens has deflected the blue rays, as shewn by the dotted lines, more than the red, and this will cause the image, as viewed by the blue rays, to appear under a larger angle than by the red rays, hence arises the blue margin to the field, and a blue inner and red outer margin to every dark feature in the field of view, and the eye-lens can only render one of the colours in each pencil parallel, as shewn in fig. 1; all the others will either converge or diverge a little. From this error decreasing towards the centre till it leaves only the first-named error in the central pencil, opticians have been in the habit of saying that all eye-lenses perform well at their centre, whereas they only perform less ill as their aperture is reduced, and not perfectly well even at the centre.

Single eye-lenses will bear only a small aperture on account of the lateral error increasing with the diameter, and this small aperture, taking but few pencils from the object-glass, gives but a small field. The object-glass gives the image in the curve *b c*, fig. 1, whilst the dotted curve *g h* is demanded by the eye-lens, to enable us to see the whole image distinctly; so that, in addition to its having a small field, a small part only is distinct at one time.

I will now shew the means by which these errors are either corrected, or very much reduced.

Compound object-glasses are constructed to prevent dispersion, and thus bring all the differently coloured rays to the same point; from this property they are called achromatic. But such an object-glass, though it does in practice, will not mathematically, serve the purpose, because we do not make the lenses of the eye-piece achromatic also; therefore, to enable the eye-lens to conduct all the coloured rays of the central pencils parallel into the eye, the object-glass must be over-corrected—it must protrude the blue and yellow foci exactly as much beyond the rod, as the blue and yellow foci of the eye-lens are shorter than its red focus. Fig. 3 describes such a case, the dotted lines representing the blue rays, which cross at the blue focus *f* of the eye-lens, and are refracted into a

Fig. 3.



smaller parallel pencil than the red rays; but this has not yet been found to produce any ill consequence, as the eye brings them all together on the retina. Now, the deeper the eye-lens, or, in other words, the shorter its focus is, so much less will be the difference between its blue and red foci. Therefore, if an object-glass were over-corrected to suit a lens one quarter of an inch in focus, it would want four times as much over correction to suit an inch lens; from which this conclusion may be drawn, that an object-glass ought to be constructed in its achromatism for a given power, and, though it might be so successfully made as to bear a higher, yet its most perfect performance would be with the power for which it was constructed. Thus we see the corrections for the longitudinal error of the eye-lenses may be included in that of the object-glass; and this is a fortunate circumstance, because none of the eye-pieces in use can in any way lessen this error in the central pencils.

In figs. 1 and 3 I have shewn only the central pencil, and have made it so large as nearly to fill the eye-lens; this proportion is scarcely like any thing in use, except the opera-glass and my smallest graphic telescope. Pencils of rays begin of the same diameter as the object-glass, and are reduced in size at their emergence from the eye-lens directly as the power, *i. e.* if the telescope magnifies 100 times, the diameter of each emerging pencil will be 100 times less than the object-glass.

Having, for the present, got rid of the longitudinal error, there remain three more faults, all of which are cured at the same time, and by the same means; namely, a small field, want of flatness or equal distinctness all over the whole field at the same time, and lateral chromatic aberration. This is done by using two lenses instead of one, of a certain figure, of a certain proportion of foci, and placed at a certain distance apart.

Fig. 4.

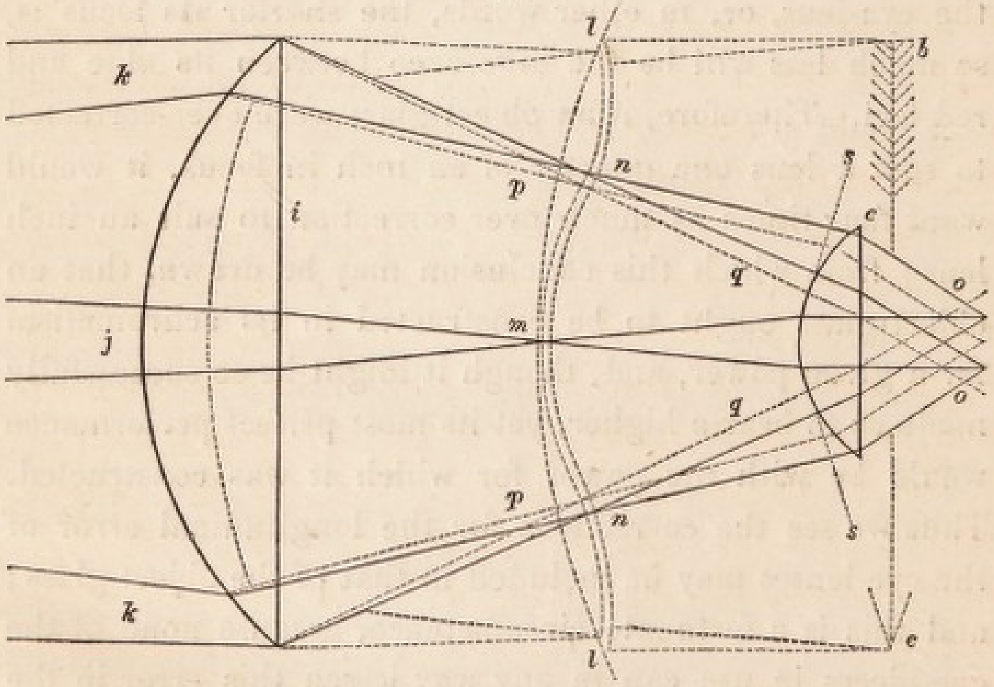
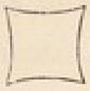


Fig. 4 represents one of the combinations that will effect these purposes; *e* is the eye-lens, and *i* the additional lens, called from its most obvious benefits, the field-glass; these are both plano-convex lenses, having their convex sides towards the object-glass. *j* is the central pencil, and *k k* two lateral pencils proceeding from the object-glass, which forms the base to all these cones. If the eye-piece was removed, these various conical pencils would proceed to their foci at *b c*, and give the image shewn by the dotted arrow, and curved the wrong way for being viewed through an eye-glass; here the field-lens is placed considerably within the focus or nearer to the object-glass, it will consequently shorten the focus of all the pencils; but its middle being by its whole thickness nearer to the object-glass, will shorten the focus of the central pencils most, and, if it did nothing else, it would remove the image *b c* into the opposite curve *l m l*, which would be some gain. The field-lens always has a large aperture, but thus far it may be considered, and really acts, as an assemblage of lenses with very small apertures, as numerous as there are pencils of light to pass through it; but, being made altogether in one, a circular series of prisms may be considered as added to them, which causes it at the same time to have deflected the lateral pencils *k l* from *l l* to *n n;* consequently the image *b c* will be reduced into the smaller curve *n m n*, and this is the very curve required by the eye-lens, every part being equi-distant or in focus, so the whole image will be seen at once distinctly.

The second benefit is a large field; for the lateral pencils *k b* and *k c* pass wide astray from the eye-lens, and would be lost; but the field-glass having deflected them towards the eye-lens, they enter it and are still more deflected towards the axis, in parallel pencils *o o*, where the eye receives them all under a very wide angle.

The third benefit is a complete correction of the lateral chromatic aberration. The field-glass has brought the image into the right curve *n m n*, retaining a portion of the over correction originally effected by the object-glass. This portion is represented by the distance between the two parallel curved lines *n m n*, which have hitherto been treated as one curve. The over correction first produced by the object-glass was much greater than the distance between these lines, but it has been reduced to this quantity by the field-lens, which has taken up the amount required by it. The first curve *m* is that in which the red rays of the various pencils will now cross, whilst the blue will extend to the second curve *n n* and cross there; the small difference between these two curves is to be made to correspond with the difference between the blue and red foci of the eye-lens, by which it will be enabled to refract both the red and blue rays in parallel pencils to the eye, and so far give perfect vision; but, in addition to this, the coloured rays of the outer pencils will be separated laterally, the red rays will be deflected only as shewn by the continuous lines *k n*, whilst the blue will be deflected nearer to the axis, as shewn by the dotted lines *p q*. If the rays had not been so separated, the blue would be over deflected by the eye-lens, as shewn in fig. 2; but this previous deflection has caused them to impinge on the eye-lens nearer to its centre, where, owing to the difference of angle they make with its surface, they will not suffer so much deflection as the red; consequently both will emerge in pencils of parallel rays lying parallel with each other, as shewn by the lines and dotted lines *o o*.

Thus, three very important objects apparently irreconcilable, are obtained; a large field, equally distinct in every part, and freedom from colour. But these are not obtained without loss, for the eye-lens magnifies the lateral portions of an object more than the centre, and that evil has been increased by the means that has given equal distinctness all over the field; namely, by shortening the focus of the central pencils to make them all equi-distant from the eye-lens, for this has lessened the size of the central parts of the image, as will be fully shewn further on. Therefore, if we look at a square whose image fills the field, the four sides will be shewn concave, thus, . When the field appears very flat, it has been shewn that the image must in reality be curved to place all parts in focus at once; let the arrow, fig. 7, represent such a curved image. Whilst looking with one eye at this image we may see a rule with the other, and place it so as to appear to touch the image; the rule will then measure the middle portions of it almost correctly, whilst the ends of the image will appear to coincide with the points *r r* beyond the ends of the rule, and thus measure more than they ought; this joins with the other cause to destroy the true proportions. This imperfection in the form of the image is submitted to for the sake of the other good qualities of the eye-piece.

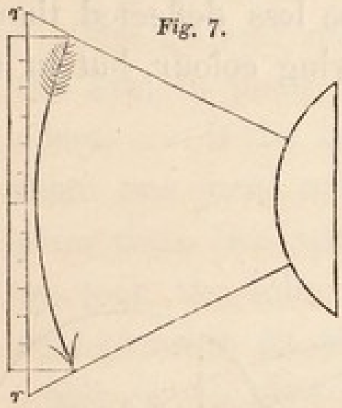
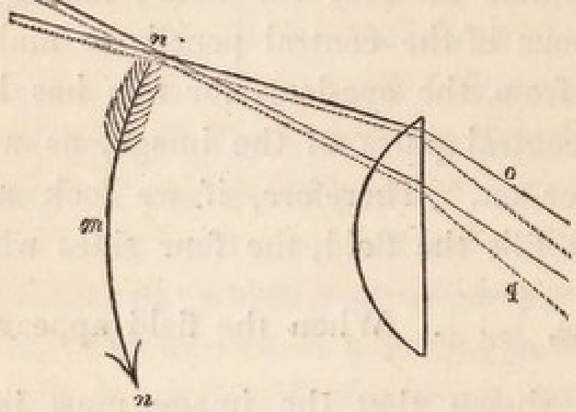


Fig. 7.

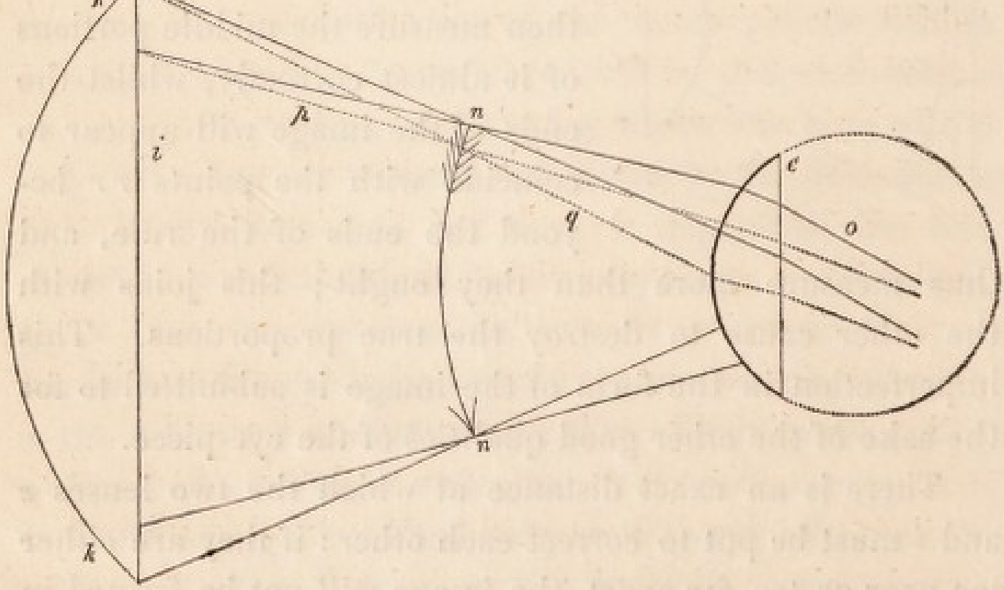
There is an exact distance at which the two lenses *e* and *i* must be put to correct each other: if they are either too near or too far apart, the image will not be formed in the right curve for viewing each part distinctly at the same time; when they are too near each other, the coloured rays will not be separated enough to obtain equal deflections by the eye-lens, the blue will still be most deflected, as at *q* in fig. 5; in this case the aperture of the

Fig. 5.



field-glass will appear blue. If, on the contrary, the lenses are too far apart, the coloured rays will be so much separated as to cause the blue to be less deflected than the red, as at *q* in fig. 6, again shewing colour, but in a

Fig. 6.



reverse position, for the margin of the field will be red. This over correction, whilst it re-induces colour, also destroys flatness of field. These faults may be increased till the image is restored to a true form, so that straight lines will appear straight in any part of the field; this is caused by the greater distance of the eye-lens allowing the pencils to converge so much nearer to the axis before it receives them; it therefore causes less deflection to the lateral pencils, and thus lessens the outer parts of the image, whilst the central pencils pass on much the same as before; but the consequent loss of defining power is too great a sacrifice to make for truth of form.

I have now described a correcting eye-piece, but there are several combinations of this sort that are spoken of as though any one would serve without even indicating a preference; and a rule for placing the lenses is given which I will state, and then shew how much room there is for choice.

The general statement is, with the flat sides towards the eye, to place the lenses half the sum of their foci apart, *i. e.* if the two lenses are of the same focus, place them one focus apart; if their foci are as one to three, place them two apart. This rule would never be right if we took the solar focus of the field-glass; but put the field-glass in its place, and then take the distance at which it will give an image of its own object-glass, and that will be the focus intended by the rule.

To prove that there is room for choice, take, in the first place, two lenses of the same focal length; they will stand as in fig. 8. The focus of the object-glass will meet that of the eye-lens in the field-glass *i*, where the image formed is shewn by an arrow; this lens will deflect the lateral pencils so as to meet in the middle of the eye-lens, which will only render them parallel and let them pass on without additional deflection; but the field-glass will have deflected the blue rays *q* more than the red, as in

Fig. 8.

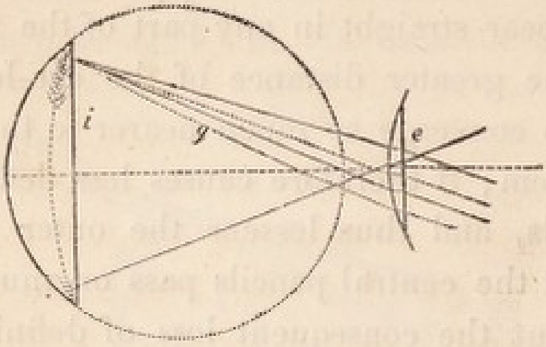
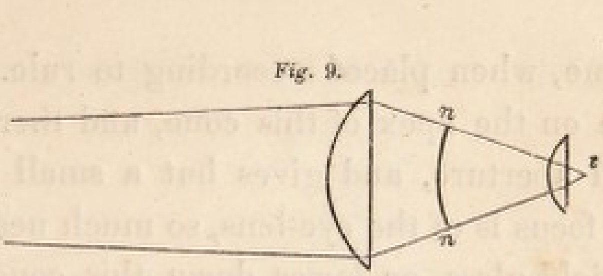


fig. 4, and the eye-lens, though it will not render the blue perfectly parallel at the same time with the red, will very nearly do it; but it will lay the whole blue emergent pencil quite parallel with the red one, and so far accurately correct the colour: but the pencils have met and crossed short of the outer surface of the eye-lens, and, as the eye ought always to be put at the place of crossing to receive all the pencils at once, it is evident in this case that it cannot be so placed, but is obliged to move about to find the different pencils; from this circumstance the field, though much better, is smaller than without a field-glass; here, therefore, it may lose that name and only be called a correcting lens; but it acts as such imperfectly, for the blue rays, crossing the axis sooner than the red, have to extend further before they can reach the surface of the eye-lens; therefore, although the general blue pencil is laid parallel to the red, yet, when by adjustment the red is rendered parallel, the blue rays will converge a little, and if the blue are rendered parallel the red will diverge a little, so this is an imperfect eye-piece.

Secondly, take the proportions one to two, their distance will be one and a half apart; here the eye-lens is so placed that its centre of curvature t, fig. 9, is exactly on the working focus of the field-lens, the point towards which all the pencils converge: consequently, they all

Fig. 9.

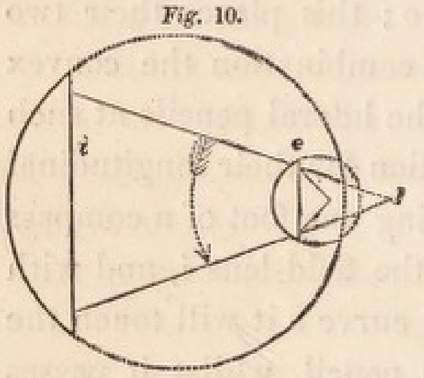


will enter the surface alike, every pencil being quite perpendicular to it; from this circumstance the whole of the lateral dispersions will be most equally and truly corrected, whilst the longitudinal error in all the pencils will be equally left unaltered. On this account, as this eye-piece gives a moderate sized field, where that is sufficient it appears to be the very best eye-piece for working an object-glass to, because the over correction is equally needed for every pencil.

For a third example, in fig. 4, the proportions are one to three, their distance apart two; this places their two foci on the same point. In this combination the convex surface of the eye-lens receives the lateral pencils at such an angle as to afford some correction for their longitudinal error; this will be shewn by placing one foot of a compass on the pencil *k* where it passes the field-lens *i*, and with the other foot drawing the dotted curve *s* it will touch the lens *e* in the middle of the blue pencil, whilst it passes short of the middle of the red pencil. Thus the natural action of lenses being to shorten or to require a shorter blue focus will be satisfied; for the blue pencil being deflected nearer to the axis, enters the lens *e* at a part of its surface nearer to the field-glass than that which receives the red pencil, in consequence of which the rays of each coloured pencil may emerge parallel among themselves.

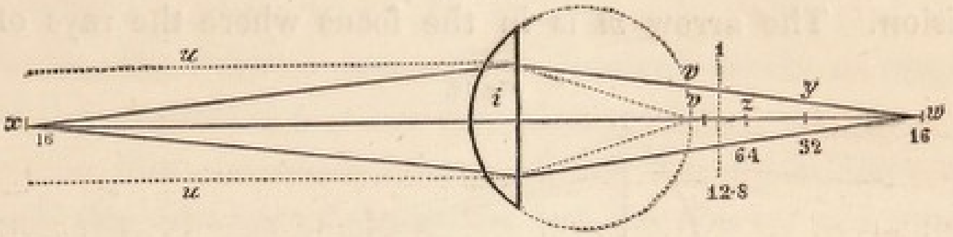
The field-lens always deflects the pencils to a particular focus which depends on its distance from the object-glass, forming a cone of pencils, and with the proportions of one to one, when placed according to rule. The eye-lens will be on the apex of this cone, and therefore needs but a small aperture, and gives but a small field. The shorter the focus is of the eye-lens, so much nearer must it be to the field-glass, or lower down this cone; the proportion, therefore, of aperture must increase as the focus decreases, and the larger will be the field. To make this clear as a fourth example, I have placed fig. 10 under fig. 8, using the same field-glass with the same convergence of the pencils, but only a single line to represent a pencil of rays. In fig. 8 the pencils all meet at the centre of the eye-lens, and, therefore, receive no additional deflection to enlarge the field, which, on the contrary, is reduced, because the eye cannot be placed close enough to receive all the pencils at once. In fig. 10 the proportion of foci is one to four, and the distance two and a half. This brings the eye-lens so much nearer to the field-lens than the point or apex *t* as to require the largest aperture to give it diameter enough to take in all the pencils; consequently, the very great angle which the margin of this lens makes with the outer pencils, causes it to deflect them under a great angle towards the axis, still giving room for the eye to receive them all at once, thus causing a very large field of view.

Fig. 10.



When stating the rule for combining eye-lenses, it has been said that the shortest or solar focus of the field-lens would never be the right one to use. It will, therefore, be proper to know how much the actual focus is liable to vary from the solar focus. In fig. 11, *i* is a plano-convex lens, suited for a field-glass; its solar focus is

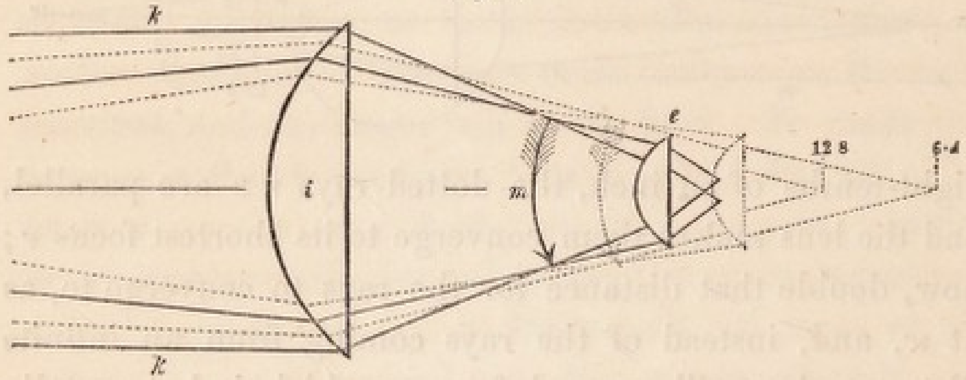
Fig. 11.



eight-tenths of an inch, the dotted rays *u u* are parallel, and the lens makes them converge to its shortest focus *v*; now, double that distance for the rays to converge to, as at *w*, and, instead of the rays coming from an infinite distance, they will proceed from *x*, which is but equally distant on the opposite side; consequently, the distance from *v* to *w* (the length of one focus) is the whole range of foci for rays proceeding from objects that are placed between *x* and an infinite distance. The foci *x* and *w* are each sixteen-tenths of an inch distant from the lens. If we halve the distance between *v* and *w* at *y*, the opposite focus *x* will be removed to double the distance which will make it 32; again, halve *v* and *y* to *z*, the opposite focus will be 64, and so on to infinity, always doubling the last focus when we halve the distance remaining beyond *v*. Likewise, if we place an object-glass at *x*, the pencils proceeding from it and through the lens *i* will be deflected to the point *w*; from double the distance of *x* they will be deflected to *y*, and so on; from eight times *x* they would meet at 1.

Let us now apply this to an eye-piece and object-glass. Fig. 12 is twice the size of fig. 11, and, therefore, the numbers are doubled that mean similar proportions. The pencils *k k*, coming from an object-glass 12 inches 8 tenths distance, will be deflected towards the point 12·8, and be received by the lens *e*, which is placed at the proper distance to refract them into parallel pencils much more deflected, and therefore giving a large field and correct vision. The arrow *m* is in the focus where the rays of

Fig. 12.



each pencil cross, as was shewn in fig. 4. Next, from an object-glass placed at half that distance, or 6·4, will proceed the pencils shewn by dotted lines; they will be refracted towards the further point 6·4. This less convergence of the pencils would widen and thus lessen the curve of the image if it was still formed at *m*, and so destroy the apparent flatness or equal distinctness of the image, and it would require an increase of diameter in the lens *e* to receive them; but it will be seen, that the refracting angle which the two surfaces of the lens *e* make with each other at the extreme diameter, will increase more rapidly than the diameter. The dispersive power of this additional part will, therefore, be too great to suit the lens *i*, so the image will remain under-corrected; but let the lens *e* be removed to the dotted figure (its true place assigned by the rule), it will receive the pencils only as much further from the former diameter as will be requisite to balance the increased dispersion of the lens *i*, occasioned by the greater distance of the two lenses from each other, and thus complete correction of colour will again be produced; and the image also being removed further to the dotted arrow, will be again lessened, and so restored to the right curve for being seen equally distinct in every part. In this second position of the lenses, the field of view will be lessened nearly as much as the angle at 6·4 is less than that at 12·8.

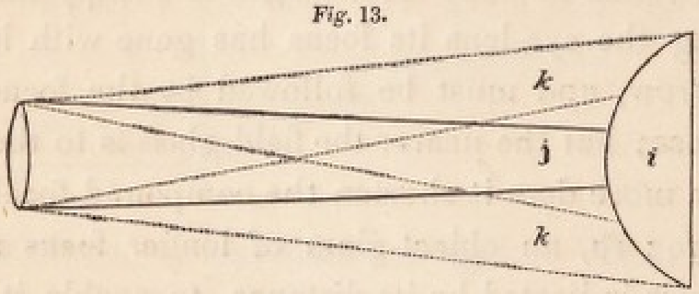
In this statement I have placed one object-glass at half the distance of the other, but the shorter one must have more than half the focal length to occupy that place. In moving the eye-lens its focus has gone with it to the dotted arrow, and must be followed by the focus of the object-glass; but the nearer the field-glass is to the object-glass, the more does it shorten the compound focal length of the two; so, an object-glass of longer focus must be used than is indicated by its distance, to enable it to protrude its focus so much further through the field-glass as to keep in union with the focus of the eye-lens.

As regards motives of choice, I have shewn that the proportion of one to one is not perfect, and gives the smallest field; and that one to two makes an eye-piece the most detached from the object-glass, in that it does not any way interfere with the longitudinal correction, and in that respect appears to be the best; but other considerations may extend our choice to the proportions of one to three, as in fig. 4, because the rays cross midway between the two lenses, and are therefore more equally acted on by the inclined surfaces of the two lenses, the inner ray from the field-glass becoming the outer one at the eye-glass, and the corresponding portions of these lenses being parallel, cause a more equal action on the rays.

There is one more circumstance to be noticed, particularly with the proportion of one to four, because the effect increases with the disproportion of the two lenses.

The shorter the focus of the eye-lens is to a given field-glass, the nearer must it be put, but the further will the distance be through the field-glass to which the object-glass must protrude its focus. This will bring thicker parts of the pencils *j* and *k k*, fig. 13, to the field-glass *i*. The pencil *k* has to extend further than the middle pencil *j* to reach the field-glass, therefore in one direction the

Fig. 13.



diameter of the area on which it impinges will be smaller, but in the opposite direction it will be much longer, as is very visible in the figure; thus, the lateral pencils take an oval area, yet, as they cross between the lenses they are received by as great a deformity in the eye-lens in the opposite direction, by which they are so nearly restored as to be transmitted almost parallel to the eye: it matters not what shape a pencil takes so long as the rays of it can be rendered strictly parallel to enter the eye, yet this is one of the deformities that occur when using very large apertures, which in this case we do in the eye-lens, and it is one of the causes why the margin of a large field will not be so good as the centre.

When the focus of the object-glass falls in the field-glass, that lens does not alter the magnifying power—such constitutes a neutral eye-piece; but when the focus is between the two lenses, as in figs. 4, 9, 10, and 12, the field-glass does lessen the power that would be obtained by the eye-lens and object-glass alone, and from this reduction of power they are called negative eye-pieces. The following is their power, or the focus of an equivalent single lens :

One to two is equalled by a lens one and a third in focus ; one to three, by a lens one and a half ; and one to four, by a lens that is one and six-tenths focus.

These powers are obtained by dividing twice the product of the focal lengths of the two lenses by the sum of them.

I have now traced the leading effects produced by these eye-pieces on the pencils of light ; and, by figs. 11 and 12, have shewn that no change can be made in the distance of the object-glass from the field-glass, without requiring a corresponding change in the distance of the eye-lens to restore vision to the same degree of perfection it had before ; yet, notwithstanding this fact, eye-pieces are not usually made to adjust, although it is very common to take the eye-piece from one instrument and apply it to another of a different length.

The range of adjustment is very small that will make an eye-piece suit any length of telescope ; but when we consider the difficulty of obtaining great powers with accurate definition, surely nothing ought to be lost that can possibly bring them nearer to perfection.

In microscopes, this is a much greater evil ; yet they are frequently made to slide out to two or three times their length with an eye-piece that will not adjust. Here is evidently a great neglect of obtaining the most perfectly defining power ; so much so, as to throw a doubt on the usual instruments, whether their eye-pieces are at all adjusted to best suit the lengths to which they are applied.

The evil hence arising to microscopes causes great confusion in comparing one instrument with another, and with the same at different lengths; in some, the eye-pieces may be suited for a great length, whilst in others they may suit the shortest, and unless this is known the comparison becomes vague. As in telescopes this evil cannot amount to so much as it does in microscopes, to remove the weight of censure as far as regards telescopes that may seem to be implied in the above statement, I will shew the real limits of adjustment required in eye-pieces for different lengths of microscopes and telescopes.

In fig. 11 let the lens *i* be a field-glass, and call its focus, which is at *v*, two, and suppose an eye-lens suited to it whose focus is one. The rule for placing them being half the sum of their foci apart so long as this is the working focus, their distance apart will be one and a half; but let an object-glass be placed at *x*, the working focus of the lens *i* would become four, and extend to *w*. This would require the lenses to be placed two and a half apart, one whole focus of the eye-lens more distant, thus altering the proportions just as if the lenses were one to four.

It is quite evident that this latter combination could not be used in the place to which the first was suited. But the distance from *v* to *w* is the whole range of variation in the convergence of pencils from the field-lens that can occur, from the shortest microscope to the longest telescope; and half that distance, from *v* to *y*, measures the whole range of adjustment for the eye-lens, to suit either extreme (these spaces are not the exact places for the eye-lens, but they are referred to because they are the exact measures of its range). Next, let the object-glass be twice the distance of *x*; the pencils will converge to *y*, and *v z* measures the range for the eye-lens, to suit all greater distances of the object-glass.

ON EYE-PIECES

FOR

TELESCOPES AND MICROSCOPES.

By Mr. CORNELIUS VARLEY.

FROM THE TRANSACTIONS OF THE SOCIETY OF ARTS, MANUFACTURES, COMMERCE, &c.

VOL. LI.

When I invented the graphic telescope (described in Vol. L. of the Society's Transactions), the chief obstacle was in the eye-piece; the usual achromatic eye-pieces shewing the image beautifully distinct, but with all the lateral lines so curved as to become useless for any purpose of art: and, as perfect truth of form in every part of the image is the chief requisite for a drawing instrument, I was obliged to give up the perfect correction of colour to obtain truth of form; but as low powers are the most useful in drawing from nature, the loss from imperfect correction is not so much felt as I at first feared.

Although the compound microscope, as well as the astronomical telescope, requires truth of form along with the most accurately defining power, these two qualities have not, to the present time, been well reconciled, so as to be found in the same eye-piece. Yet there are resources in optical science which, I believe, are fully able to effect this union in the most satisfactory manner.

I therefore propose giving a full view of the three principal eye-pieces: namely, the achromatic, which is used both in the astronomical telescope and the compound microscope; the micrometer eye-piece, used by Ramsden; and a variation of it which I use for my graphic telescope and microscope: in order to shew every effect produced by their lenses on the pencils of light, and so lead to the perfecting them; and also to enable persons who use these instruments to know how to alter or adopt them to suit any particular purpose, without causing that deterioration which otherwise is so liable to occur.

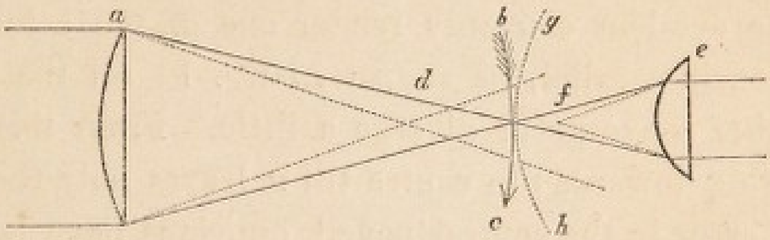
Great magnifying powers must evidently be first obtained by the object-glasses or specula, and to them, accordingly, workmen have directed their chief attention; but many who have succeeded in this difficult task, and have produced really excellent object-glasses, have quite neglected the eye-pieces, and have in consequence greatly impaired the performance of their object-glasses.

As eye-pieces are never used alone, and are not intended to receive every sort of light, but to act on particular pencils presented to them from an object-glass, it will be requisite first to consider what sort of light it is that is so presented, and to know how it may be altered to suit the purpose. We may, therefore, begin with a single lens for an object-glass with a single eye-lens, and take only the central pencil of rays.

A pencil of rays consists of that portion of the rays of light which enters an object-glass from any point of an object; consequently, there are as many pencils as there are points in the object. The lens causes all these to converge to their separate foci, in a curve of which itself is the centre; therefore, all the pencils that we use begin as cones, having the object-lens for their base, and may be considered as originating there, because it limits their diameter.

It is well known, that when light passes through a single lens it is separated into the different colours, and that red rays are the least, and blue rays the most refrangible. Therefore, an object-glass like *a*, fig. 1, will have three foci; the longest one will be red, the next yellow, and the shortest blue: if we place the arrow *b c* on the red focus, then the dotted lines may represent the blue rays meeting together in a shorter focus at *d*. Let *e* be an eye-lens, so placed that its red focus meets that of the object-glass at the arrow *b c*; it will then refract the red

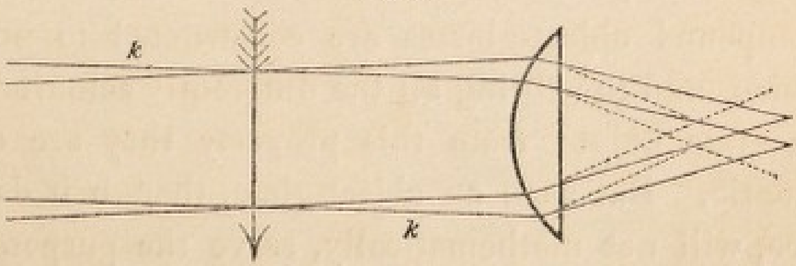
Fig. 1.



rays into a parallel pencil, a condition requisite to give distinct vision; but the blue rays having crossed at *d*, they will be dispersed to right and left of the red pencil, and, instead of helping to give vision, they will only confuse the image by causing coloured margins; in addition to this evil, the eye-lens also has its focus for blue parallel rays shorter as at *f*. So the two foci *f* and *d* must meet to enable the blue rays to give distinct vision, which, of course, would put the red out of focus and cause as much confusion.

Having traced the course of the central pencils, let us examine the lateral pencils, and we shall find another evil, increasing with the diameter of the eye-lens. Fig. 2

Fig. 2.



shews two lateral pencils *k k* arriving at the eye-lens with the imperfections just stated; this lens, besides rendering them parallel, deflects them towards the axis, so that the eye receives them at the same time with the central pencils; but the eye-lens has deflected the blue rays, as shewn by the dotted lines, more than the red, and this will cause the image, as viewed by the blue rays, to appear under a larger angle than by the red rays, hence arises the blue margin to the field, and a blue inner and red outer margin to every dark feature in the field of view, and the eye-lens can only render one of the colours in each pencil parallel, as shewn in fig. 1; all the others will either converge or diverge a little. From this error decreasing towards the centre till it leaves only the first-named error in the central pencil, opticians have been in the habit of saying that all eye-lenses perform well at their centre, whereas they only perform less ill as their aperture is reduced, and not perfectly well even at the centre.

Single eye-lenses will bear only a small aperture on account of the lateral error increasing with the diameter, and this small aperture, taking but few pencils from the object-glass, gives but a small field. The object-glass gives the image in the curve *b c*, fig. 1, whilst the dotted curve *g h* is demanded by the eye-lens, to enable us to see the whole image distinctly; so that, in addition to its having a small field, a small part only is distinct at one time.

I will now shew the means by which these errors are either corrected, or very much reduced.

Compound object-glasses are constructed to prevent dispersion, and thus bring all the differently coloured rays to the same point; from this property they are called achromatic. But such an object-glass, though it does in practice, will not mathematically, serve the purpose, be-