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PROVISIONAL SPECIFICATION.

A Simplified Form and Improved Type of Photographic Lens.

I, HAROLD DENNIS TAYLOR, of 20 Bootham Terrace, Bootham, York, Optical Manager to the Firm of T. Cooke & Sons, Engineers and Scientific Instrument Makers, Buckingham Works, Bishophill, York do hereby declare the nature of this invention to be as follows:—

The chief object of my invention is the simplification & therefore cheapening of photographic lenses. At the same time a very considerable improvement in the optical performance of the lens, as compared with the ordinary forms of lens, is attained.

My lens is essentially a triplet as substantially shown in the accompanying drawings. The two outside lenses are simple positive lenses, while the central negative lens which I herein call the "corrector," may be either simple or compound, preferably the former.

The lens has the form of a simple doublet with a diaphragm placed half way between, such diaphragm being filled in as it were, with the "corrector" lens.

The two positive lenses are made of glass of a comparatively low dispersive power, in fact the lower the dispersive power the better for the final result, while the "corrector" lens is made of a flint glass of such a dispersive power as to enable it to correct the colour aberrations of the two positive lenses consistently with the other conditions being attained although the form of the whole lens is very simple yet the nature of the corrections involved in the lens are very complex & interlocked together. For the "corrector" lens has to perform the following functions simultaneously.

1. To correct the colour aberrations of the two positive lenses & thus render the whole combination achromatic in the sense required by the actual uses to which the whole lens is put, whether for photographic purposes celestial or terrestrial or for lantern projection.

2. To correct the spherical aberration of the two positive lenses & render the whole combination aplanatic.

3. To correct the curvature of image of the two positive lenses & thus render the final image perfectly flat, while the astigmatism generally incidental to the oblique pencils in the case of ordinary lenses, is simultaneously eliminated.

This last or third condition is secured by the application of much the same principle as that which I have involved in a previous application for a Patent for photographic lenses numbered & dated No. 1991, (1893).

That principle is that two positive lenses on a common optic axis may have their curvature of field & astigmatism of the oblique rays simultaneously corrected by a negative lens, made of the same sort of glass, placed anywhere between them so long as its centre is on the common optic axis and provided that the power of the negative lens is equal to the sum of the powers of the two positive lenses combined and provided that the diaphragm corrections of all three lenses are eliminated by giving to them suitable forms.

If a meniscus positive lens is placed with its convex side towards distant objects it is well known that the presence of a stop or diaphragm placed axially between the lens & its focus has the effect of flattening the image of those distant objects, whereas placing the same stop in front of the same lens has the effect of rendering the image still more round than that yielded by the naked lens.

On the other hand if the same lens is turned so that the concave side faces the distant objects then it is well known that the effect of a stop placed between the lens & its focus is to render the field of view or image more round or curved than that yielded by the naked lens, while placing the stop in front of the lens will flatten the image or field of view. But by these methods of applying diaphragms or stops to simple lenses it is always impossible to obtain a flat image which is at the same time free from astigmatism.

Now it can be shown that, given any special case or circumstances in which a simple lens has to be used, a certain form can always be given to it such as to render it free from diaphragm corrections; that is, it can be so shaped, agreeably to calculation, as to render the presence of a stop placed at a certain distance behind it quite ineffective for modifying the curvature of the image. In the case of such a lens the curvature of its image is in no appreciable degree modified by the stop or diaphragm which is virtually formed by the aperture of the negative lens. In Fig. 1. I have shown roughly the form of one of these simple triplet combinations of about 7 inches focal length, which is initially designed for copying equal size, so that the two positive lenses are precisely similar & the corrector lens equi-concave. Here all three lenses are so shaped as to be free from diaphragm corrections, as above defined, when the whole lens is being used for copying equal size. That condition being attained, then the whole burden of flattening the final image & correcting the astigmatism of the oblique pencils is thrown upon the negative corrector lens and the principle of correction, which I have defined above, has full play; & the power of the negative corrector lens can be so regulated as to render the final image quite flat and at the same time practically free from astigmatism. Its focal power will then be about equal to the combined focal powers of the two positive lenses.

These corrections being properly adjusted when the triplet is being used for copying equal size, it can be shown that when the triplet is used for forming an image of distant objects; although diaphragm corrections will now come into operation in the case of the front lens (which is exposed to the distant objects) which tend to round the final image, still this tendency is about neutralised by the diaphragm corrections simultaneously coming into operation in the case of the back lens, which have an opposite tendency towards hollowing the final image. Therefore the final image tends to remain flat in all cases in which the triplet is likely to be used. But it should be pointed out that, although when copying equal size the corrector lens should be placed exactly half way between the two positive lenses in the case of Fig. 1. yet when using the triplet on distant objects this position for the corrector lens will no longer suffice; for now the image painted by the blue rays will be a trifle larger than the image of the same objects painted by the yellow rays, also a slight amount of pincushion distortion may be expected. These defects are remedied either by causing the corrector lens to approach nearer to the front lens by a very slight amount or else by screwing the front positive lens slightly nearer to the corrector lens. And a means of easily making the necessary adjustment & the amount of the adjustment I will leave to be more precisely described & ascertained in my Complete Specification. Fig. 2 shows another form of the simple triplet, so designed that the lenses are severally free from diaphragm corrections when the rays first entering the front lens F are parallel. Fig. 3. shows roughly a form in which the front & back lenses are of unequal powers & the whole lens initially designed for parallel rays. Fig. 4. shows a form in which, by making the corrector lens compound, its spherical aberrations can be so reduced as to render a shorter distance between the two positive lenses feasible, thus obtaining a shorter & more compact lens, more suitable perhaps for wide angles of view. Fig. 5 shows a form in which the corrector lens is split into two portions & the stop is inserted between. Altogether it can be shown that many forms of this lens are possible all alike embodying the same principle of correcting the field of view; in all cases the corrector lens performing the triple function of (1) correcting the field of view or rendering the final image flat & free from astigmatism (2) correcting the combined colour aberrations of the two positive lenses, & (3) correcting the spherical aberrations of the two positive lenses combined.

Thus it will be easily seen that owing to the functions of the corrector lens being interlocked together in such a way that no single correction can be modified without altering the amount of the other corrections, at any rate without resorting to a different sort of glass, therefore the actual planing & perfecting of a triplet of this type is a highly complex & difficult operation, requiring much calculation & patience; although when once the proper form & curves necessary to good performance have been determined, the manufacture of any number of them presents no serious difficulty. The form which I have sketched in Fig. 1, the symmetrical triplet promises the greatest practical advantages & ease in working out & doubtless is the form which I shall first perfect sufficiently for practical use.

I should point out that the bare idea of placing a negative lens between two positive lenses for the purpose of tending to flatten the final image is not by any means, a new one; for as long ago as 1858 a certain scientific man named Mr. Sutton pointed out the advantage of such a combination & possibly applied the idea in practice; but he placed a negative lens between the two ordinary meniscus like combinations generally used for doublet lenses & moreover the focal power of the negative lenses thus applied by himself & others was never more than a mere fraction of the combined focal powers of the positive lenses with which they were combined. Thus the flattening of the field was principally due to the diaphragm corrections of the positive lenses; neither Mr. Sutton nor those working on the same lines seem to have been conscious of the fact that diaphragm corrections should be eliminated or that they could be eliminated, or of the principle that the power of the negative lens should be approximately equal to the sum of the powers of the positive lenses if a flat field, free from astigmatism, was to be attained. The same remarks apply to Dallmeyer's & Ross's triplets and to Petzvals' orthoscopic lens.

Dated this 20th day of November 1893.

H. DENNIS TAYLOR.

COMPLETE SPECIFICATION.

A Simplified Form and Improved Type of Photographic Lens.

I, HAROLD DENNIS TAYLOR of 20 Bootham Terrace, York Optical Manager to the Firm of Messrs. T. Cooke & Sons, Opticians & Engineers &c. Buckingham Works, Bishophill, York do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In order to make clear the essential difference of principle between the photographic lenses made according to this Specification and the older forms of photographic lenses manufactured & used up to this date, it will first be necessary to shortly explain 1st the older optical devices employed in such lenses for the purpose of correcting the oblique pencils of light against curvature of field and astigmatism & 2nd the new principle of correction employed by me, & embodied in the herein specified lenses, for attaining the same ends in a more simple manner & more radically perfect degree.

Fig. 1. represents the action of the front lens of an ordinary symmetrical doublet, which is nearly always a double achromatic combination having the exterior form of a meniscus lens placed with its convex surface outwards to receive the parallel rays $c—a—b—d$, a^1, b^1, d^1 from any distant point.

Supposing these rays to be oblique, then the corresponding focus at c formed by the naked * lens L, is of a peculiar form. Let A—F be the optic axis and F the principal focus. It is well known to opticians that the image formed by a naked

*(By the term "naked lens" I mean a lens whose aperture is bounded merely by its own periphery.)

lens of a distant landscape is not a flat one, but is violently curved and marred also by a greater and greater amount of astigmatism according to the angular distance of the image from the optic axis.

Let it be supposed that the oblique rays *c*, *a*, *b*, *d* a^1, b^1, d^1 are proceeding from a very distant point of light. All such rays contained either in the plane of the paper or in planes parallel thereto are said to be rays in primary planes or primary rays.

Any two rays situated extremely closely to the central oblique ray *c*—*c* intercross or come to a focus close to the point *c* & almost upon the line C—C. But the two rays *a* and a^1 falling on the lens at equal distances on either side of C—C do not intercross or focus on the line C—C but at the point A situated below C—C. The more widely situated pair of rays *b* & b^1 focus at the point B still further below the point C, while the pair of widely separated rays *d* and d^1 intercross or focus at a point D at a considerable distance below the line C—E. This line C—D may be considered to be, roughly speaking, perpendicular to the optic axis A—F. Its length is exaggerated in the figure for the sake of clearness. This lateral displacement of foci for symmetrical pairs of rays such as *a* & a^1, *b* & b^1, *d* & d^1, increasing rapidly according to the distances of each pair of rays from the oblique axis C—C, brings about at the focus C—D a sort of balloon shaped image (Fig. 1. *e*) or "coma" as it is generally termed by opticians. In this case the effect may best be called "inward" coma because the lateral displacement of foci for symmetrical pairs of rays is inwards towards the optic axis A—F and moreover the more diffused and larger end of the coma is also directed inwards towards the optic axis. The effect of this lateral displacement of foci for symmetrical pairs of rays such as *a* & a^1, *b* & b^1, *d* & d^1 is very important with regard to the consequent effects upon the foci or intercrossing points of any pairs of rays which are unsymmetrically situated with regard to C—C, such pairs as *a* & *d* *c* & a^1 *c* & b^1, a^1 & d^1 &c. for instance. For their intercrossing points or foci are necessarily displaced either nearer to or further from the lens L.

Thus the two rays *a* & *d* focus at the point $a + d$ much nearer to the lens *c* & a^1 focus at the point C + a^1, *c* & b^1 at $c + b^1$, a^1 & d^1 at the point $a^1 + d^1$ and these points are successively further away from the lens. It follows therefore that if a stop or diaphragm *s*—*s* is placed at any distance behind the lens L so as to limit the pencils effective for forming the image,—only allowing rays to pass which are refracted eccentrically through the lens such as the eccentric rays *c* & b^1 in Figure 1, then a considerable flattening of the image must take place owing to those oblique and eccentric pairs of rays only being allowed to pass which have their foci much further away from the lens and possibly upon or even beyond the focal plane F—P. Thus it may be said of a lens like that shown in Fig. 1 when used for parallel or divergent rays, that it has considerable "diaphragm corrections" or that its image is capable of being flattened by the presence of a smaller circular aperture or diaphragm *s*—*s* placed axially behind it.

Fig. 2 well represents the case of an ordinary achromatic meniscus single photographic lens or the back lens of a photographic doublet lens. In this case the meniscus lens, being inverted, has just the opposite effects on parallel rays to those shown in Fig. 1. The foci for symmetrical pairs of rays such as *a* & a^1, *b* & b^1 *d* & d^1 are displaced to the points A. B and D successively further away from the optic axis than the point C on the central oblique ray. Instead of inward coma the lens gives outward coma, the outlying & more diffused extremity of the coma Fig. 2. *e*. being directed outwards, away from the axis A—F. It is obvious that if the curved image yielded by such a lens is to be flattened then the stop or diaphragm must be placed in front of the lens, at *s*—*s* for instance. This stop only allows to pass the eccentric rays *c* & *b* and those between, and *c* and *b* have their foci at the point $c + b$ much nearer to the focal plane F—P. Having now dealt with the rays in primary planes, that is those rays contained either in the plane of the paper or in planes cutting the lens along chords parallel to the plane of the paper or diagram, it will be necessary to consider the case of those rays, belonging to the same oblique incident pencil, which are contained in planes cutting the lens along chords which are perpendicular to the plane of the paper or diagram. It would be extremely difficult to diagrammatically illustrate the course of such rays. n the first place the image formed by a naked lens is always violently curved along a curve F—*h* for rays in primary planes and the radius of this curvature is a fixed quantity for any given lens and is independent of the degree of convergence or divergence of the rays first incident on the lens. The radius of curvature of the image formed by primary rays is generally $\frac{3}{11}$ths of the principal focal length and only varies within narrow limits according to the refractive indices &c. of the glass or glasses employed. On the other hand the image formed by the naked lens by means of those rays contained in a secondary plane cutting through the centre of the lens, is formed along a much flatter curve F—*g*, and the radius of curvature of this curve is generally $\frac{3}{5}$ths of the principal focal length, is a fixed quantity for any given lens and is likewise independent of the degree of convergence or divergence of the rays first incident on the lens, and varies only within small limits according to the refractive indices &c. of the glass or glasses employed. In the case of ordinary glass lenses whether simple or achromatic the image formed by rays in secondary planes is curved to a radius just about 2·2 times the radius of curvature of the image formed by rays contained in primary sections of the same pencils, and it follows that, for any given oblique pencil, the focal point formed by rays in primary planes is situated approximately 2·2 times as far short of a plane F—P passing through the focus and perpendicular to the optic axis, as the focal point at *g* formed by rays in the secondary section. With a properly fashioned lens & by means of diaphragm corrections it is quite possible to lengthen out the foci for rays in primary planes to such a degree as to form a flat image upon the plane F—P, but it can be shown that it is in nearly all cases impossible to simultaneously flatten the image formed by rays contained in secondary sections of the same pencils. For it can be mathematically demonstrated that any diaphragm correction which lengthens out the focus of rays contained in a primary section of an oblique pencil, by a certain amount *c*, is invariably accompanied by a lengthening out of the focus for rays contained in a secondary section of the same pencil whose amount is just one third of the correction in primary section or $\frac{c}{3}$. But in the case of the naked lens the deviation of focus for a primary section of an oblique pencil from the plane F—P is in the case of ordinary glasses about $2\frac{1}{5}$ times the deviation of focus from the plane F—P for a secondary section of the same pencil. Hence if the diaphragm corrections are just sufficient to form a flat image for primary sections of the oblique pencils, it is evident that the corresponding diaphragm corrections for secondary sections of the same pencils will not be sufficient to fully compensate their curvature of image and therefore the image formed by rays in secondary sections will remain curved, and to a radius generally equal to somewhat more than double the focal length. This difference of foci for rays in primary and in secondary sections of the same oblique pencil constitutes what is known as the marginal astigmatism of photographic lenses. In the case of all lenses made of ordinary crown and flint glasses &c. and compensated by the usual diaphragm corrections, it has been found impossible to obtain an image both flat and free from astigmatism at the same time; if a flat image is obtained it is astigmatic; if an image free from astigmatism is obtained then it is considerably curved, (to a radius equal generally to $1\frac{1}{2}$ times the principal focal length). There is however a new sort of glass now obtainable, combining a very high refractive index with a very low dispersive power and another sort, combining a low refractive index with a relatively high dispersive power, which may be so combined together as to form an achromatic meniscus whose curvature of image for rays in primary planes is just 3 times the curvature for rays contained in the secondary section of the same oblique pencil and these curvature aberrations are therefore in the right relation for being simultaneously corrected by means of diaphragm corrections and so a flat image also free from astigmatism can be obtained. But the thorough carrying out of the above principle in combinations made of these exceptional glasses unfortunately precludes the use of a large relative aperture.

In order to obtain a lens of a large relative aperture which at the same time has a flat image or field of view in conjunction with a general freedom from astigmatism at the outskirts of its field, I have recourse to a principle of correction which, as far as I know, is entirely novel. This principle may be explained as follows.

Fig. 1 shows a case of a lens giving inward coma and consequently capable of having its image flattened by placing a diaphragm behind it.

Fig. 2 on the other hand shows a lens having the opposite characteristic of outward coma and capable of having its image flattened by placing a diaphragm in front of it. It is obvious then that a form of lens should be possible intermediate in form between these two, which should give neither outward nor inward coma. This is actually the fact, and Fig. 3 shows the action of such a lens. Here the foci of all symmetrical pairs of rays such as a & a^1, b and b^1 d and d^1 fall at the same point C upon the oblique axis C—C if the lens is free from spherical aberration as in Fig. 3, or if not free from spherical aberration, as in Fig. 4 which represents a simple lens, then the foci of all such symmetrical pairs of rays fall upon the oblique axis C—C although not all at the same point. In either case the oblique focus is a symmetrical formation. In the case of Fig. 3, since all the rays pass through the same focal point C, it is plainly evident that diaphragms placed axially either in front of or behind the lens, can have no effect whatever in modifying the curvature of its image. Such an aplanatic lens, giving symmetrical oblique refraction may therefore be said to have its diaphragm corrections eliminated. The appearances seen at the focus of a distant point of light, formed by such a lens, pass through the successive phases l, m, n, o, p as the lens is receded from; first the luminous line l which is formed at C vertically to the plane of the diagram and lastly the luminous line p which is formed at g and lies in the plane of the diagram. These and the intermediate appearances are quite symmetrical. In the case however of the uncorrected simple lens in Fig. 4, although the oblique focus is likewise symmetrical, yet it is evident that the placing of a diaphragm s—s either in front of or behind such a lens must necessarily have the tendency to curve its image more than before, since the diaphragm only admits eccentric sets of rays like a^1 and d^1 which focus at the point $a^1 + d^1$ short of the ultimate focus at C. But it is possible to eliminate diaphragm corrections from such a simple uncorrected lens having positive spherical aberration by the following device. Given the position of the diaphragm behind the simple lens in Fig. 4, it is easy to give the lens a form which is more bulged out towards the left hand so as to approximate slightly to the case of Fig. 1. by an amount easily assignable by calculation, and which will bring about such an amount of inward coma as to give rise to diaphragm corrections which will just neutralize those diaphragm corrections dependent upon the spherical aberration. Thus the diaphragm corrections dependent upon inward coma can be made to flatten the image just as much as the diaphragm corrections dependent upon positive spherical aberration tend to further curve the image and thus I obtain a simple lens which may as truly be said to have its diaphragm corrections eliminated as in the case of the aplanatic lens shown in Fig. 3. All such lenses therefore have their images curved to the normal degree, uninterfered with by diaphragm corrections. In the case of a simple lens whose diaphragm corrections are thus eliminated formed of glass whose index of refraction is about 1·52, the image formed by rays in primary sections of the oblique pencils is curved to a radius equal to about $\frac{3}{11}$ths of the principal focal length, and the image formed by rays in secondary sections of the same oblique pencils is curved to a radius equal to about $\frac{3}{5}$ths of the principal focal length and thus, in lenses of this type as used by me, the curvature error of the focus for rays in primary sections of a given oblique pencil is always about 2·2 times the curvature error of the focus for rays in the secondary section of the same oblique pencil. This ratio of 2·2 may be looked upon as practically constant in all lenses used by me.

It can be proved that exactly the same law of curvature of image and rules as to diaphragm corrections and the elimination of diaphragm corrections applies to negative lenses as well as positive lenses, and I will now show how a flat image almost perfectly free from astigmatism may be obtained by judiciously combining together positive and negative lenses whose diaphragm corrections have been eliminated. Fig. 5 shows a simple positive lens (L) of this type and N is a negative lens of the same type and of the same focal power as L and *s*—*s* a diaphragm or stop placed conveniently between them. The diaphragm corrections of L are supposed to be eliminated on the condition that the rays first incident on it are parallel as if coming from distant points.

The lens N, being placed in any desired position between L and its image, must also have its diaphragm corrections eliminated so that the presence of the diaphragm *s*—*s* between them shall have no effect upon the curvature errors of either lens. Under these conditions the positive lens L tends to produce an image F—K, for rays in primary planes, of the normal curvature and an image F—*g* for rays in secondary planes also of the normal curvature. But the negative lens N considerably extends the focal length N—F and tends to throw a larger image upon the plane *f*—*p* and this image must be approximately flat and free from astigmatism, since the curvature errors of N, being normal and uninterfered with by diaphragm corrections, are equal and opposite to the curvature errors of the positive lens L, since the two lenses are of equal focal power. Or the rays may be traced backwards as follows :—

Supposing *f*—*p* to be the original flat object, then oblique rays in primary planes originating from the point *p*, after refraction through the negative lens N, appear to come from the point K while rays originating from *f* on the axis appear after refraction through the negative lens, to diverge from the point F and the virtual image of the original *f*—*p* which is formed at F—K is curved to the normal radius equal to $\frac{3}{11}$ths of the principal focal length of N. But the principal focal length of N is equal to the principal focal length of L, and therefore the virtual image F—K is curved to the same radius as is the real image of distant objects on the left formed by the positive lens L. Therefore the rays apparently diverging from the point K will, after being refracted through the positive lens L, emerge on the left in a condition of parallelism. Conversely, rays in primary planes entering the lens L from an infinitely distant plane object or landscape on the left hand will after refraction through both lenses come to focus upon a flat surface *f*—*p* perpendicular to the optic axis. And precisely the same reasoning applies to the rays contained in secondary sections of the same pencils, in this case also the curvature errors of the two lenses are equal but opposite and therefore neutralize one another. In this way a flat image may be obtained which is also free from astigmatism.

This simple example of only two lenses serves to illustrate the principle, but in practice two lenses only cannot be employed owing to two defects necessarily inherent in such a combination one being the presence of an unsightly amount of negative distortion of marginal straight lines and the other being the failure of such a lens to adapt itself to copying or enlarging, for it can only give a flat image for rays of a certain degree of divergence. For instance if the lens shown in Fig. 5 were used on a near object on the left, then the rays entering L would become strongly divergent and diaphragm corrections tending to flatten the image formed by L would ensue. At the same time the rays entering N would grow less convergent and the effect would be to give rise to diaphragm corrections in N whose tendency would be the same as the diaphragm corrections in L and the final effect would be that an image would be formed actually curved backwards.

I get over these difficulties by the simple device of dividing my positive lens into two portions and placing my negative corrector lens between them, thus forming what is generally a triplet combination. The above principle of corrections remains equally in force as may be gathered from Fig. 6 which roughly represents such a triplet lens having its two positive lenses L_1 and L_2 alike in power and shape but turned in opposite directions. The whole combination is shown in Fig. 6 as though being used for copying a diagram to equal size the rays entering L diverging to the same degree as the rays leaving L_2 are converging and each lens is in itself supposed to be free from diaphragm corrections under these circumstances. In such a case the negative lens N would be equiconcave & since its focal power has to be approximately equal to the sum of the focal powers of the two positive lenses. it is obvious that if the negative lens is imagined to be split along the dotted line into two equal plano concave lenses then we should have virtually two double combinations placed together in reverse order 1st the double combination consisting of a positive lens L_1 and a negative concavo-plane lens being the left hand half of N these two being equal in principal focal length or focal power according to what has preceded and 2nd the double combination consisting of a plano concave lens, being the right hand half of N, and a positive lens L_2, these two also being equal in principal focal length or focal power. Therefore the curvature errors of the positive lens L will be compensated by one half of the negative lens N and the curvature errors of the positive lens L_2 will be compensated by the other half of the negative lens N. Such a combination is free from distortion and moreover compensates itself when used on a distant subject for if the rays first entering L_1 become parallel or nearly so instead of divergent then diaphragm corrections arise in the case of L_1 whose tendency is to make its image more curved than normal. But at the same time owing to the much lessened divergence of the rays entering L_2 diaphragm corrections arise in its case whose tendency is to flatten its image and these corrections more or less perfectly neutralise those operating in the other lens L_1 while no appreciable diaphragm corrections can arise in the case of the negative lens so long as the oblique pencils pass centrally or almost centrally through it, as they must do if the diaphragm is placed very closely to N. In such manner all the lenses made according to my principle may be designed to answer as well for copying or enlarging as for distant work. Given the fact that each lens used in my combinations is individually free from diaphragm correction when the rays first entering have a certain assigned degree of divergence or parallelism, then the combination as a whole will remain sufficiently free from diaphragm corrections, supposing the combination is used for rays having any other likely degree of divergence: and thus, diaphragm corrections being practically eliminated from my combinations, then the whole burden of flattening the final image and compensating its marginal astigmatism is thrown upon the negative lens whose errors of curvature of image are, as I have stated, of the same character and amount but opposite in sign to the curvature errors of the positive lenses, provided that the focal power of the negative lens is approximately equal to the sum of the focal powers of the two positive lenses. I thus discard altogether the old principle of diaphragm corrections hitherto relied upon for flattening the image of photographic lenses, in favor of the above explained principle which renders possible a much more perfect correction for astigmatism in conjunction with a flat image of considerable angular extent. I do not claim priority for the mere expedient of mounting a negative lens behind a positive lens or between two positive lenses, for the purpose of merely helping to flatten the final image, for these devices were long ago carried out in Prof. Petzvals orthoscopic lens also in Sutton's, Dallmeyer's and Ross's triplet lenses. But it can be shown that in none of these lenses does the focal power of the negative lens amount to more than a fraction, four tenths or so, of the sum of the focal powers of the positive lenses, while a large part of the flattening of the final image is due to the influence of the usual diaphragm corrections, the idea of eliminating the diaphragm corrections and throwing the whole burden of flattening the final image and correcting marginal astigmatism apparently not having occurred to these inventors. So far I have dealt with the principle adopted in my lenses for correcting the curvature and astigmatic errors of the oblique rays. I will now, before giving the curves and other particulars relating to my lenses, touch upon the other important corrections against spherical aberration and chromatic aberration which must be more or less perfectly carried out in any lens that is to be practically useful.

It has almost always been the practice to make each lens of a doublet or triplet lens in itself compound and self corrected against spherical and chromatic aberrations. However Prof. Abbe of Jena in a triplet lens patented a few years ago in this country practically demonstrated that it was possible to make a triplet lens in which the two outside positive lenses were perfectly simple, while the chromatic and spherical aberrations both of the central direct pencil and the oblique pencils were simultaneously corrected by means of a compound lens, of scarcely any focal power or even positive, placed half way between the two positive lenses. But this central correcting lens was not designed to contribute anything towards the flattening of the image and eliminating marginal astigmatism, whereas in my lenses I make my negative correcting lens perform the triple function of—

1st. Correcting the final image against curvature and astigmatism thus permitting an unusually flat and perfect image of considerable angular extent to be attained.

2nd. Correcting both the direct and oblique pencils against chromatic aberration.

3rd. Correcting both the direct and oblique pencils sufficiently against spherical aberration.

Fig. 7 represents a rapid portrait lens with a full opening of $\frac{F}{3\cdot7}$ made according to my principle.

It consists of only 3 simple lenses and forms with an aperture of $\frac{F}{4}$ a flat and very good image over the whole of a plate whose greater side is equal to one half of the equivalent focal length.

The glasses employed are as follows

The positive lenses L_1 and L_3 are made of a hard and beautifully colourless borosilicate crown glass having the following optical properties

Index of refraction for the D ray - - -	= 1·5108
Difference between refractive indices for D & G rays or $\mu_G - \mu_D$ - - - - -	= ·01037

The negative lens L_2 is made of a light silicate flint glass having the following optical properties

Refractive index for D ray - - - - -	= 1·6042
Difference between refractive indices for the D & G rays or $\mu_G - \mu_D$ - - - -	= ·02086

I will now give the radii of curvatures of the surfaces, the central or axial thicknesses of the lenses and their finished diameters and the axial air spaces between them, expressing them in fractions of the equivalent focal length of the whole combination, so that if any lens of a certain focal length is required, all that is necessary is to multiply the following figures or fractions by the focal length required and the proper radii &c. will then be obtained. Convex surfaces have a + sign before their radii and concave surfaces a — sign before their radii.

$$\left\{\begin{array}{l}\text{1st surface radius } r_1 \\ \text{6th} \quad ,, \quad ,, \quad r_6\end{array}\right\} = +\ \cdot2636$$

$$\left\{\begin{array}{l}\text{2nd surface, radius } r_2 \\ \text{5th} \quad ,, \quad ,, \quad r_5\end{array}\right\} = +\ 1\cdot507$$

$$\left\{\begin{array}{l}\text{3rd surface, radius } r_3 = -\ \cdot2977 \\ \text{4th} \quad ,, \quad ,, \quad r_4 = -\ \cdot2415\end{array}\right.$$

Finished diameter of L_1 = ·282
Axial thickness of L_1 = ·059

Finished diameter of L_2 = ·233
Axial thickness of L_2 = ·002

Finished diameter of L_3 = ·273
Axial thickness of L_3 = ·059

Axial air space between L_1 & L_2 = about ·109
„ „ „ „ L_2 & L_3 = „ ·125

The corrections against axial spherical and chromatic aberrations in this combination depend on the total reparation between the two outside lenses. If too wide apart there will arise positive spherical aberration and undercorrection for colour. At the same time the relation between the two air spaces must be correct in order to make the combination rectilinear and achromatic towards the edge of the image.

If the image is at all round or concave towards lens and at the same time the spherical and colour aberrations are more or less undercorrected and there is also outward coma towards sides of image then the combination requires shortening up, at both ends if the lens is rectilinear, or only at the front end L_1 if the lens gives negative or pincushion distortion, or only at the back end L_3 if the lens gives positive or barrel shaped distortion of straight lines. But if the above specification is rigidly carried out there should not be much occasion for further serious adjustments.

It should be pointed out that the correction for spherical aberration in this portrait lens is not perfect, there being a zone of rays (focussing shorter than the rest) at about half way between the edge and centre of the aperture when $\frac{F}{4}$ is used. But this zonal aberration is not so great as to interfere with as much sharpness of definition as is most suitable for portrait work.

The diaphragms for regulating the aperture are placed as closely as possible behind the negative lens L_2 and the aperture of such diaphragm necessary to give a working aperture of $\frac{F}{4}$ should be ·177, expressed in the same manner as the previous figures. It should be understood that this lens should be tested upon distant, or moderately distant objects.

I will now give the figures, expressed in the same manner as the last, for a rapid lens giving a wider angle of view than the preceding.

This lens is shown in Fig. 8. in about correct proportions. Its full working aperture is $\frac{F}{5 \cdot 65}$ with that aperture it will give a well defined flat image up to the corners of a plate whose longer side is equal to $\frac{4}{5}$ths of the equivalent focal length, while with $\frac{F}{8}$ stop it will about cover a plate whose greater side is equal to the equivalent focal length, while the aperture of full $\frac{F}{8}$ is in operation up to the extreme margins of the plate. Thus its illumination is remarkably even in its character.

The two positive lenses L_1 and L_4 are made of a borosilicate crown glass having the following optical properties.

Refractive index for the D ray - - - - = 1·5101

Difference between refractive indices for D and G rays = ·01010

The second lens L_2 is composed of a silicate glass having the following optical properties.

Refractive index for the D ray	=	1·5365
Difference between refractive indices for D and G rays	=	·01348

The third lens L_3 is composed of densest baryta crown glass having the following optical properties.

	Refractive index for the D ray	=	1·6110
	Difference between refractive indices for the D and G rays	=	·01386
L_1	Radius of 1st surface r_1	=	+ ·2158
	" " 2nd surface r_2	=	+ ·4655
L_2	Radius of 3rd surface r_3	=	— ·3472
	" " 4th surface r_4	=	— ·1150
L_3	Radius of 5th surface r_5	=	+ ·1150
	" " 6th surface r_6	=	— ·1910
L_4	Radius of 7th surface r_7	=	1·265
	" " 8th surface r_8	=	·5843
L_1	Finished diameter	=	·208
	Axial thickness	=	·0603
L_2	Finished diameter	=	·223
	Axial thickness	=	·0044
L_3	Finished diameter	=	·160
	Axial thickness	=	·0218
L_4	Finished diameter	=	·208
	Axial thickness	=	·0393
	Axial air space between L_1 and L_2	=	about ·008
	Axial air space between L_3 and L_4	=	" ·090
	Aperture of diaphragm necessary for $\frac{F}{5·65}$	=	·1500
	Ditto for $\frac{F}{8}$	=	·1040

I have not adopted a symmetrical construction for this lens, for the fact that the diaphragms regulating the aperture have to be placed to one side or other of the negative lens, if the latter is a cemented combination, renders it advantageous to make the front lens much more powerful than the back lens. Each of the three main lenses of this combination is calculated to be in itself free from diaphragm corrections when the distance between the original object and the front lens L_1 is $\frac{1}{2·7}$th of the distance of the final image from the back lens L_4, the focal length of L_4 being 2·7 times the focal length of L_1. This lens is equally good for copying and enlarging & is well adapted for lantern work.

In adjusting this lens the tube must be shortened and the front lens L_1 be allowed to approach the negative lens L_2 until the final image of distant objects so judged to be quite flat. Then the colour correction should be correct. But when properly adjusted there should be a certain amount of positive spherical aberration. It has not been my aim to make this lens perfectly corrected for spherical aberration as it easily can be made, for in practice a little spherical aberration is an advantage, since in the case of lenses of such large aperture, it increases their depth of focus considerably without interfering with as much sharpness of definition as is likely to be required.

The freedom from or presence of distortion in the image thrown by this lens depends upon L_4 being adjusted to the right distance from L_3. If there is positive or barrelshaped distortion present, then L_4 should be screwed nearer up to L_3 and *vice versa.*

The above are specifications of the only two lenses on my principle which I have yet had the time or opportunity to work out; it being a work of great theoretical and practical difficulty, owing to all the various corrections performed by the negative lens being so interlocked together and interdependent. I have yet to work out a wider angle lens than the one shown in Fig. 8, among others. These lenses may be easily made on a scale small enough for microscopic work with the lantern.

It is not at all necessary to the embodiment of my principle that the negative lens should be a cemented combination, if made of two lenses. For instance Fig. 9 sketches out a perfectly symmetrical combination in which the negative lens consists of two equal lenses turned opposite ways with the diaphragm placed halfway between them. Such an arrangement has certain features much in its favour and I hope to be able to work it out more exactly. I should here point out that the deep curves and comparatively large thicknesses required in my lenses render necessary an apparent departure from the rule that the focal power of the negative lens should be equal to the combined focal powers of the two positive lenses. In the lenses I have herein specified the focal power of the negative lens amounts to appreciably less than the combined focal powers of the two positive lenses when reckoned by the usual approximate formulæ; but such formulæ become less and less accurate and reliable as the curves are deepened and the relative thicknesses increased.

The most perfect and approved types of modern photographic lenses, the only ones which can claim to give results at all comparable with those obtainable with lenses made on my principle, rarely consist of so few as four separate lenses, five or six separate lenses being very commonly employed in such combinations and therefore, relatively speaking, I may describe my invention as involving a simplification in form as well as an improvement in type.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

A photographic lens, lantern or microscope projecting lens, composed of two simple positive lenses and a simple or compound negative lens placed between the two positive lenses; all three lenses being severally so designed as to be simultaneously free from diaphragm corrections or have their diaphragm corrections eliminated when the rays first incident on the front lens are either parallel or else have a certain assigned degree of divergence; while the focal power of the negative lens is made as closely equal to the combined focal powers of the two positive lenses as is found necessary to the complete flattening of the final image or field of view; the whole burden of correcting the oblique pencils of light against curvature of image and astigmatism thus falling entirely upon the negative lens, by which device a flat image characterised by a substantial freedom from marginal astigmatism, is secured.

Dated this 10th day of August 1894.

H. DENNIS TAYLOR.

London: Printed for Her Majesty's Stationery Office, by Darling & Son, Ltd.—1894

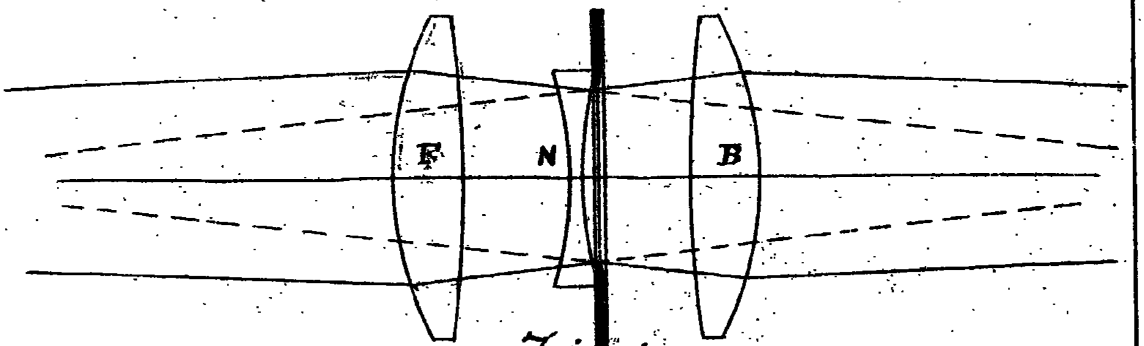

Fig. 1.

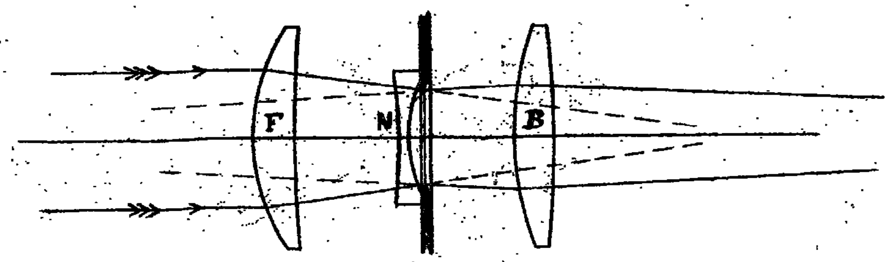

Fig. 2.

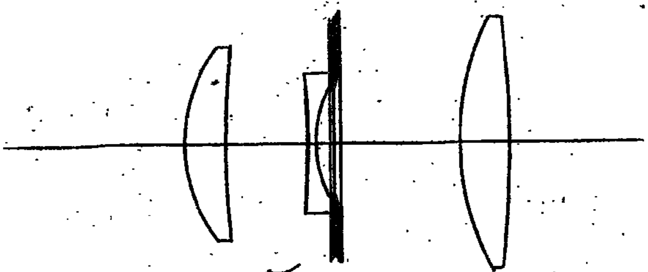

Fig. 3.

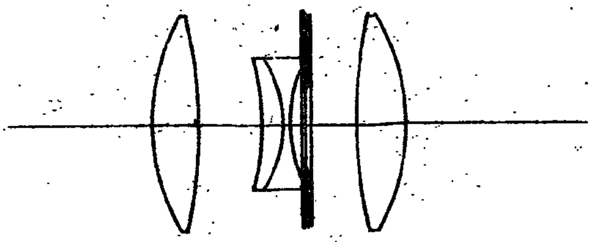

Fig. 4.

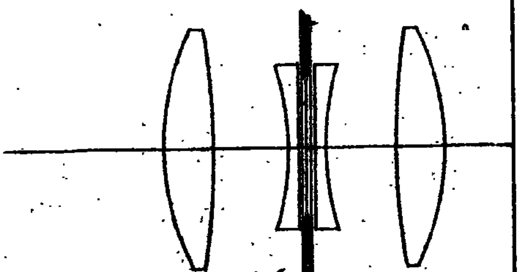

Fig. 5.

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TAYLOR'S Complete Specification.

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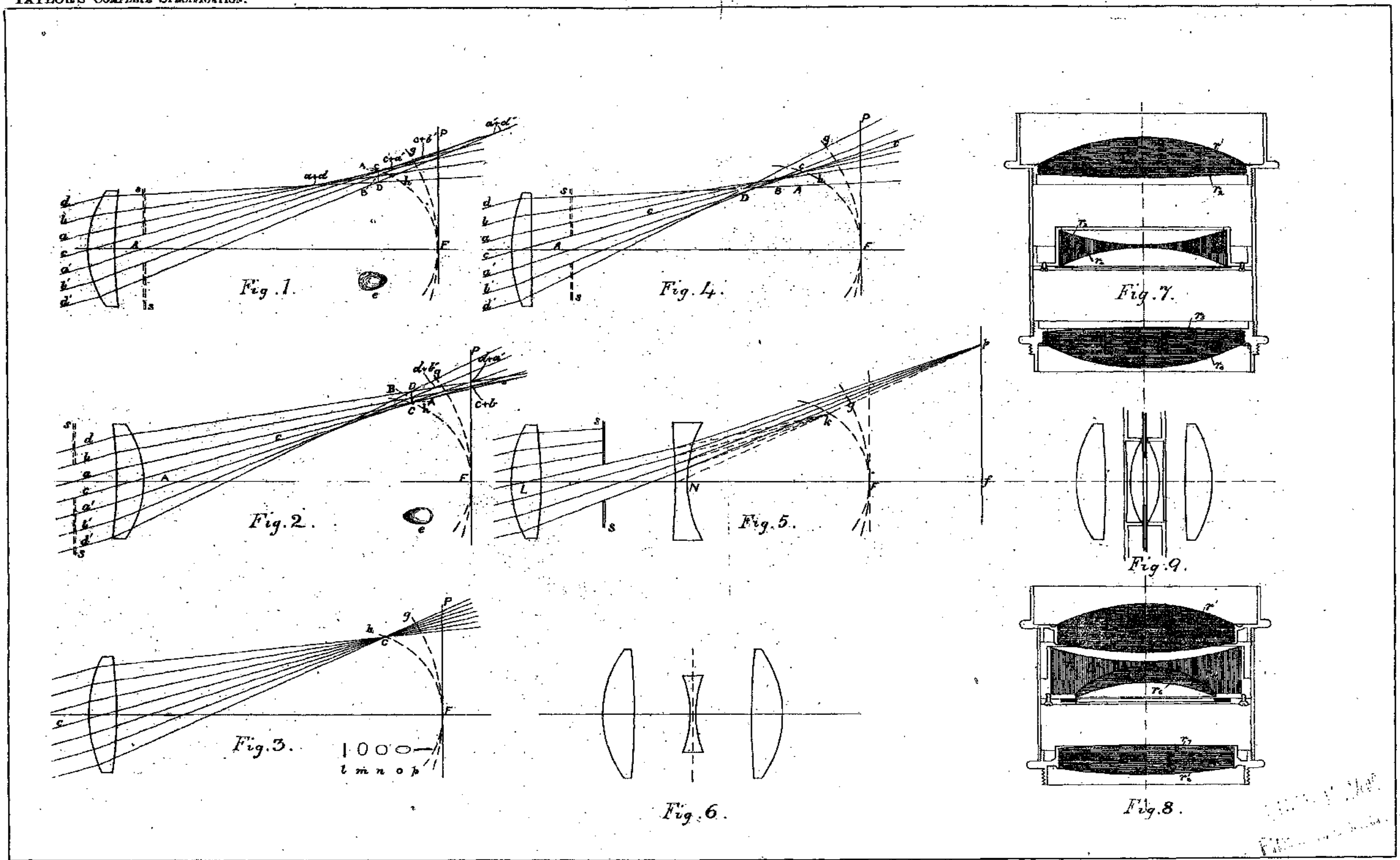

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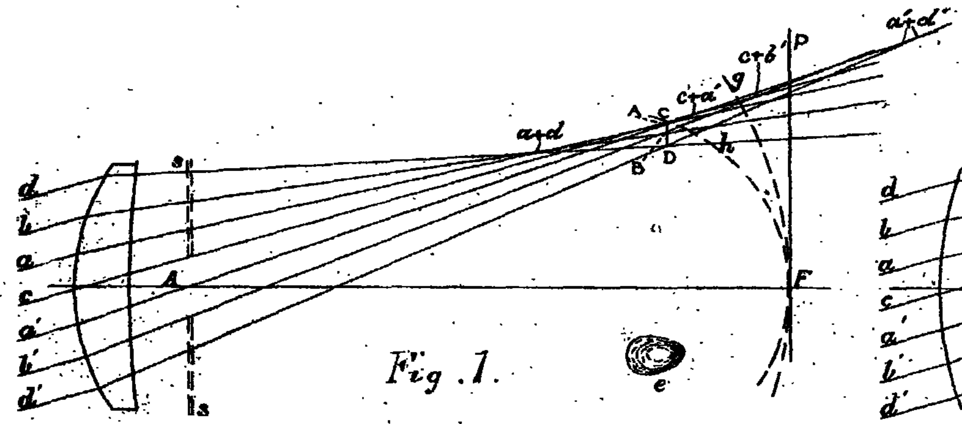


Fig. 1.

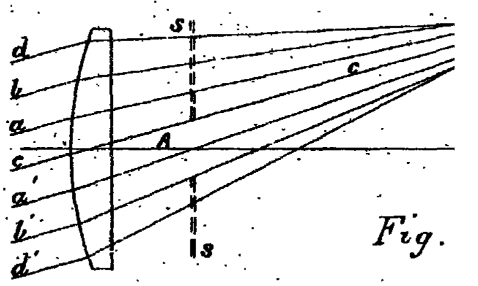


Fig.

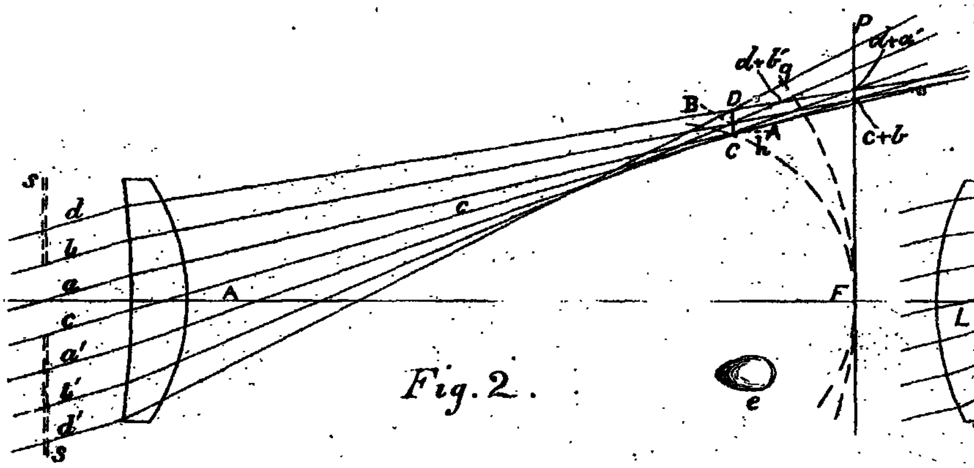
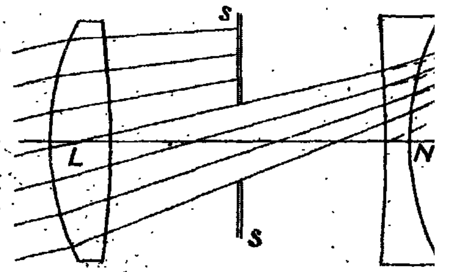


Fig. 2.



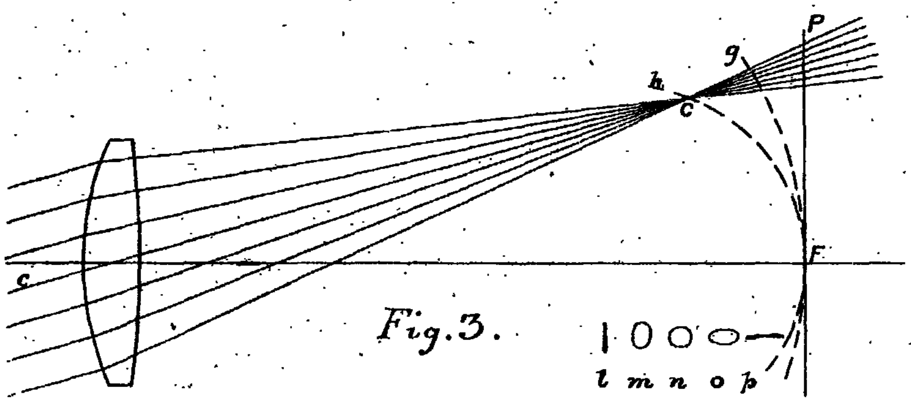


Fig. 3.

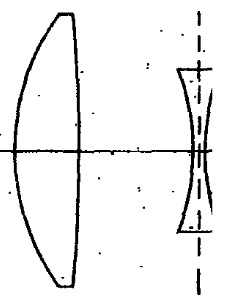


Fig.

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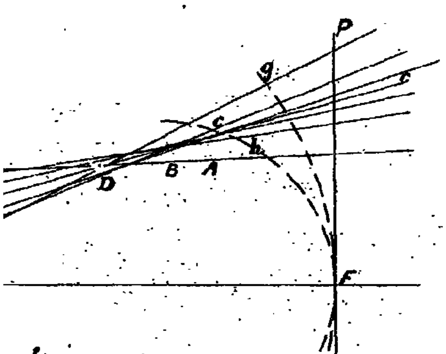

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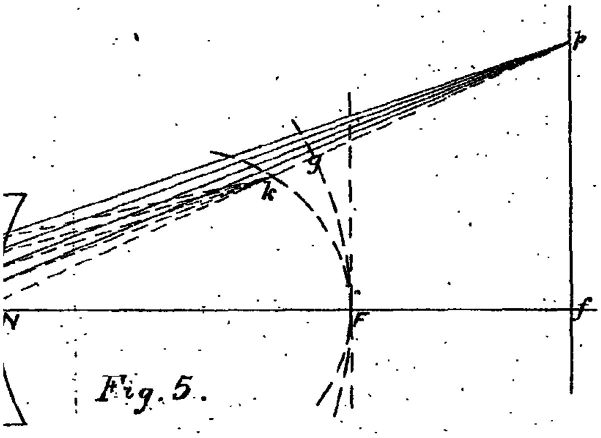
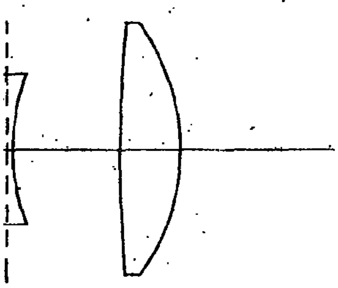


Fig. 5.



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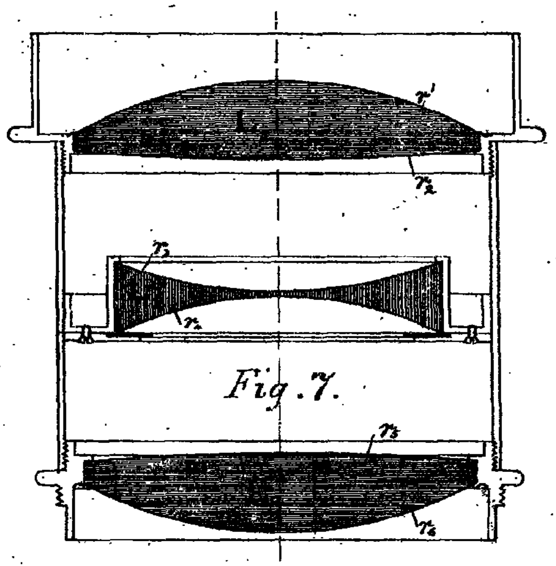

Fig. 7.

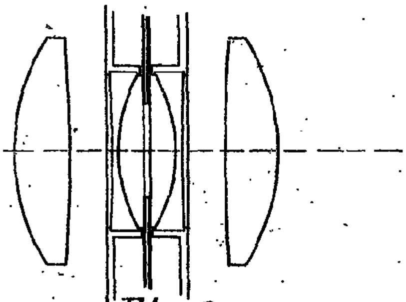

Fig. 9.

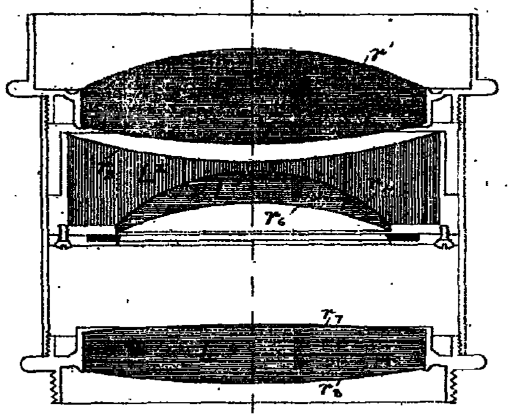

Fig. 8.

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