PATENT SPECIFICATION

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COMPLETE SPECIFICATION

Improvements in or relating to Photographic Objectives

I, ALBRECHT WILHELM TRONNIER, of 50*a*, Salinenstrasse, Bad Kreuznach, Rhineland, Germany, a German citizen, 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:—

This invention relates to photographic objectives of the kind in which two air spaced collective components are disposed in front of a simple, uncemented, and substantially unsymmetrical dispersing lens which is followed at its rear side by only one collective component, the latter in prior systems being generally constituted as a simple, unsymmetrical biconvex collective lens. Triplets of this type, in which all of the four air spaced components consist of uncemented individual lenses, are described, for example, in British Patent Specifications 237,212 and 347,996.

These prior arrangements either have but a small field of view with good zonal correction, or else, if the field of view is increased to a range of about 45° they possess quite appreciable residual zonal errors. In the latter case both available correctional possibilities are utilised. Either the central portion of the image must be favoured at the expense of marginal definition, or else a moderately satisfactory marginal error correction is effected while permitting considerable residual axial aberration.

Although good zonal correction of spherical aberration was fundamentally provided in the case of particularly large primary apertures of the system without sacrificing a visual field of at least average expanse, it was necessary, in order to obtain this correction (which, in general, obviously had to embrace at least two colours) to form one or more of the air spaced members of two or more lenses of different refractive index and of different mathematical sign as well as different dispersive power.

The cemented surfaces entering into the structure of the system may have either collective or dispersive power, and in general, at least one of these cemented surfaces is constituted so as to overcorrect chromatically.

In the case of a plurality of cemented surfaces, these were preferably so arranged, with a view to proper balancing of the colour zones that they operated in sequence in chromatically opposite manner. Lenses of this sub-type of developed triplets are described, for example, in British Patent Specifications 191,702, 193,376 and 237,529.

These lenses are all intended for apertures greater than f.3.5 and in general possess good zonal correction over a useful field of view of about 40°.

In utilising such a field of view it is found that the image exhibits appreciable comatic defects which can be distinctly decreased, insofar as they deleteriously affect the quality of the image, by using a smaller lens diameter at the image-facing end, that is, by permitting the occurrence of correspondingly appreciable indistinct portions which manifest themselves in the form of considerable marginal decrease in luminosity extending towards the margins of the image.

It has also been proposed, in order to reduce these comatic defects, so to subdivide one of the externally facing collective members into two parts of opposite mathematical sign that these two portions of the resulting substitute members include between themselves an air space in the shape of a dispersing lens, thus making the entire system consist of a total of five air spaced members. But even in this case the visual field cannot usefully be appreciably increased above a 40° range without decreasing the luminous intensity.

For the purposes of photography which are those which are most usually involved, and to a certain extent also for projection purposes, however, a useful image field of over 50° and up to 60° is required; this can be produced by the optical designer up to an aperture of about f.3.5 and with good zonal error correction and supplied as a standard triplet type, particularly of the special type having a collective cemented surface in the collective member at the end associated with the shorter conjugate distance, in which case the spherical aberrational and comatic errors, even with such a large expanse of image field can be kept sufficiently small.

However, as soon as the primary aperture of these three component Taylor type objectives of large visual field is increased appreciably beyond f.3.5, then their correctional construction must take care of increased zonal residual errors which cannot adequately be decreased by the above mentioned insertion of additional cemented surfaces in one or more of the three components.

By the present invention the advantages of the two above described triplet variations are combined while thoroughly obviating their drawbacks. The new objectives, considered as a further step in triplet development are provided with at least one cemented surface, viz. a collective cemented surface in the collective image-facing member (i.e. generally expressed, in the collective member at the end associated with the shorter conjugated distance) making a total of four air spaced members embodying at least five components and having a relative aperture of more than f.3.5. The excellent correction extends over a field of more than 50° and up to 60° without requiring for this high total efficiency the use of extremely curved surfaces or especially long glass paths, the system of the invention being likewise admirably adapted to the requirements of commercial manufacture.

The new objectives therefore permit of such correction of errors that within the aforesaid visual field the positional deviations of the sagittal and meridional image surfaces i.e. their distances from the ideal image plane are kept below about $\frac{3}{4}$ per cent of the focal length accompanied by such correction of spherical aberration that its greatest zonal horizontal error remains below about $\frac{3}{8}$ per cent of the focal length. By meeting the sine-coincidence condition the images coincide in the neighbourhood of the axes not only as to position but also as to size for the various aperture zones.

Consequently in objectives made according to the present invention the coma may be advantageously corrected so that the image produced by the lateral rays even at large apertures essentially permits, within the useful visual field, the production of as good definition as is produced in the centre of the image.

In order to explain the subject of the present invention use will be made of the elements of the parallel auxiliary rays to which the Schwarzschild equation applies.

$$\phi_{1K} = \sum_{i=1}^{K} \frac{n^1_i - n_i}{r_i} h_i = 1$$

where n_i and n_i^1 are the indices of refraction before and after the radius of curvature r_i, and the height of incidence of the parallel auxiliary ray is denoted by h_i, and the index i is the surface number from the first to the rear radius of the system.

In the equation, the abbreviation $\bar{\phi}_F$ (surface effect) may be substituted for each of the " i " terms. If the effect of the ν—1 surfaces preceding the ν surface be designated by

$$\bar{\phi}^1_{V_{\nu-1}} = \bar{\phi}_V \qquad \text{(rest effect)}$$

then we have,

$$\bar{\phi}^1_{V_\nu} = \bar{\phi}_{V_\nu} + \bar{\phi}_{F_\nu} = \bar{\phi}_{V_{\nu+1}}$$

and for the transit from the ν to the $\nu+1$ surface we have

$$h_{\nu+1} = h^1_\nu = h_\nu - \delta h_\nu$$

where

$$\delta h_\nu = \bar{\phi}^1_{V_\nu} \frac{d_{\nu,\nu+1}}{n^1_\nu}$$

In explaining this invention the terms " surface effect " and " rest effect " have their usual meaning as employed in this art, and the equations given above are also recited in the Specification of British Patent 438,671.

This effect value makes it possible clearly to depict the constructional system involved since the individual surfaces are defined by the $\bar{\phi}$ value, not only according to difference in refractive indices and curvature, but also according to position, wherefore these values, in addition, serve directly or indirectly for expressing the aberrational coefficients, e.g. of the 3rd order. The essence of the invention in this case is expressed as involving such distribution of the refractive effect among the individual components of the new objectives that the surface effect $\bar{\phi}_{F_K}$ considered as the product of the incident height of the auxiliary ray (h_K), refractive index difference ($n^1_K - n_K$), and radius reciprocal ($1 : r_K$) for the collective cemented surface (K) in the positive outer member (IV) associated with the shorter conjugate distance is numerically greater than a quarter of but not more than $1\frac{1}{2}$ times the rest effect $\overleftarrow{\phi}^{1}_{V_{III}}$ the algebraic sum of all the surface effects of the three air spaced members (I, II, III) of the entire system which precede said outer member and of which the two outer ones (I, II) act also as collective components, while the third inner member (III) adjoining the cemented outer member (IV) located at the side of shorter conjugate distance has a strongly dispersive action and the radius of the cemented surface of the outer member (IV) is less than $1\frac{1}{2}$ times the radius of the rear outer surface of the objective.

It has furthermore developed that particularly excellent correctional relations may be secured if in addition the refractive effect in the members III and IV is distributed in such a manner among the individual outer surfaces of these members that the surface effect of the front surface (v, III) facing away from the outer member IV of the dispersing component III is numerically greater than a third of (at most, however, equal to) the surface effect of the rear surface (IV, h) facing away from the inner member III of the positive outer component IV, that is, that the ratio $\overleftarrow{\phi}_{F_{V,III}} : \overleftarrow{\phi}_{F_{IV,h}}$ lies between the absolute values 1/3 and 1.

Furthermore, very advantageous constructional arrangements are obtained if in addition to distributing the refractive effect care be taken that the rest effect $\overleftarrow{\phi}^{1}_{V_{II}}$ the algebraic sum of all surface effects of both front collective members I and II, is greater than two-thirds (at most, however, is twice as great as) the surface effect $\overleftarrow{\phi}_{F_{IV,h}}$ of the rear surface IV, h that is, that the ratio $\overleftarrow{\phi}^{1}_{V_{II}} : \overleftarrow{\phi}_{F_{IV,h}}$ lies between the values 2/3 and 2.

The accompanying drawing illustrates diagrammatically an objective according to the invention having a focal length of 100 mm. The objective is shown in vertical side section in Fig. 1. Fig. 2 diagrammatically illustrates the optical characteristics as referred to the table giving the features of the described embodiment. Fig. 1a, 1b and 1c show the curves of the correction for the embodiment. Fig. 1a shows the spherical aberration for the yellow as a full line curve and for violet as a dotted curve relative to the ideal image plane, indicated as the ordinate axis. On the abscissæ, the plus and minus deviations from this ideal image plane are indicated in percentages of the focal distances, while on said ordinates the distances in mm. of the parallel incident marginal rays from the optical axis are indicated.

Fig. 1b shows the astigmatic state of correction of the new objective. The full line curve shows the deviations of the sagittal, while the dotted line curve shows that of the meridional image point from the axial image point lying in the ideal image plane (the ordinate axis) in percentages of the focal distances, which latter are indicated on the abscissæ. The main ray inclinations are indicated in angle degrees on the ordinate, the ordinate being in the zero point of these horizontals.

Fig. 1a and 1b correspond to the v. Rohr-Merte method.

The curve of Fig. 1c shows the designation for the image scale $N=\infty$, that is, for the "infinitely remote object." On the abscissa, according to the method of E. Wandersleb, the main ray inclinations are shown in degrees, while the indications on the ordinates, in the zero point of this line, are shown in percentages of the image height and may be read off.

The indicia given correspond to the values given in the table, the correctional relations being those based on W. Merte's recently proposed scale (W. Merte: "Handbuch der wissenschaftlichen und angewandten Photographie" (=Handbook of scientific and applied photography), volume I "Das photographische Objektiv" (="The Photographic Objective"), 1932. Fig. 1a shows the spherical aberration for the yellow and violet colour; Fig. 1b the sagittal and meridional deviation from the ideal image plane (shown in full and dotted lines) and Fig. 1c the indicia for the image scale $N=\infty$. The aberrations are given in percentages of the focal length of the objective, the distortion in percentages of the image height. The distance of the Gauss image plane from the vertex of the last lens on the image side is indicated by p^{1}_{o}. In the numerical example the focal length is equal to unity. The indicated refractive indices relate to the violet ray whereas the colour dispersion of the glasses used is characterised by the Abbe number ν. In the drawings the members of the objective are designated left to right by numerals I, II, III and IV. The individual lenses of which these members are composed are designated from left to right by reference characters L1, L2, L3, L4, L5 and L6. The distances of the members apart are designated $\Delta 1$, $\Delta 2$, and $\Delta 3$. The axial thicknesses of the individual lenses are indicated by characters $d1$, $d2$, $d3$, $d4$, $d5$ and $d6$, while the radii of the surfaces of the lenses are designated left to right by R1 . . . R10. The second of the two front collective members of this embodiment is composed of two individual lenses of opposite algebraic sign cemented together. Consequently the cemented surface radius K of the outer member IV has the position number 9, the radius of the rear surface of this number is therefore R10.

The front radius of the uncemented dispersive inner member III R6 is identical with the surface (v, III) so that $\vec{\phi}_{F_6}$ may be written for $\vec{\phi}_{F_{v,III}}$ and similarly for the rest effect of the last surface of the collective member II, i.e. the radius R 5 of the embodiment shown, where $\vec{\phi}^1{}_{v_5}$ may be substituted for the general term $\vec{\phi}^1{}_{v_{II}}$. In an analogous manner $\vec{\phi}^1{}_{v_7}$ may be substituted for $\vec{\phi}^1{}_{v_{III}}$.

Relative aperture f.2.9 $p^1{}_0 = .8059$

$R_1 = +\ .8285$
$d_1 = .04147$ $n_1 = 1.63290$ $\nu 1 = 60.4$
$R_2 = +\ 1.7255$
$\Delta 1 = .00407$ air
$R_3 = +\ .4392$
$d_2 = .06221$ $n_2 = 1.57175$ $\nu 2 = 60.7$
$R_4 = -\ .6897$
$d_3 = .01667$ $n_3 = 1.57620$ $\nu 3 = 45.3$
$R_5 = -12.428$
$\Delta 2 = .06627$ air
$R_6 = -\ .6897$
$d_4 = .03663$ $n_4 = 1.60085$ $\nu 4 = 40.8$
$R_7 = +\ .3345$
$\Delta 3 = .08314$ air diaphragm space
$R_8 = -\ 2.6928$
$d_5 = .03527$ $n_5 = 1.52625$ $\nu 5 = 54.7$
$R_9 = +\ .3998$
$d_6 = .07248$ $n_6 = 1.65170$ $\nu 6 = 56.1$
$R_{10} = -\ .4268$

Here $\vec{\phi}_{F_9}$ (or $\vec{\phi}_{F_k}$) $= .249705$, $\vec{\phi}^1{}_{v_7}$ (or $\vec{\phi}^1{}_{v_{III}}$) $= -.326853$ and .249705 is greater than .326853 : 4 but less than $\frac{3}{2} \times .326853$.

Furthermore, $\vec{\phi}_{F_6}$ is $= -.680523$, $\vec{\phi}^1{}_{v_5} = +1.714414$ and $\vec{\phi}_{F_{10}} = +1.230500$. Therefore the ratio values are .680523 : 1.230500 = .553046, and 1.714414 : 1.230500 = 1.393266; hence, as claimed, .553046 lies between the values 1/3 and 1 while 1.393266 lies between the values 2/3 and 2. Moreover the radius of curvature R_9 of the cemented surface k is less than $1\frac{1}{2}$ times the radius of curvature R_{10} of the rear outer surface of the objective.

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:—

1. A photographic objective composed of four air-spaced members comprising a simple, uncemented, and essentially unsymmetrical dispersing lens, two air-spaced collective lenses, disposed in front of said dispersing lens, and a collective component following said dispersing lens on its rear side, said following collective component including a collective, cemented surface, refractive effect being so distributed among the individual components that the surface effect $\vec{\phi}_{F_K}$, considered as the product of the auxiliary ray incident height (h_K), refractive index difference ($n_K{}^1 - n_k$), and radius reciprocal ($1 : r_K$) for the collective cemented surface k in the positive rear component is numerically greater than $\frac{1}{4}$ of but not over $1\frac{1}{2}$ times the rest effect $\vec{\phi}^1{}_{v_{III}}$ viz: the algebraic sum of all the surface effects of the dispersing lens and the two preceding collective lenses, the radius of curvature of the cemented surface k of said rear component being less than $1\frac{1}{2}$ times the radius of the rear outer surface of the objective, and the refractive effect being so distributed among the individual outer surfaces of the dispersing lens and following collective component that the surface effect $\vec{\phi}_{F_{v,III}}$ of the front surface (v, III) of the dispersive lens is numerically greater than one-third, but at the most is equal to the surface effect of the rear surface of the positive following component, that is, that the ratio $\vec{\phi}_{F_{v,III}} : \vec{\phi}_{F_{IV,h}}$ lies between the numerical values 1/3 and 1.

2. Photographic objective composed of four air-spaced members according to claim 1, in which the refractive effect is distributed among the collective components of the system, so that the rest effect $\vec{\phi}^{1}_{\mathrm{V}_{\mathrm{II}}}$ viz. the algebraic sum of all the surface effects of both front collective members, is greater than two thirds but not over double the surface effect $\overleftarrow{\phi}_{\mathrm{F}_{\mathrm{IV,h}}}$ of the rear surface of the positive outer member following the dispersive lens, that is, that the ratio $\vec{\phi}^{1}_{\mathrm{V}_{\mathrm{II}}} : \overleftarrow{\phi}_{\mathrm{F}_{\mathrm{IV,h}}}$ lies between the values 2/3 and 2.

Dated this 31st day of August, 1936.

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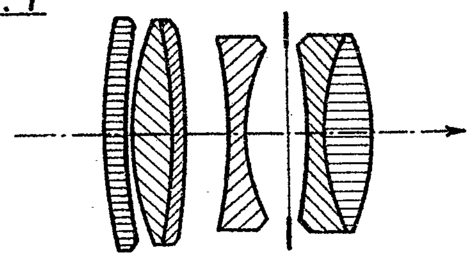
Fig. 1



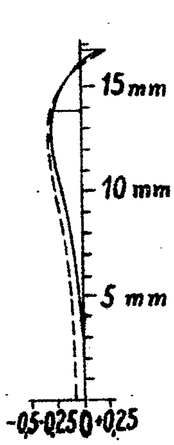


Fig. 1a

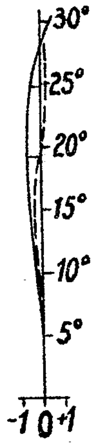


Fig. 1b

Fig. 1c

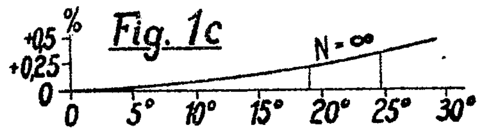


Fig. 2