# PATENT SPECIFICATION

Application Date: Nov. 27, 1941. No. 15292/41.

553,639

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Complete Specification Accepted: May 31, 1943.

## PROVISIONAL SPECIFICATION

## Improvements in or relating to Optical Objectives

We, TAYLOR, TAYLOR & HOBSON LIMITED, a Company registered under the Laws of Great Britain, ARTHUR WARMISHAM, British Subject, and CHARLES GORRIE WYNNE, British Subject, all of 104, Stoughton Street, Leicester, do hereby declare the nature of this invention to be as follows:—

This invention relates to an optical objective for photographic or other purposes of the kind corrected for spherical and chromatic aberrations, coma, astigmatism, field curvature and distortion, and comprising two compound divergent meniscus component located between two simple convergent components and each having a divergent element cemented to a convergent element.

The invention has for its object to provide an objective of this kind well-corrected over a wider angle of view than hitherto.

In the objective according to the invention the two divergent elements are made of potassium bromide crystal. Preferably the average value of the Abbé numbers for the four convergent elements is not greater than 49. Conveniently the rear surface of the front convergent component is convex to the front (that is to the side of the longer conjugate) and has a radius of curvature lying between .85 and 1.6 times the equivalent focal length of the objective.

In one convenient arrangement the convergent element in one of the divergent components (preferably the front divergent component) is made of a dense barium crown glass whilst dense flint or dense barium flint glasses are used for the other convergent elements. In another arrangement all four convergent elements are made of dense barium flint glasses.

Numerical data for three convenient practical examples of objective according to the invention are given in the following tables, in which $R_1$ $R_2$ . . . . . represent the radii of curvature of the individual lens surfaces counting from the front (the positive sign indicating that the surface is convex to the front and the negative sign that it is concave thereto), $D_1$ $D_2$ . . . . represent the axial thicknesses of the various elements, and $S_1$ $S_2$ $S_3$ represent the axial air separations between the components. The tables also give the mean refractive indices and the Abbé V numbers of the materials used for the individual elements of the objective.

EXAMPLE I.

Equivalent focal length 1.000. Relative aperature F/2.0.

| Radius | Thickness or Air Separation | Refractive Index $n_D$ | Abbé V Number |
|---|---|---|---|
| $R_1$ + .5618 | | | |
| | $D_1$ .0647 | 1.652 | 33.5 |
| $R_2$ + 1.049 | | | |
| | $S_1$ .0059 | | |
| $R_3$ + .3954 | | | |
| | $D_2$ .0890 | 1.6128 | 56.3 |
| $R_4$ ∞ | | | |
| | $D_3$ .0494 | 1.558 | 31.5 |
| $R_5$ + .2701 | | | |
| | $S_2$ .1590 | | |
| $R_6$ − .3066 | | | |
| | $D_4$ .0198 | 1.558 | 31.5 |
| $R_7$ ∞ | | | |
| | $D_5$ .0779 | 1.644 | 48.3 |
| $R_8$ − .4397 | | | |
| | $S_3$ .0049 | | |
| $R_9$ + 5.492 | | | |
| | $D_6$ .0791 | 1.6529 | 46.2 |
| $R_{10}$ − .7461 | | | |

[Price 1/-]

EXAMPLE II.

Equivalent focal length 1.000. Relative aperature F/2.0.

| Radius | Thickness or Air Separation | Refractive Index $n_D$ | Abbé V Number |
|---|---|---|---|
| $R_1$ + .5423 | | | |
| | $D_1$ .0495 | 1.652 | 33.5 |
| $R_2$ + 1.0312 | | | |
| | $S_1$ .0059 | | |
| $R_3$ + .3702 | | | |
| | $D_2$ .1226 | 1.6128 | 57.6 |
| $R_4$ ∞ | | | |
| | $D_3$ .0294 | 1.558 | 31.5 |
| $R_5$ + .2550 | | | |
| | $S_2$ .1413 | | |
| $R_6$ − .3292 | | | |
| | $D_4$ .0196 | 1.558 | 31.5 |
| $R_7$ + 3.674 | | | |
| | $D_5$ .0834 | 1.644 | 48.3 |
| $R_8$ − .4948 | | | |
| | $S_3$ .0049 | | |
| $R_9$ + 2.844 | | | |
| | $D_6$ .0873 | 1.6529 | 46.2 |
| $R_{10}$ − .8934 | | | |

EXAMPLE III.

Equivalent focal length 1.000. Relative aperature F/2.0.

| Radius | Thickness or Air Separation | Refractive Index $n_D$ | Abbé V Number |
|---|---|---|---|
| $R_1$ + .5208 | | | |
| | $D_1$ .0476 | 1.6529 | 46.2 |
| $R_2$ + .9902 | | | |
| | $S_1$ .0057 | | |
| $R_3$ + .3736 | | | |
| | $D_2$ .1200 | 1.644 | 48.3 |
| $R_4$ ∞ | | | |
| | $D_3$ .0283 | 1.558 | 31.5 |
| $R_5$ + .2448 | | | |
| | $S_2$ .1356 | | |
| $R_6$ − .3160 | | | |
| | $D_4$ .0188 | 1.558 | 31.5 |
| $R_7$ + 3.527 | | | |
| | $D_5$ .0800 | 1.644 | 48.3 |
| $R_8$ − .4750 | | | |
| | $S_3$ .0047 | | |
| $R_9$ + 6.495 | | | |
| | $D_6$ .0942 | 1.6529 | 46.2 |
| $R_{10}$ − .7742 | | | |

It will be noticed that in all these examples the radius $R_2$ lies between .85 and 1.6, and that the average Abbé V number for the convergent elements is 46.1 in Example I, 46.4 in Example II and 47.25 in Example III. In Examples I and II dense barium crown glass is used for the convergent element in the front divergent component and dense flint glass for the simple front component, whilst the other two convergent elements are both made of dense barium flint glass. In Example III all four convergent elements are made of dense barium flint glass. These examples are well corrected for all the abberations over a semi-angular field of 25°.

It is of especial interest to note that the paraxial secondary spectrum in all these examples is reversed as compared with that for similar objectives employing glass elements throughout. Thus for instance in Example II the paraxial back focus is .70128 for the $b$-line (7065), .70187 for the C-line (6563), .70131 for the $d$-line (5875) and .70067 for the $g$-line (4359), so that the two ends of the spectrum focus short of a maximum value in the neighbourhood of the C-line, whereas for ordinary glass the two ends of the spectrum focus beyond a minimum value. Such reversed secondary spectrum is an important characteristic in objectives according to the invention.

It will be appreciated that these examples have been given by way of example only and that the invention may be carried into practice in other ways.

Dated this 27th day of November, 1941.

FULLINGER & MALET,
Agents for the Applicants.

## COMPLETE SPECIFICATION

# Improvements in or relating to Optical Objectives

We, TAYLOR, TAYLOR & HOBSON LIMITED, a Company registered under the Laws of Great Britain, ARTHUR WARMISHAM, British Subject, and CHARLES GORRIE WYNNE, British Subject, all of 104, Stoughton Street, Leicester, 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 an optical objective for photographic or other purposes of the kind corrected for spherical and chromatic aberrations, coma, astigmatism, field curvature and distortion, and comprising two compound divergent meniscus components located between two simple convergent components and each having a divergent element cemented to a convergent element.

The invention has for its object to provide an objective of this kind well-corrected over a wider angle of view than hitherto.

In the objective according to the invention the two divergent elements are made of potassium bromide crystal. Preferably the paraxial secondary spectrum is reversed as compared with that for usual objectives of the above-mentioned kind, that is to say the paraxial focus at the two ends of the visible spectrum is short of a maximum value occurring in the neighbourhood of the C-line, whereas in known objectives the paraxial focus at the ends is beyond a minimum value at an intermediate point of the spectrum. Preferably the average value of the Abbé V numbers for the four convergent elements of the objective is not greater than 49.

To express the desired results mathematically, it is convenient to make use of a mathematical expression representing the contribution of an individual surface to secondary spectrum, namely the expression

$$E\,Q\,H^2\left(\frac{\delta N}{N}-\frac{\delta n}{n}\right)$$

wherein E is the equivalent focal length of the objective and the remaining terms are all related to any one particular surface of the objective and may be defined as follows:—N is the mean refractive index for the D-line of the material on the emergent side of the surface, and $n$ that of the material on the incident side of the surface: $\delta N$ is the difference in refractive index between the C and F lines for the material on the emergent side, and $\delta n$ the corresponding difference for the material on the incident side; H is the ratio of the incident height at the surface to the incident height at the front surface of the objective of a paraxial ray traversing the objective; and Q is defined by $\left(\frac{1}{r}-\frac{1}{s}\right)n$, wherein $r$ is the radius of curvature of the surface and $s$ is the axial distance from the surface of the axial intersection of the paraxial ray on the incident side.

If now the letter K be used for brevity to represent the above expression, and numerical suffixes be used to indicate individual surfaces counting from the front, then we have for the two cemented surfaces

$$K_4=E\,Q_4\,H_4^2\left(\frac{\delta N_4}{N_4}-\frac{\delta n_4}{n_4}\right) \text{ and } K_7=E\,Q_7\,H_7^2\left(\frac{\delta N_7}{N_7}-\frac{\delta n_7}{n_7}\right)$$

In order to obtain the desired results the algebraic sum of $K_4$ and $K_7$ should preferably lie between −.005 and −.015. It is also preferable that the algebraic sum of $K_4^1$ and $K_7^1$ should be numerically less than that of $K_4$ and $K_7$, where the expression $K^1$ differs from K solely in the substitution of the terms $\delta^1N$ and $\delta^1n$ for $\delta N$ and $\delta n$, $\delta^1N$ being the difference in refractive index between the *e* and *g* lines for the material on the emergent side of the surface and $\delta^1n$ the corresponding difference for the material on the incident side.

Utilising a different method of calculation it is also possible to obtain the desired results if the algebraic sum of the reciprocals of the radii of curvature of the two cemented surfaces of the objective (reckoned as positive if concave to the diaphragm and negative if convex to the diaphragm) is numerically less than half the equivalent power of the objective.

Conveniently the rear surface of the convergent front component is convex to the front and has a radius of curvature lying between .85 and 1.6 times the equivalent focal length of the objective.

In one convenient arrangement the convergent element in one of the divergent components (preferably the front divergent component) is made of a dense barium crown glass, whilst dense flint or dense barium flint glasses are used for the other convergent elements. In another arrangement all four convergent elements are made of dense barium fint glasses.

Numerical data for three convenient practical examples of objective according to the invention, as illustrated in the accompanying drawing, are given in the following tables in which $R_1$ $R_2$ . . . represent the radii of curvature of the individual lens surfaces counting from the front (the positive sign indicating that the surface is convex to the front and the negative sign that it is concave thereto), $D_1$ $D_2$ . . . . represent the axial thicknesses of the various elements, and $S_1$ $S_2$ $S_3$ represent the axial air separations between the components. The tables also give the mean refractive indices of the Abbé V numbers of the materials used for the individual elements of the objective.

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EXAMPLE II.

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EXAMPLE III.

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It will be noticed that in all these examples the radius $R_2$ lies between .85 and 1.6, and that the average Abbé V number for the convergent elements is 46.1 in Example I, 46.4 in Example II and 47.25 in Example III. In Examples I and II dense barium crown glass is used for the convergent element in the front divergent component and dense flint glass for the simple front component, whilst the other two convergent elements are both made of dense barium flint glass. In Example III all four convergent elements are made of dense barium flint glass.

The algebraic sum of the reciprocals of the $R_4$ and $R_7$ (reckoned as negative if convex to the diaphragm) is zero in Example I, and is about −.27 in Example II and −.28 in Example III.

The algebraic sum of $K_4$ and $K_7$ is −.00985 in Example I, −.01029 in Example II and −.00795 in Example III. The algebraic sum of $K_4^1$ and $K_7^1$ is −.00973 in Example I, −.01017 in Example II and −.00746 in Example III.

All three examples give a reversed secondary spectrum. Thus, for instance, in Example II the paraxial back focus is .70128 for the *b*-line (7065), .70187 for the C-line (6563), .70131 for the *d*-line (5875), and .70067 for the *g*-line (4359). All three examples are well corrected for all the aberrations over a semi-angular field of 25°.

It will be appreciated that these examples have been given by way of example only and that the invention may be carried into practice in other ways.

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

1. An optical objective corrected for spherical and chromatic aberrations, coma, astigmatism, field curvature and distortion, and comprising two compound divergent meniscus components located between two simple convergent components and each having a divergent element cemented to a convergent element, wherein the two divergent elements are made of potassium bromide crystal.

2. An optical objective as claimed in Claim 1, in which the paraxial secondary spectrum is reversed.

3. An optical objective as claimed in Claim 1 or Claim 2, in which the average value of the Abbé V numbers of the glasses used for the four convergent elements is not greater than 49.

4. An optical objective as claimed in Claim 1 or Claim 2 or Claim 3, in which the algebraic sum of $K_4$ and $K_7$, as defined herein, lies between −.005 and −.015.

5. An optical objective as claimed in Claim 4, in which the algebraic sum of $K_4^1$ and $K_7^1$, as defined herein, is numerically less than that of $K_4$ and $K_7$.

6. An optical objective as claimed in any one of Claims 1 to 5, in which the rear surface of the front convergent element is convex to the front and has a radius of curvature lying between .85 and 1.6 times the equivalent focal length of the objective.

7. An optical objective as claimed in any one of Claims 1 to 6, in which a dense barium crown glass is used for the convergent element in one of the divergent components, whilst the other convergent elements are made of dense flint or dense barium flint glasses.

8. An optical objective as claimed in any one of Claims 1 to 6, in which the four convergent elements are all made of dense barium flint glasses.

9. An optical objective having numerical data substantially as set forth in any one of the tables herein.

Dated this 27th day of November, 1942.

FULLINGER & MALET,
Agents for the Applicants.

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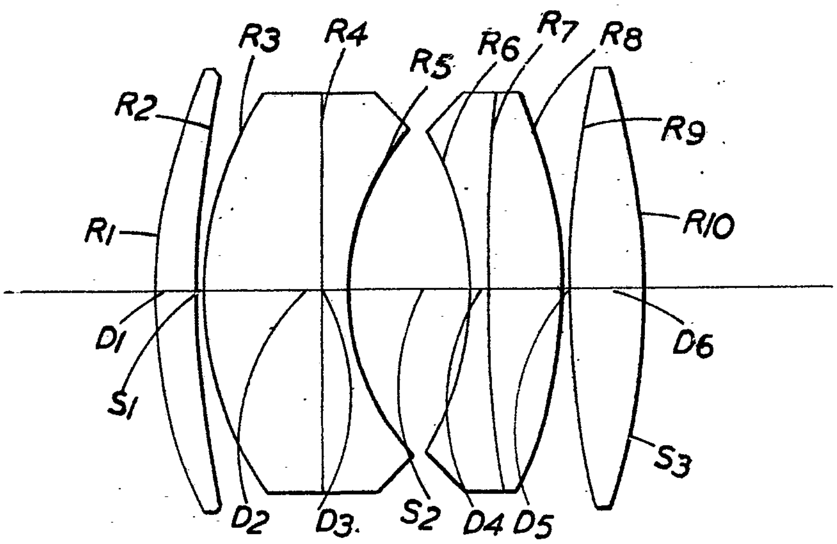


[This Drawing is a full-size reproduction of the Original.]