PATENT SPECIFICATION

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PROVISIONAL SPECIFICATION

No. 17142 A.D. 1940.

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 optical objectives for photographic or like purposes, comprising two or more divergent elements and two or more convergent elements, and corrected for spherical and chromatic aberrations, coma, astigmatism, curvature of field and distortion, and having small zonal spherical aberration.

It is well-known to provide paraxial chromatic correction in a doublet in respect of two colours, for example red and green, by the use of an appropriate combination of crown and flint glass, but owing to the different relative partial dispersions of the two kinds of glass the correction does not extend throughout the spectrum, and there is a residual colour aberration known as secondary spectrum. Reasonably good correction can be obtained in the well-known triplet objective, which however does not provide correction for field curvature or astigmatism.

The present invention has for its object to provide good correction for secondary spectrum in a photographic or like objective having small zonal spherical aberration without sacrificing correction for astigmatism, field curvature and distortion.

The necessary conditions can be expressed mathematically as follows. If f_p and m_p are respectively the focal length and the magnification of a lens element p having refractive indices n_c n_D n_e n_F n_g respectively for the lines CD*e* F*g* Abbé V number

$$V_p\left(=\frac{n_D-1}{n_F-n_C}\right)$$

and relative partial dispersion

$$\theta_p\left(=\frac{n_g-n_e}{n_F-n_C}\right)$$

then good secondary spectrum correction is obtained if

$$\Sigma\frac{m_p^2}{f_p}\cdot\frac{1}{V_p}=0$$

and

$$\Sigma\frac{m_p^2}{f_p}\cdot\frac{\theta_p}{V_p}=0$$

for all the elements of the objective.

In the objective according to the invention one of the divergent elements is made of an alkaline halide crystal and the remaining elements are all made of optical glass. Preferably the other divergent element, or one of the other divergent elements, is made of a dense flint glass, whilst at least one of the convergent elements is made of a glass having an Abbé V number less than 50.

The invention may be applied to photographic or like objectives of various types. Thus, when applied to an objective of the type comprising two compound meniscus divergent components located between two convergent components, each divergent component comprising a convergent element cemented to a divergent element, the rear divergent element may be made of an alkaline halide crystal having mean refractive index greater than 1.6. For instance, the convergent front component and the convergent front element of the second component may be made of dense barium crown glass, and the divergent elements of the second and third components respectively of dense flint glass and of sodium bromide crystal, the convergent rear element of the third component and the convergent rear component being made of dense barium flint glass.

It is to be understood that the terms

[*Price* 1/-]

Price 25p

"front" and "rear" are herein used to relate to the sides of the objective respectively nearer to and further from the longer conjugate in accordance with the usual convention.

Alternatively the front divergent element may be made of an alkaline halide crystal, preferably having mean refractive index lower than 1.6. Thus the two convergent components and the convergent elements of the second and third components may be made of dense barium flint glass, the divergent elements of the second and third components being made respectively of potassium bromide crystal and of dense flint glass.

In the case of an objective comprising five components and consisting of a simple element, of which the front two components and the rear component are convergent and the third and fourth divergent, the fourth component may be made of an alkaline halide crystal having mean refractive index greater than 1.6. Thus the convergent front and rear components may be made of dense barium flint glass and the convergent second component of dense barium crown glass, the divergent third and fourth components being made respectively of dense flint glass and of sodium bromide crystal.

Again in an objective comprising two compound divergent components located behind two convergent components and in front of a third convergent component, each divergent component consisting of a convergent element cemented to a divergent element, the rear divergent element is preferably made of an alkaline halide crystal having a mean refractive index greater than 1.64. Thus the front two convergent elements may be made of dense barium crown glass and the divergent elements of the third and fourth components respectively of dense flint glass and of potassium iodide crystal, the convergent rear component and the convergent elements of the third and fourth components being made of dense barium flint glass.

Another important application of the invention is to a telephoto objective comprising two compound meniscus components with their concave air-exposed surfaces facing one another. Usually in such objectives the front component consists of a convergent element cemented in front of a divergent element, and the rear component of a divergent element cemented in front of a convergent element. In this case, when the invention is applied thereto, the divergent element of one of the components is preferably divided into two divergent elements, one of which is made of an alkaline halide crystal. It will usually be preferable for the crystal to be used for the middle element of the triplet component. The crystal used preferably has a mean refractive index greater than 1.64. Thus in one convenient example the front component is of triplet construction with its middle element made of potassium iodide crystal, the rear component being a doublet, and the rear elements of the two components are each made of dense flint glass, whilst light barium flint and crown glasses are used respectively for the front elements of the first and second components.

Numerical data for five 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 individual lens elements, and S_1 S_2 . . . represent the axial lengths of the air gaps between the components. The tables also give the mean refractive indices n_D, the Abbé V numbers, and the relative partial dispersions θ for the intervals $(e$ to $g)/(C$ to F of the glasses or crystals used for the individual elements.

The first two examples relate to objectives of the type comprising two compound divergent meniscus components having their concave surfaces facing one another and located between two simple convergent components.

EXAMPLE I.

Equivalent focal length 1.000. Relative aperture F/2.

Radius	Thickness or Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 + .90				
	D_1 .081	1.6128	59.6	1.00
R_2 +25.75				
	S_1 .0065			
R_3 + .4075				
	D_2 .151	1.6128	59.6	1.00
R_4 + 1.0324				
	D_3 .044	1.6136	37.3	1.05
R_5 + .2655				
	S_2 .1955			
R_6 − .3048				
	D_4 .0455	1.6410	29.9	.985
R_7 + 1.596				
	D_5 .1596	1.6423	48.3	1.02
R_8 − .4127				
	S_3 .003			
R_9 + 1.8135				
	D_6 .1015	1.6423	48.3	1.02
R_{10} − .9804				

In this example sodium bromide is used for the rear divergent element and dense flint glass for the front divergent element, the two front convergent elements being of dense barium crown glass and the two rear convergent elements being of dense barium flint glass. This example gives a very marked improvement in secondary spectrum correction over known objectives of similar type using glass throughout. Thus between the C and F lines the wave surface retardation is $+.05\lambda$ at the edge and $-.02\lambda$ at an intermediate zone (.7 of edge aperture) as contrasted with $-.93\lambda$ and $-.64\lambda$ respectively for a typical objective using glass, and the corresponding figures between the e and g lines are $-.06\lambda$ and $-.03\lambda$ as contrasted with $+1.33\lambda$ and $+.39\lambda$. Similar results can also be obtained with the use of potassium iodide or rubidium iodide instead of sodium bromide.

Instead of using the crystal for the rear divergent element, it may be used for the front divergent element, but in this case a crystal of lower refractive index, such as potassium bromide should preferably be used. Data for one such example are given in the following table:—

EXAMPLE II.

Equivalent focal length 1.000. Relative aperture F/2.0.

Radius	Thickness or Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 + .6432				
	D_1 .0845	1.644	48.3	1.02
R_2 +1.599				
	S_1 .0053			
R_3 + .4175				
	D_2 .0950	1.644	48.3	1.02
R_4 ∞				
	D_3 .0418	1.558	31.5	1.00
R_5 + .2781				
	S_2 .1591			
R_6 − .3162				
	D_4 .0398	1.651	33.5	1.07
R_7 ∞				
	D_5 .1043	1.644	48.3	1.02
R_8 − .4158				
	S_3 .0050			
R_9 +3.167				
	D_6 .0746	1.644	48.3	1.02
R_{10} − .8773				

The third example is applied to an objective of the type comprising two compound divergent meniscus components located behind two simple convergent components and in front of a third simple convergent component.

EXAMPLE III.

Equivalent focal length 1.000. Relative aperture F/1.4.

Radius	Thickness or Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 + .8106				
	D_1 .0671	1.613	59.6	1.00
R_2 +1.653				
	S_1 0			
R_3 + .8284				
	D_2 .0597	1.613	59.6	1.00
R_4 +1.650				
	S_2 .002			
R_5 + .442				
	D_3 .1474	1.644	48.3	1.02
R_6 ∞				
	D_4 .0305	1.621	36.1	1.05
R_7 + .2661				
	S_3 .2033			
R_8 − .3482				
	D_5 .0297	1.6634	21.3	.987
R_9 −1.169				
	D_6 .1474	1.644	48.3	1.02
R_{10} − .4854				
	S_4 .0019			
R_{11} +2.126				
	D_7 .0813	1.644	48.3	1.02
R_{12} − .7544				

This example has potassium iodide for the rear divergent element and dense flint glass for the front divergent element, and gives a considerable improvement in secondary spectrum correction over known objectives of similar type using glass throughout. Thus between the C and F lines the wave retardation is $-.10\lambda$ at the edge and $+.10\lambda$ at an intermediate zone (.7 of edge aperture) as contrasted with -1.91λ and -1.13λ respectively for a typical known objective, the corresponding figures between e and g lines being $+.07\lambda$ and $+.20\lambda$ as contrasted with $+2.34\lambda$ and $+.77\lambda$.

The fourth example relates to an objective of the type comprising two simple divergent components located behind two simple convergent components and in front of a third simple convergent component.

EXAMPLE IV.

Equivalent focal length 1.000. Relative aperture F/2.5.

Radius	Thickness or Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 + .6433				
	D_1 .0578	1.644	48.3	1.025
R_2 +1.690				
	S_1 0			
R_3 + .3707				
	D_2 .0852	1.613	53.3	1.016
R_4 +1.469				
	S_2 .0416			
R_5 −2.444				
	D_3 .0152	1.652	33.5	1.060
R_6 + .4130				
	S_3 .0406			
R_7 +2.930				
	D_4 .0155	1.641	29.9	.985
R_8 + .4512				
	S_4 .0660			
R_9 + .8520				
	D_5 .0568	1.644	48.3	1.025
R_{10} − .5847				

This example uses sodium bromide for the divergent fourth element and dense flint glass for the divergent third element, whilst the convergent front and rear elements are made of dense barium flint glass and the convergent second element of dense barium crown glass.

The fifth example is of the type known as a telephoto objective wherein known examples using glass throughout have suffered from serious secondary spectrum. Such objectives usually consist of a pair of meniscus doublets with their concave surfaces facing one another, but in the present example the front component consists of a divergent element cemented between a front convergent element and a rear divergent element, the rear component consisting of a divergent element cemented in front of a convergent element.

EXAMPLE V.

Equivalent focal length 1.000. Relative aperture F/5.6.

Radius	Thickness or Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 + .2075				
	D_1 .0423	1.5732	51.9	1.012
R_2 − .5768				
	D_2 .0115	1.6634	21.3	.987
R_3 − 1.390				
	D_3 .0115	1.652	33.5	1.07
R_4 + .5585				
	S_1 .2460			
R_5 − .1308				
	D_4 .0082	1.509	64.3	.994
R_6 − .6702				
	D_5 .0170	1.613	36.9	1.051
R_7 − .2152				

This example uses potassium iodide crystal for the divergent middle element of the front component and dense flint glass for the divergent rear element of the front component as also for the convergent rear element of the rear component, the front elements of the first and second components being respectively made of light barium flint and crown glasses.

This example may be modified by employing the crystal for the rear element of the front component and the dense flint glass for the middle element, or again by making the rear component of triplet construction and the front component of doublet construction with the crystal as one of the elements, preferably the middle element, of the rear component.

It will be understood that the foregoing examples have been given by way of example only and may be modified in various ways within the scope of the invention, as for instance by employing other alkaline halide crystals in place of those specified.

Dated this 2nd day of December, 1940.

PULLINGER & MALET-VEALE,
Agents for the Applicants.

PROVISIONAL SPECIFICATION
No. 12446 A.D. 1941.

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 optical objectives for photographic or like purposes, comprising two or more divergent elements and two or more convergent elements, and corrected for spherical and chromatic aberrations, coma, astigmatism, curvature of field and distortion, and having small zonal spherical aberration.

It is well-known to provide paraxial chromatic correction in a doublet in respect of two colours, for example red and green, by the use of an appropriate combination of crown and flint glass, but owing to the different relative partial dispersions of the two kinds of glass the correction does not extend throughout the spectrum, and there is a residual colour aberration known as secondary spectrum. Reasonably good correction can be obtained in the well-known triplet objective, which however does not provide correction for field curvature or astigmatism.

The present applicants' copending British Patent Application No. 17142 of 1940 (Serial No. 547,666) relates to a photographic or like objective of the above-mentioned type having small zonal spherical aberration wherein good correction for secondary spectrum is provided without sacrificing correction for astigmatism, field curvature and distortion.

In the objective according to the invention of such copending application, one of the divergent elements is made of an alkaline halide crystal and the remaining elements are all made of optical glass. Preferably the other divergent element, or one of the other divergent elements is made of a dense flint glass, whilst at least one of the convergent elements is made of a glass having an Abbé V number less than 50.

The necessary theoretical conditions for correction of secondary spectrum can be expressed mathematically as follows. If f_p and m_p are respective the focal length and the magnification of a lens element p having refractive indices n_C n_D n_e n_F n_g respectively for the lines CDe Fg Abbé V number

$$V_p\left(=\frac{n_D-1}{n_F-n_C}\right)$$

and relative partial dispersion

$$\theta_p\left(=\frac{n_g-n_e}{n_F-n_C}\right)$$

then good secondary spectrum correction is obtained if

$$\Sigma\frac{m_p^2}{f_p}\cdot\frac{1}{V_p}=0$$

and

$$\Sigma\frac{m_p^2}{f_p}\cdot\frac{\theta_p}{V_p}=0$$

for all the elements of the objective. these conditions are approximately fulfilled in the objective according to the invention of the above-mentioned application.

The specification of such copending application gives examples of the application of the invention to photographic or like objectives of various types, and the present invention is concerned with the application of the invention of the copending application to still further types of photographic or like objective.

According to the present invention an objective of known type having at least one divergent element and two or more convergent elements is modified to afford correction for secondary spectrum by replacing the divergent element by two divergent elements compounded together, one of such elements being made of an alkaline halide crystal, whilst the other and also the remaining elements of the objective are made of optical glass. The divergent element compounded with the crystal element is preferably made of dense flint glass.

Thus one arrangement of objective according to the invention (whose analogue consisting of five simple elements forms the subject of British Patent No. 536,448 standing in the names of the present applicants) comprises five components of which the first and fourth counting from the front, that is the side of the longer conjugate, are divergent whilst the other three are convergent, the fourth component being compounded of two divergent elements of which one is made of an alkaline halide crystal having a mean refractive index greater than 1.64. In this arrangement the two divergent elements of the fourth component are preferably made respectively of potassium iodide crystal and of dense flint glass.

In another arrangement the objective comprises an asymmetrical divergent component located behind two simple convergent components and in front of a third simple convergent component, and the divergent component (instead of being in the form of a simple element as in the known type) consists of two divergent elements compounded together, one of such elements being made of an alkaline halide crystal having a mean refractive index greater than 1.64. Conveniently the two divergent elements are made respectively of potassium iodide crystal and of dense flint glass.

Numerical data for two 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 individual lens elements, and S_1 S_2 . . . represent the axial lengths of the air gaps between the components. The tables also give the means refractive indices n_D, the Abbé V numbers, and the relative partial dispersions for the intervals (e to g)/(C to F) of the glasses or crystals used for the individual elements.

EXAMPLE I.

Equivalent focal length 1.000. Relative aperture F/1.4.

Radius	Thickness or Air Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 +2.312				
	D_1 .1013	1.516	64.1	.988
R_2 +1.267				
	S_1 1.395			
R_3 +1.447				
	D_2 .1391	1.6125	37.3	1.051
R_4 +6.031				
	S_2 .0101			
R_5 + .6427				
	D_3 .2432	1.6125	59.6	.999
R_6 ∞				
	S_3 .0137			
R_7 −5.066				
	D_4 .1619	1.6973	30.5	1.067
R_8 +1.420				
	D_5 .1721	1.6634	21.4	.988
R_9 + .3746				
	S_4 .2343			
R_{10} + .8120				
	D_6 .1391	1.6216	60.2	.998
R_{11} −1.286				

EXAMPLE II.

Equivalent focal length 1.000. Relative aperture F/1.4.

Radius	Thickness or Air Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 + 1.066				
	D_1 .1081	1.6135	59.6	.999
R_2 + 7.262				
	S_1 .0094			
R_3 + .4848				
	D_2 .2453	1.5732	51.9	1.012
R_4 + 3.505				
	S_2 .0110			
R_5 −25.80				
	D_3 .1001	1.7492	27.8	1.078
R_6 + .9102				
	D_4 .1083	1.6634	21.4	.988
R_7 + .2955				
	S_3 .1747			
R_8 + .5238				
	D_5 .1081	1.613	37.3	1.051
R_9 − 1.428				

In the first example the objective comprises five components of which the first and fourth are divergent and the others convergent, the fourth component being compound and consisting of two divergent elements, whilst the remaining four components all consist of simple elements. Potassium iodide crystal is used for the rear element of the fourth component and dense flint glass for the front element thereof. Dense flint glass is also used for the convergent second component, the other two convergent components being made of dense barium crown glass, whilst barium silicate crown glass is used for the divergent front component.

In the second example the objective comprises a divergent compound component located behind two simple convergent components and in front of a third simple convergent component, the front and rear divergent elements of the divergent third component being made respectively of dense flint glass and of potassium iodide crystal. The convergent front component is made of dense barium crown glass, and the convergent second component of light barium flint glass, whilst dense flint glass is used for the convergent rear component.

These two examples are respectively derived from examples given in the specifications of the British Patent No. 536,448 above mentioned and of the copending British Patent Application No. 11603 of 1940 (Serial No. 542,508), also standing in the names of the present applicants, and generally retain the advantages of such prior objectives with the added advantage in each case of greatly improved correction for secondary spectrum.

It will be appreciated that these examples may be modified in various ways within the scope of the invention, for instance by the use of other high index alkaline halide crystals in place of the potassium iodide crystal described.

Dated this 25th day of September, 1941.

PULLINGER & 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 optical objectives for photographic or like purposes, comprising two or more divergent elements and two or more convergent elements, and corrected for spherical and chromatic aberrations, coma, astigmatism, curvature of field and distortion, and having small zonal spherical aberration.

It is well-known to provide paraxial chromatic correction in a doublet in respect of two colours, for example red and green, by the use of an appropriate combination of crown and flint glass, but owing to the different relative partial dispersions of the two kinds of glass the correction does not extend throughout the spectrum, and there is a residual colour aberration known as secondary spectrum. Reasonably good correction can be obtained in the well-known triplet objective, which however does not provide correction for field curvature or astigmatism.

The present invention has for its object to provide good correction for secondary spectrum in a photographic or like objective having small zonal spherical aberration without sacrificing correction for astigmatism, field curvature and distortion.

The necessary conditions can be expressed mathematically as follows. If f_p and m_p are respectively the focal length and the magnification of a lens element p having refractive indices n_C n_D n_e n_F n_g respectively for the lines CDe Fg Abbé V number

$$V_p\left(=\frac{n_D-1}{n_F-n_C}\right)$$

and relative partial dispersion

$$\theta_p\left(=\frac{n_g-n_c}{n_F-n_C}\right)$$

then good secondary spectrum correction is obtained if

$$\Sigma\frac{m_p^2}{f_p}\cdot\frac{1}{V_p}=0$$

and

$$\Sigma\frac{m_p^2}{f_p}\cdot\frac{\theta_p}{V_p}=0$$

for all the elements of the objective. It should be made clear that the magnification m_p, herein referred to, may be defined as being equal to the ratio h_p/h_1, where h_p and h_1 are respectively the ordinates of the points of intersection with the lens element p and with the first lens element of a paraxial ray of the wave-length of the D-line through the conjugate points for which the objective is corrected.

In the objective according to the invention one of the divergent elements is made of an alkaline halide crystal and the remaining elements are all made of optical glass. Preferably the other divergent element, or one of the other divergent elements, is made of a dense flint glass, whilst at least one of the convergent elements is made of a glass having an Abbé V number less than 50.

The invention may be applied to photographic or like objectives of various types.

Thus, when applied to an objective of the type comprising two compound meniscus divergent components located between two convergent components, each divergent component comprising a convergent element cemented to a divergent element, the rear divergent element may be made of an alkaline halide crystal having mean refractive index greater than 1.6. For instance, the convergent front component and the convergent front element of the second component may be made of dense barium crown glass, and the divergent elements of the second and third components respectively of dense flint glass and of sodium bromide crystal, the convergent rear element of the third component and the convergent rear component being made of dense barium flint glass.

It is to be understood that the terms "front" and "rear" are herein used to relate to the sides of the objective respectively nearer to and further from the longer conjugate in accordance with the usual convention.

Alternatively the front divergent element may be made of an alkaline halide crystal, preferably having mean refractive index lower than 1.6. Thus the two convergent components and the convergent elements of the second and third components may be made of dense barium flint glass, the divergent elements of the second and third components being made respectively of potassium bromide crystal and of dense flint glass.

In the case of an objective comprising five components each consisting of a simple element, of which the front two components and the rear component are convergent and the third and fourth divergent, the fourth component may be made of an alkaline halide crystal having mean refractive index greater than 1.6. Thus the convergent front and rear components may be made of dense barium flint glass and the convergent second component of dense barium crown glass, the divergent third and fourth components being made respectively of dense flint glass and of sodium bromide crystal.

Again in an objective comprising two compound divergent components located behind two convergent components and in front of a third convergent component, each divergent component consisting of a convergent element cemented to a divergent element, the rear divergent element is preferably made of an alkaline halide crystal having a mean refractive index greater than 1.64. Thus the front two convergent elements may be made of dense barium crown glass and the divergent elements of the third and fourth components respectively of dense flint glass and of potassium iodide crystal, the convergent rear component and the convergent elements of the third and fourth components being made of dense barium flint glass.

Another important application of the invention is to a telephoto objective comprising two compound meniscus components with their concave air-exposed surfaces facing one another. Usually in such objectives the front component consists of a convergent element cemented in front of a divergent element, and the rear component of a divergent element cemented in front of a convergent element. In this case, when the invention is applied thereto, the divergent element of one of the components is preferably divided into two divergent elements, one of which is made of an alkaline halide crystal. It will usually be preferable for the crystal to be used for the middle element of the triplet component. The crystal used preferably has a mean refractive index greater than 1.64. Thus in one convenient example the front component is of triplet construction with its middle element made of potassium iodide crystal, the rear component being a doublet, and the rear elements of the two components are each made of dense flint glass, whilst light barium flint and crown glasses are used respectively for the front elements of the first and second components.

According to a further feature of the invention an objective of known type having at least one divergent element and two or more convergent elements is modified to afford correction for secondary spectrum by replacing the divergent element (or one of the divergent elements) by two divergent elements compounded together, one of such elements being made of an alkaline halide crystal, whilst the other and also the remaining elements of the objective are made of optical glass. The divergent element compounded with the crystal element is preferably made of dense flint glass.

Thus one such arrangement (whose analogue consisting of five simple elements forms the subject of British Patent No. 536,448 standing in the names of the present applicants) comprises five components of which the first and fourth counting from the front, that is the side of the longer conjugate, are divergent whilst the other three are convergent, the fourth component being compounded of two divergent elements of which one is made of an alkaline halide crystal having a mean refractive index greater than 1.64. In this arrangement the two divergent elements of the fourth component are preferably made respectively of potassium iodide crystal and of dense flint glass.

In another arrangement the objective comprises an asymmetrical divergent component located behind two simple convergent components and in front of a third simple convergent component, and the divergent component (instead of being in the form of a simple element as in the known type) consists of two divergent elements compounded together, one of such elements being made of an alkaline halide crystal having a mean refractive index greater than 1.64. Conveniently the two divergent elements are made respectively of potassium iodide crystal and of dense flint glass.

The invention may be carried into practice in various ways, but seven convenient practical examples of objective according thereto are illustrated respectively in the seven figures of the accompanying drawings. Numerical data for these examples 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 individual lens elements, and S_1 S_2 . . . represent the axial lengths of the air gaps between the components. The tables also give the mean refractive indices n_D, the Abbé V numbers, and the relative partial dispersions θ for the intervals $(e$ to $g)/(C$ to $F)$ of the glasses or crystals used for the individual elements.

The first two examples relate to objectives of the type comprising two compound divergent meniscus components having their concave surfaces facing one another and located between two simple convergent components.

EXAMPLE I.

Equivalent focal length 1.000. Relative aperture F/2.

Radius	Thickness or Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 + .90				
	D_1 .081	1.6128	59.6	1.00
R_2 +25.75				
	S_1 .0065			
R_3 + .4075				
	D_2 .151	1.6128	59.6	1.00
R_4 + 1.0324				
	D_3 .044	1.6136	37.3	1.05
R_5 + .2655				
	S_2 .1955			
R_6 − .3048				
	D_4 .0455	1.6410	29.9	.985
R_7 + 1.596				
	D_5 .1596	1.6423	48.3	1.02
R_8 − .4127				
	S_3 .003			
R_9 + 1.8135				
	D_6 .1015	1.6423	48.3	1.02
R_{10} − .9804				

In this example sodium bromide is used for the rear divergent element and dense flint glass for the front divergent element, the two front convergent elements being of dense barium crown glass and the two rear convergent elements being of dense barium flint glass. This example gives a very marked improvement in secondary spectrum correction over known objectives of similar type using glass throughout. Thus between the C and F lines the wave surface retardation is +.05λ at the edge and −.02λ at an intermediate zone (.7 of edge aperture) as contrasted with −.93λ and −.64λ respectively for a typical objective using glass, and the corresponding figures between the *e* and *g* lines are −.06λ and −.03λ as contrasted with +1.33λ and +.39λ. Similar results can also be obtained with the use of potassium iodide or rubidium iodide instead of sodium bromide.

Instead of using the crystal for the rear divergent element, it may be used for the front divergent element, but in this case a crystal of lower refractive index, such as potassium bromide should preferably be used. Data for one such example are given in the following table:—

EXAMPLE II.

Equivalent focal length 1.000. Relative aperture F/2.0.

Radius	Thickness or Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 + .6432				
	D_1 .0845	1.644	48.3	1.02
R_2 +1.599				
	S_1 .0053			
R_3 + .4175				
	D_2 .0950	1.644	48.3	1.02
R_4 ∞				
	D_3 .0418	1.558	31.5	1.00
R_5 + .2781				
	S_2 .1591			
R_6 − .3162				
	D_4 .0398	1.651	33.5	1.07
R_7 ∞				
	D_5 .1043	1.644	48.3	1.02
R_8 − .4158				
	S_3 .0050			
R_9 +3.167				
	D_6 .0746	1.644	48.3	1.02
R_{10} − .8773				

In this example the two convergent components and the convergent elements of the second and third components are all made of dense barium flint glass. The divergent element of the second component is made of potassium bromide crystal, and the divergent element of the third component is made of dense flint glass.

The third example is applied to an objective of the type comprising two compound divergent meniscus components located behind two simple convergent components and in front of a third simple convergent component.

EXAMPLE III.

Equivalent focal length 1.000. Relative aperture F/1.4.

Radius	Thickness or Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 + .8106				
	D_1 .0671	1.613	59.6	1.00
R_2 +1.653				
	S_1 0			
R_3 + .8284				
	D_2 .0597	1.613	59.6	1.00
R_4 +1.650				
	S_2 .002			
R_5 + .442				
	D_3 .1474	1.644	48.3	1.02
R_6 ∞				
	D_4 .0305	1.621	36.1	1.05
R_7 + .2661				
	S_2 .2033			
R_8 − .3482				
	D_5 .0297	1.6634	21.3	.987
R_9 −1.169				
	D_6 .1474	1.644	48.3	1.02
R_{10} − .4854				
	S_4 .0019			
R_{11} +2.126				
	D_7 .0813	1.644	48.3	1.02
R_{12} − .7544				

This example has potassium iodide for the rear divergent element and dense flint glass for the front divergent element, and gives a considerable improvement in secondary spectrum correction over known objectives of similar type using glass throughout. Thus between the C and F lines the wave retardation is −.10λ at the edge and +.10λ at an intermediate zone (.7 of edge aperture) as contrasted with −1.91λ and −1.13λ respectively for a typical known objective, the corresponding figures between e and g lines being +.07λ and +.20λ as contrasted with +2.34λ and +.77λ.

The fourth example relates to an objective of the type comprising two simple divergent components located behind two simple convergent components and in front of a third simple convergent component.

EXAMPLE IV.

Equivalent focal length 1.000. Relative aperture F/2.5.

Radius	Thickness or Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 + .6433				
	D_1 .0578	1.644	48.3	1.025
R_2 +1.690				
	S_1 0			
R_3 + .3707				
	D_2 .0852	1.613	53.3	1.016
R_4 +1.469				
	S_2 .0416			
R_5 −2.444				
	D_3 .0152	1.652	33.5	1.060
R_6 + .4130				
	S_3 .0406			
R_7 +2.930				
	D_4 .0155	1.641	29.9	.985
R_8 + .4512				
	S_4 .0660			
R_9 + .8520				
	D_5 .0568	1.644	48.3	1.025
R_{10} − .5847				

This example uses sodium bromide for the divergent fourth element and dense flint glass for the divergent third element, whilst the convergent front and rear elements are made of dense barium flint glass and the convergent second element of dense barium crown glass.

The fifth example is of the type known as a telephoto objective wherein known examples using glass throughout have suffered from serious secondary spectrum. Such objectives usually consist of a pair of meniscus doublets with their concave surfaces facing one another, but in the present example the front component consists of a divergent element cemented between a front convergent element and a rear divergent element, the rear component consisting of a divergent element cemented in front of a convergent element.

EXAMPLE V.

Equivalent focal length 1.000. Relative aperture F/5.6.

Radius	Thickness or Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 + .2075				
	D_1 .0423	1.5732	51.9	1.012
R_2 − .5768				
	D_2 .0115	1.6634	21.3	.987
R_3 −1.390				
	D_3 .0115	1.652	33.5	1.07
R_4 + .5585				
	S_1 .2460			
R_5 − .1308				
	D_4 .0082	1.509	64.3	.994
R_6 − .6702				
	D_5 .0170	1.613	36.9	1.051
R_7 − .2152				

This example uses potassium iodide crystal for the divergent middle element of the front component and dense flint glass for the divergent rear element of the front component as also for the convergent rear element of the rear component, the front elements of the first and second components being respectively made of light barium flint and crown glasses.

This example may be modified by employing the crystal for the rear element of the front component and the dense flint glass for the middle element, or again by making the rear component of triplet construction and the front component of doublet construction with the crystal as one of the elements, preferably the middle element, of the rear component.

EXAMPLE VI.

Equivalent focal length 1.000. Relative aperture F/1.4.

Radius	Thickness or Air Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 +2.312				
	D_1 .1013	1.516	64.1	.988
R_2 +1.267				
	S_1 1.395			
R_3 +1.447				
	D_2 .1391	1.6125	37.3	1.051
R_4 +6.031				
	S_2 .0101			
R_5 + .6427				
	D_3 .2432	1.6125	59.6	.999
R_6 ∞				
	S_3 .0137			
R_7 −5.066				
	D_4 .1619	1.6973	30.5	1.067
R_8 +1.420				
	D_5 .1721	1.6634	21.4	.988
R_9 + .3746				
	S_4 .2343			
R_{10} + .8120				
	D_6 .1391	1.6216	60.2	.998
R_{11} −1.286				

EXAMPLE VII

Equivalent focal length 1.000. Relative aperture F/1.4.

Radius	Thickness or Air Separation	Refractive Index n_D	Abbé V Number	Relative Partial Dispersion $\frac{e-g}{C-F}$
R_1 + 1.066				
	D_1 .1081	1.6135	59.6	.999
R_2 + 7.262				
	S_1 .0094			
R_3 + .4848				
	D_2 .2453	1.5732	51.9	1.012
R_4 + 3.505				
	S_2 .0110			
R_5 −25.80				
	D_3 .1001	1.7492	27.8	1.078
R_6 + .9102				
	D_4 .1083	1.6634	21.4	.988
R_7 + .2955				
	S_3 .1747			
R_8 + .5238				
	D_5 .1081	1.613	37.3	1.051
R_9 − 1.428				

In the sixth example the objective comprises five components of which the first and fourth are divergent and the others convergent, the fourth component being compound and consisting of two divergent elements, whilst the remaining four components all consist of simple elements. Potassium iodide crystal is used for the rear element of the fourth component and dense flint glass for the front element thereof. Dense flint glass is also used for the convergent second component, the other two convergent components being made of dense barium crown glass, whilst barium silicate crown glass is used for the divergent front component.

In the seventh example the objective comprises a divergent compound component located behind two simple convergent components and in front of a third simple convergent component, the front and rear divergent elements of the divergent third component being made respectively of dense flint glass and of potassium iodide crystal. The convergent front component is made of dense barium crown glass, and the convergent second component of light barium flint glass, whilst dense flint glass is used for the convergent rear component.

These two examples are respectively derived from examples given in the specifications of the British Patent No. 536,448 above mentioned and of the copending British Patent Application No. 11603 of 1940, (Serial No. 542,508), also standing in the names of the present applicants, and generally retain the advantages of such prior objectives with the added advantage in each case of greatly improved correction for secondary spectrum.

It will be appreciated that the foregoing examples may be modified in various ways within the scope of the invention, for instance by the use of other high index alkaline halide crystals in place of the potassium crystal described.

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 having two or more divergent lens elements and two or more convergent lens elements, in which one of the divergent elements is made of an alkaline halide crystal and all the other elements of the objective are made of optical glass.

2. An optical objective as claimed in Claim 1, in which one of the divergent elements is made of a dense flint glass and at least one of the convergent elements is made of a glass having an Abbé V number less than 50.

3. An optical objective as claimed in Claim 1 or Claim 2, comprising two compound meniscus divergent components located between two convergent components, each divergent component consisting of a convergent element cemented to a divergent element, in which the rear divergent element is made of an alkaline halide crystal having a mean refractive index greater than 1.6.

4. An optical objective as claimed in Claim 3, in which the convergent front component and the convergent front element of the second component are made of dense barium crown glass, and the divergent elements of the second and third components are made respectively of dense flint glass and of sodium bromide crystal, whilst the convergent rear element of the third component and the convergent rear component are made of dense barium flint glass.

5. An optical objective as claimed in Claim 1 or Claim 2, comprising five components each consisting of a simple element of which the front two components and the rear component are convergent and the third and fourth divergent, the fourth element being made of an alkaline halide crystal having a mean refractive index greater than 1.6.

6. An optical objective as claimed in Claim 5, in which the convergent front and rear components are made of dense barium flint glass and the convergent second component of dense barium crown glass, whilst the divergent third and fourth components are made respectively of dense flint glass and of sodium bromide crystal.

7. An optical objective as claimed in Claim 1 or Claim 2, comprising two compound divergent components located behind two convergent components and in front of a third convergent component, each divergent component consisting of a convergent element cemented to a divergent element, in which the rear divergent element is made of an alkaline halide crystal having a mean refractive index greater than 1.64.

8. An optical objective as claimed in Claim 7, in which the front two convergent components are made of dense barium crown glass, whilst the convergent rear component and the convergent elements of the third and fourth components are made of dense barium flint glass, and divergent elements of the third and fourth components being made respectively of dense flint glass and of potassium iodide crystal.

9. An optical objective as claimed in Claim 1 or Claim 2, comprising two compound divergent meniscus components

located between two convergent components, each divergent component consisting of a convergent element cemented to a divergent element, in which the front divergent element is made of an alkaline halide crystal.

10. An optical objective as claimed in Claim 9, in which the crystal used for the front divergent element has a mean refractive index lower than 1.6.

11. An optical objective as claimed in Claim 10, in which the two convergent components and the convergent elements of the second and third components are made of dense barium flint glass, whilst the divergent elements of the second and third components are respectively made of potassium bromide crystal and of dense flint glass.

12. An optical objective as claimed in Claim 1 or Claim 2, comprising two compound meniscus components with their air-exposed concave surfaces facing one another, wherein one of the components consists of two divergent elements cemented together and to a convergent element, one of such divergent elements being made of an alkaline halide crystal.

13. An optical objective as claimed in Claim 12, in which the front component is of triplet construction including the crystal element and the rear component consists of a doublet.

14. An optical objective as claimed in Claim 12 or Claim 13, in which the crystal used for one of the divergent elements of the triplet component has a mean refractive index greater than 1.64.

15. An optical objective as claimed in Claim 12 or Claim 13 or Claim 14, in which the crystal is used for the middle element of the triplet component.

16. An optical objective as claimed in Claims 13 to 15, in which the middle element of the front component is made of potassium iodide crystal and the rear elements of the two components are each made of dense flint glass, whilst light barium flint and crown glasses are used respectively for the front elements of the front and rear components.

17. An optical objective as claimed in Claim 1 or Claim 2, in which the divergent element made of an alkaline halide crystal is compounded with another divergent element, such pair of elements replacing a single divergent element in a known type of objective.

18. An optical objective as claimed in Claim 17, in which the divergent element compounded with the crystal element is made of dense flint glass.

19. An optical objective as claimed in Claim 17 or Claim 18, comprising five components of which the first and fourth are divergent and the other three convergent, the fourth component being compounded of two divergent elements of which one is made of an alkaline halide crystal having a mean refractive index greater than 1.64.

20. An optical objective as claimed in Claim 17 or Claim 18, comprising an asymmetrical divergent component located behind two simple convergent components and in front of a third single convergent component, the divergent component being compounded of two divergent elements of which one is made of an alkaline halide crystal having a mean refractive index greater than 1.64.

21. An optical objective as claimed in Claims 18 to 19, or in Claims 18 and 20, in which the crystal consists of potassium iodide crystal.

22. The optical objective substantially as described with reference to any one figure of the accompanying drawings and having numerical data substantially as set forth in the corresponding tables herein.

Dated this 14th day of November, 1941.

PULLINGER & MALET,
Agents for the Applicants.

Leamington Spa: Printed for His Majesty's Stationery Office, by the Courier Press.—1942.

Fig. 1.

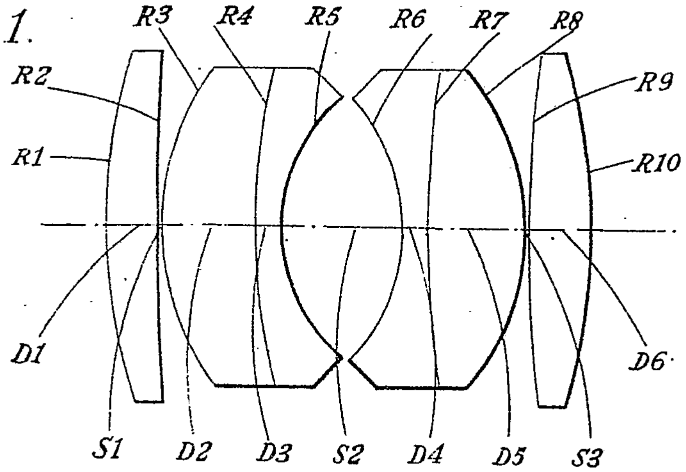


Fig. 2.

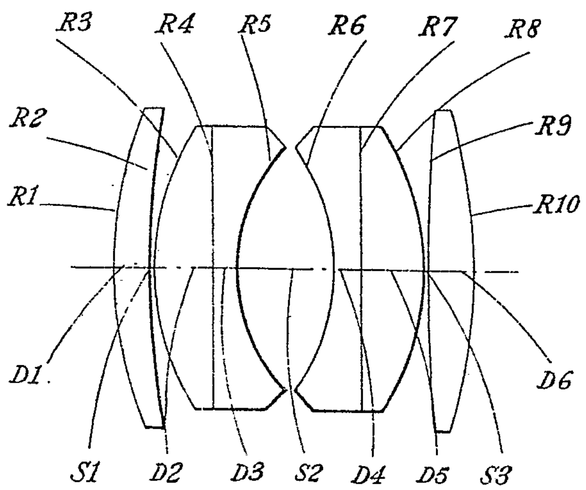
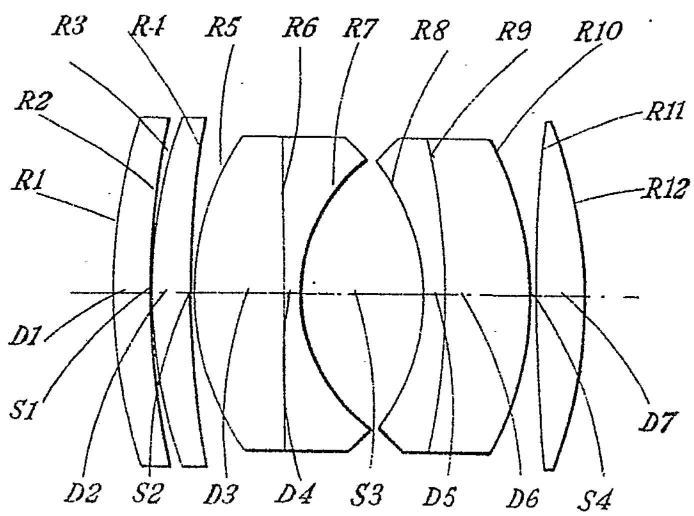


Fig. 3.



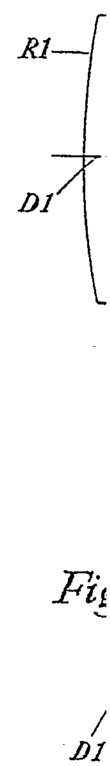


Fig. 4.

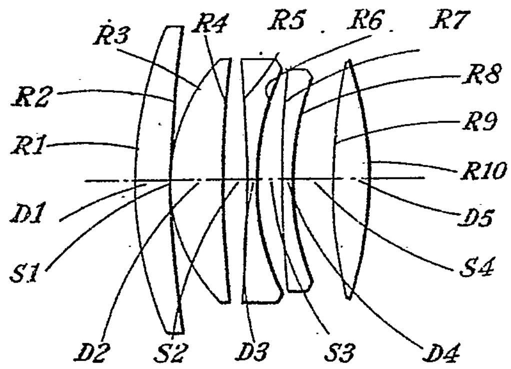


Fig. 5.

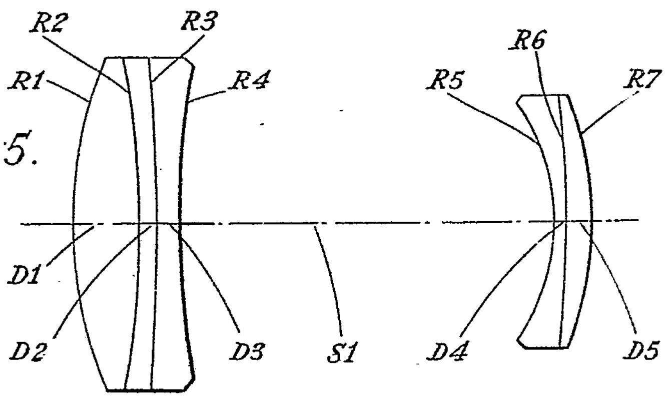


Fig. 6.

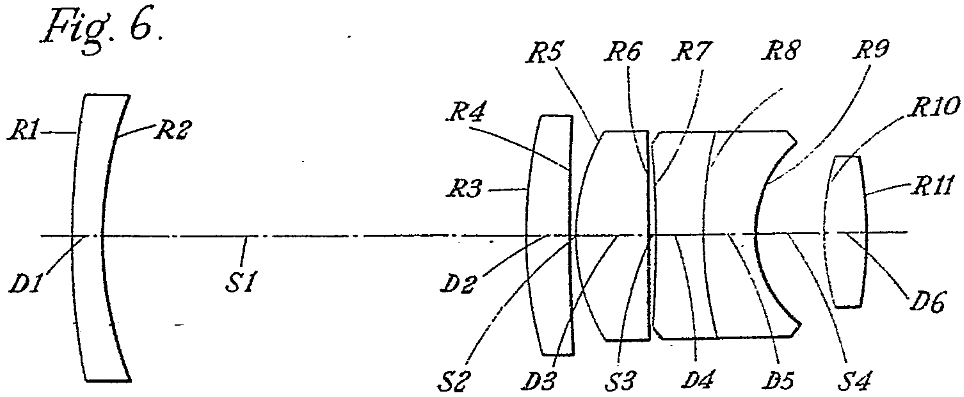
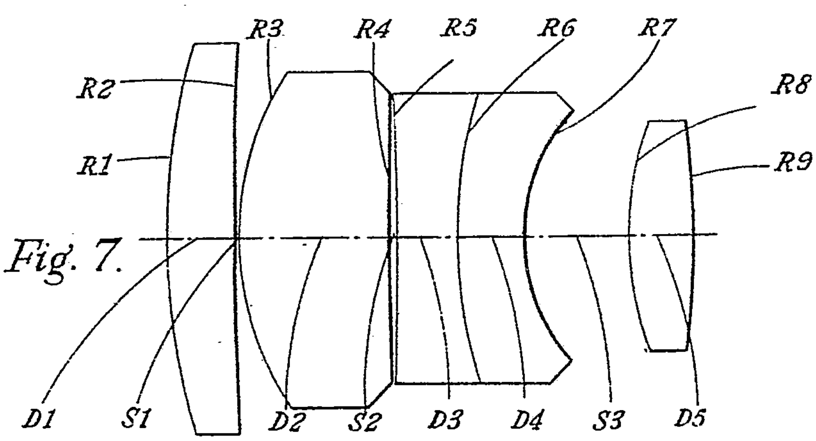


Fig. 7.



547,666 COMPLETE SPECIFICATION

2 SHEETS
SHEET 1

Fig. 1.

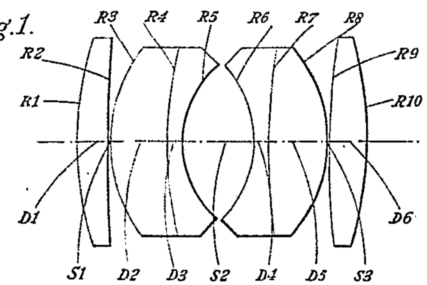


Fig. 2.

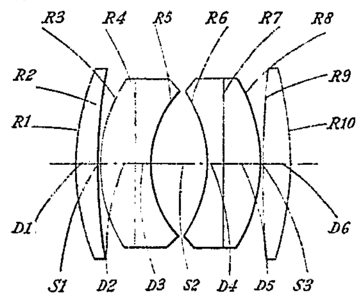
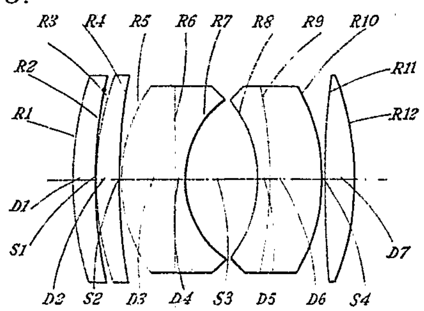


Fig. 3.



SHEET 2

Fig. 4.

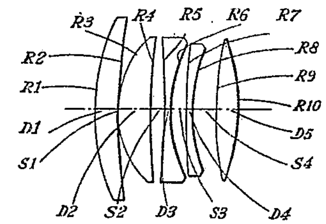


Fig. 5.

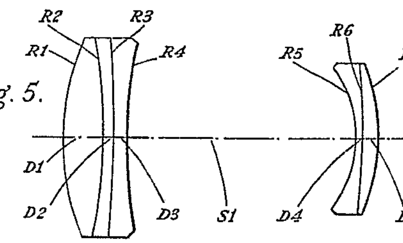


Fig. 6.

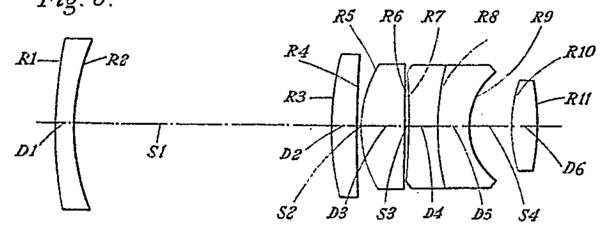
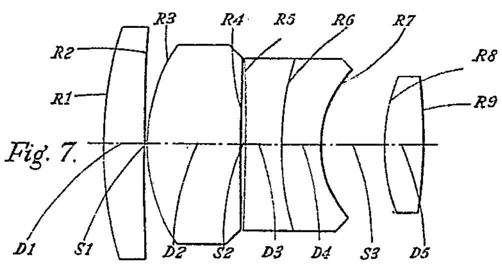


Fig. 7.



[This Drawing is a reproduction of the Original on a reduced scale.]