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, Leicetr, do hereby declare the nature of this invention to be as follows:—

This invention relates to optical objec-10 tives for photographic or like purposes, comprising two or more divergent elements and two or more convergent and elements, and corrected for spherical and chromatic aberrations, coma, astigmatism, 15 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 20 and green, by the use of an appropriate combination of crown and flint glass, but owing to the different relative partial dis-persions of the two kinds of glass the correction does not extend throughout the 25 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 cor-30 rection 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 aberra-35 tion withut sacrificing correction for astigmatism, field curvature and distor-

The necessary conditions can be expressed mathematically as follows.

40 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_n $n_e \ n_F \ n_g$ respectively for the lines CDe Fg Abbé V number

$$V_{\nu} \left(= \frac{n_{\nu} - 1}{n_{\nu} - n_{\nu}} \right)$$

and relative partial dispersion [Price 1/-]

$$\theta_{\mathrm{p}} \left(= \frac{n_{\mathrm{g}} - n_{\mathrm{e}}}{n_{\mathrm{p}} - n_{\mathrm{G}}} \right)$$

then good secondary spectrum correction is obtained if

$$\Sigma \frac{m_{\rm p}^2}{f_{\rm p}} \cdot \frac{1}{V_{\rm p}} = 0$$
 50

$$\sum \frac{m_{\rm p}^2}{f_{\rm p}} \cdot \frac{\theta_{\rm p}}{V_{\rm p}} = 0$$

for all the elements of the objective.

In the objective according to the invention one of the divergent elements is made 55 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, 60 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. 65

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 70 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. instance, the convergent front component 75 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 80 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 85

List Se. Con Price 25p

45

5 to 12. 3d.

2

"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 con-10 vergent 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 15 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 compo-20 nents 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 25 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 30 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 35 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 40 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 com-45 ponents 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

Another important application of the invention is to a telephoto objective compris-

flint glass.

ing two compound meniscus components with their concave air-exposed surfaces facing one another. Usually in such ob- 55 jectives 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 In this 60 front of a convergent element. 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 It will 65 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 Thus in one convenient example 70 1.64.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 75 elements of the two components are each 75 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 prac- 80 tical examples of objective according to the invention are given in the following tables, in which R₁ R₂... represent the radii of curvature of the individual lens surfaces counting from the front, the posi- 85 tive 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 S₁ S₂ . . . re- 90 present the axial lengths of the air gaps between the components. The tables also give the mean refractive indices n_p , the Abbé V numbers, and the relative partial dispersions θ for the intervals (e to g)/(C 95 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 10° having their concave surfaces facing one another and located between two simple convergent components.

Equivalent	focal	length	1.000.

EXAMPLE	Τ.

Relative aperture F/2.

5 Radius	Thickness or Separation	$\begin{array}{c} \operatorname{Refractive} \\ \operatorname{Index} \ n_{\scriptscriptstyle \mathrm{D}} \end{array}$	Abbé V Number	Relative Partial Dispersion $e-g$ $\overline{C-F}$
$R_1 + .90$		-		· ·
10 $R_2 + 25.75$	D_i .081	1.6128	59.6	1.00
$R_{3} + .4075$	S ₁ .0065			
$R_4 + 1.0324$	D_2 .151	1.6128	59.6	1.00
$R_{5} + .2655$	$\mathbf{D_{s}}$.044	1.6136	37.3	1.05
$R_{6}3048$	S_2 .1955		-	-
	D_4 .0455	1.6410	29.9	.985
20 R ₇ + 1.596	$\mathbf{D}_{\mathfrak{s}}$.1596	1.6423	48.3	1.02
R_s 4127	S_3 .003			
$R_9 + 1.8135$ 25	$\mathbf{D}_{\scriptscriptstyle{6}}$.1015	1.6423	4Q 9	1.00
$R_{10} = .9804$	1010	1.0440	48.3	1.02

In this example sodium bromide is used for the rear divergent element and dense flint glass for the front divergent 30 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 40 intermediate zone (.7 of edge aperture) as contrasted with -.93λ and -.64λ respec-

In this example sodium bromide is used at the rear divergent element and dense and the corresponding figures between the 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 45 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 50 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:—

	Equivalent focal le		EAMPLE II.	Relative	Relative aperture F/2.0.	
				-	Relative Partial Dispersion e-g	
5	Radius	Thickness or Separation	$\begin{array}{c} \text{Refractive} \\ \text{Index } n_{\scriptscriptstyle \mathtt{D}} \end{array}$	Abbé V Number	C—F	
	$R_1 + .6432$	D ₁ .0845	1.644	48.3	1.02	
10	R ₂ +1.599	S ₁ .0053	1.			
	$R_3 + .4175$ $R_4 \infty$	$D_2 .0950$	1.644	48.3	1.02	
15	$R_{5} + .2781$	D_a .0418	1.558	31.5	1.00	
1.0	$ m R_{\scriptscriptstyle 6} = .3162$	S_2 .1591	***************************************		-	
	$R_7 \infty$	$\mathbf{D_4}$.0398	1.651	33.5	1.07	
20	•	D_s .1043	1.644	48.3	1.02	
	R_s4158	S_3 .0050				
95	$R_9 + 3.167$ $R_2 = 8773$	D0746	1.644	48.3	1.02	

Equivalent focal length 1.000.

The third example is applied to an objective of the type comprising two components and in front of a third simple 30 convergent component.

48.3

1.02

Relative aperture F/1.4.

35	Radius	Thickness or Separation	$\begin{array}{c} \text{Refractive} \\ \text{Index } n_{\tt b} \end{array}$	Abbé V Number	Relative Partial Dispersion e—g C—F
-	$R_1 + .8106$	D0671	1.613	59.6	1.00
40	$R_2 + 1.653$	\mathbf{S}_{1} 0	1.010		1.00
	$R_3 + .8284$	$D_{2} .0597$	1.613	59.6 -	1.00
45	$R_4 + 1.650$	$S_2 .002$	_,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	33.5	2.00
10	$R_s + .442$	D ₃ .1474	1.644	48.3	1.02
	$R_6 - \infty$	D_4 .0305	1.621	36.1	1.05
50	$R_7 + .2661$	S ₃ .2033			
	$R_{\rm s}3482$	$D_{\mathfrak{s}}$.0297	1.6634	21.3	.987
55	$R_9 - 1.169$	D _c .1474	1.644	48.3	1.02
	$R_{10}4854$ $R_{11} + 2.126$	S0019			
	T011 + \$. 150	73 0019	1 644	40.0	1.00

1.644

 D_{τ} .0813

EXAMPLE III.

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 5 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 10 (.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 teing

 $+.07\lambda$ 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 com- 20 ponent.

EXAMPLE IV.

Equivalent focal length 1.000.

Relative aperture F/2.5.

25				$\begin{array}{c} \hline \text{Relative} \\ \text{Partial} \\ \text{Dispersion} \\ \hline e-g \end{array}$
Radius	Thickness or Separation	$\begin{array}{c} \text{Refractive} \\ \text{Index } n_{\text{\tiny D}} \end{array}$	Abbé V Number	<u> </u>
$\begin{array}{c} R_1 + .6433 \\ R_2 + 1.690 \end{array}$	$D_1 .0578$	1.644	48.3	1.025
$R_3 + .3707$	$S_1 = 0$ $D_2 = .0852$	1.613	53.3	1.016
$\begin{array}{c} 35 \ \mathrm{R_{4}} \ +1.469 \\ \mathrm{R_{5}} \ -2.444 \end{array}$	S_2 .0416 D_3 .0152	1 659	. 99 5	1 000
$\begin{array}{c} R_{\epsilon} + .4130 \\ R_{\tau} + 2.930 \end{array}$	$S_3 .0406$	1.652	33.5	1.060
$R_{8} + .4512$	$\mathbf{D_4} .0155$ $\mathbf{S_4} .0660$	1.641	29.9	.985
45 R ₀ + .8520 R ₁₀ 5847	D _s .0568	1.644	48.3	1.025

This example uses sodium bromide for the divergent fourth element and dense 50 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 suf-

fered from serious secondary spectrum. Such objectives usually consist of a pair of meniscus doublets with their concave sur- 60 faces 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 compo-65 nent consisting of a divergent element cemented in front of a convergent element.

EXAMPLE V.

	Equivalent focal length 1.000.			Relative aperture F_0.6.		
5	Radius	Thickness or Separation	$egin{array}{c} ext{Refractive} \ ext{Index } n_{ ext{p}} \end{array}$	Abbé V Number	Relative Partial Dispersion e-g C-F	
	$R_1 + .2075$	D ₁ .0423	1.5732	51.9	1.012	
10	R_25768	D₁ .U±≈o	T.010%	91.9	1.01~	
10		D_2 .0115	1.6634	21.3	.987	
-	$R_{a}-1.390$	D _s .0115	1.652	33.5	1.07	
15	$R_4 + .5585$ R_51308	S ₁ .2460				
		$D_4 .0082$	1.509	64.3	.994	
20	$ m R_{s}6702 \ m R_{r}2152 \ m$. D ₅ .0170	1.613	36.9	1.051	

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 25 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.

30 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 con35 struction 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 ex-40 ample 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 50 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 objec-55 tives 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, 60 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 65 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 70 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. 75

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 80 spherical aberration wherein good correc547,666 7

tion for secondary spectrum is provided without sacrificing correction for astigmatism, field curvature and distortion. In the objective according to the inven-5 tion 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 10 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 20 element p having refractive indices n_c n_D $n_{\rm e} \; n_{\rm F} \; n_{\rm g}$ respectively for the lines CDe Fg Abbé V number

$$V_{p} \left(= \frac{n_{p} - 1}{n_{F} - n_{c}} \right)$$

and relative partial dispersion

$$\theta_{\mathbf{p}} \left(= \frac{n_{\mathbf{g}} - n_{\mathbf{e}}}{n_{\mathbf{x}} - n_{\mathbf{c}}} \right)$$

then good secondary spectrum correction is obtained if

$$\Sigma \frac{m_{\rm p}^2}{f_{\rm p}} \cdot \frac{1}{V_{\rm p}} = 0$$

and

$$\Sigma \frac{m_{\rm p}^2}{f_{\rm p}} \cdot \frac{\theta_{\rm p}}{V_{\rm p}} = 0$$

for all the elements of the objective. these conditions are approximately fulfilled in the objective according to the invention of the above-mentioned applica-35 tion.

The specification of such copending application gives examples of the application of the invention to photographic or like objectives of various types, and the 40 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 45 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, 50 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 60 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 65 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 70 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 75 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 85 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 90 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 R₁ R₂ . . . represent the radii of curvature of the individual lens 100 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, D₁ D₂ . . . represent the axial thicknesses of the in-105 dividual lens elements, and S₁ S₂ . . . 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 110 dispersions for the intervals (e to g)/(C to F) of the glasses or crystals used for the individual elements.

EXAME	LE.	I.	_	_	_

	Equivalent focal len	ngth 1.000.		Relative ap	erture ${ m F}/1.4$
-					Relative Partial Dispersio e—g
	Radius	Thickness or Air Separation	$\begin{array}{c} \text{Refractive} \\ \text{Index } n_{\mathtt{p}} \end{array}$	Abbé V Number	<u>C</u> —F
-	$R_1 + 2.312$ $R_2 + 1.267$	c D ₁ .1013	1.516	64.1	.988
	$R_3 + 1.447$	S ₁ 1.395			-
	$R_4 + 6.031$	D_2 .1391 S_2 .0101	1.6125	37.3	1.051
	$R_5 + .6427$	D ₃ .2432	1.6125	59. 6	.999
	$R_{\rm g}$ ∞ $R_{\rm g} = 5.066$	S ₃ .0137		-	
	$R_s = 0.066$ $R_s + 1.420$	\mathbf{D}_{4} .1619	1.6973	30.5	1.067
	R _o + .3746	D_{5} .1721 S_{4} .2343	1.6634	21.4	.988
-	$R_{10} +8120$ $R_{11} - 1286$	D ₀ .1391	1.6216	60.2	.998
-	Equivalent focal len		MPLE II.	Relative ap	erture F/1.4
			-		Relative Partial Dispersion
-	Radius	Thickness or Air Separation	Refractive Index n_{p}	Abbé V Number	$\frac{e-g}{\text{CF}}$
	R ₁ + 1.066	D ₁ .1081	1.6135	59.6	.999
	$R_2 + 7.262$ $R_3 + .4848$	S ₁ .0094 D ₂ .2453	1.5732	51,9	1.012
	$R_4 + 3.505$	$S_2 = 0110$		5-14	
	$R_s - 25.80$ $R_s + .9102$	D ₃ .1001	1.7492	27.8	1.078
	$R_7 + .2955$	D ₄ .1083	1.6634	21.4	.988
	$R_s + .5238$	S ₃ .1747 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 5 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 10 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 15 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 20 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 25 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 35 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 correc- 40 tion 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 45 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

TAYLOR, TAYLOR & Hobson LIMITED, a Company registered under the 50 Laws of Great Britain, ARTHUR WARMI-SHAM, British Subject, and CHARLES GORRIE WYNNE, British Subject, all of 104, Stoughton Street, Leicester, do hereby declare the nature of this invention 55 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 objec-60 tives 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,

65 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 70 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 75 spectrum, and there is a residual colour aberration known as secondary spectrum. Reasonably good correction can be and obtained in the well-known triplet objective, which however does not provide cor-80 rection 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 withut sacrificing correction for 85 astigmatism, field curvature and distortion.

The necessary conditions can be expressed mathematically as follows. If f_p and m_p are respectively the focal 90 length and the magnification of a lens element p having refractive indices n_c n_p $n_{\rm e} \ n_{\rm F} \ n_{\rm g}$ respectively for the lines CDe Fg Abbé V number

$$V_{p} \left(= \frac{n_{D} - 1}{n_{F} - n_{C}} \right)$$
 95

and relative partial dispersion

$$\theta_{\rm p} \left(= \frac{n_{\rm g} - n_{\rm c}}{n_{\rm F} - n_{\rm c}} \right)$$

then good secondary spectrum correction is obtained if

$$\sum_{p} \frac{m_{p}^{2}}{f_{p}} \cdot \frac{1}{V_{p}} = 0$$
 100

$$\Sigma \frac{m_{\rm p}^2}{f_{\rm p}} \cdot \frac{\theta_{\rm p}}{V_{\rm p}} = 0$$

should be made clear that the magnification $m_{\rm p}$, herein referred to, may be defined as being equal to the ratio h_p/h_1 , where 5 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 10 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 15 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

20 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 menis-25 cus 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 36 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 35 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 compo-40 nent 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 50 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 55 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 60 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 65 an alkaline halide crystal having mean

for all the elements of the objective. It 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 70 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 75 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 80 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 &5 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 compa- 90 nents being made of dense barium flint

glass.

Another important application of the invention is to a telephoto objective comprising two compound meniscus components 95 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 compo- 100 nent of a divergent element cemented in front of a convergent element. case, when the invention is applied thereto, the divergent element of one of the components is preferably divided into two 106 divergent elements, one of which is made of an alkaline halide crystal. usually be preferable for the crystal to be used for the middle element of the triplet component. The crystal used preferably 110 has a mean refractive index greater than Thus in one convenient example the front component is of triplet construc-tion with its middle element made of potassium iodide crystal, the rear compo- 115 nent 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 120 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 125 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 130 547,666 11

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. 10 536,448 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 15 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. 20 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 25 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 30 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 35 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 40 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 45 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 con- 50 cave thereto, $D_1 \, \bar{D}_2 \, \dots$ 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 55 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 con- 65

vergent components.

EXAMPLE I.

	Equivalent focal length 1.000.			Relative aperture $F/2$.		
70	Radius	Thickness or Separation	$egin{array}{l} ext{Refractive} \ ext{Index } n_{ extbf{D}} \end{array}$	Abbé V Number	$\begin{array}{c} \text{Relative} \\ \text{Partial} \\ \text{Dispersion} \\ \underline{e-g} \\ \hline \text{CF} \end{array}$	
75	$R_1 + .90$	D ₁ .081	1.6128	59.6	1.00	
10	$R_2 + 25.75$		1.0120	09.0	1.00	
	$R_3 + .4075$	$S_1 .0065$			•	
80	$R_4 + 1.0324$	$\mathbf{D_2}$.151	1.6128	59.6	1.00	
00	•	D_{s} :044	1.6136	37.3	1.05	
	$R_s + .2655$	S ₂ .1955	•			
85	R_{σ} 3048	$D_4 .0455$	1.6410	29.9	.985	
	$R_7 + 1.596$. D _s .1596	1.6423	48.3	1.02	
	R_{s} – .4127	S_{s} .003				
90	$R_9 + 1.8135$					
	R_{10} - $.9804$	$\mathrm{D}_{\scriptscriptstyle{6}}$.1015	1.6423	48.3	1.02	

for the rear divergent element and dense glass for thefront divergent element, the two front glass and the two rear convergent elements being of dense barium flint glass. This example gives a very marked improvement in secondary spectrum correc-10 tion 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 15 contrasted with $-.93\lambda$ and $-.64\lambda$ respec-

In this example sodium bromide is used tively for a typical objective using glass, or the rear divergent element and dense and the corresponding figures between the e and g lines are $-.06\lambda$ and $-.03\lambda$ as conconvergent trasted with +1.33\lambda and +.39\lambda. Similar elements being of dense barium crown results can also be obtained with the use of 20 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 25 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. 30 Equivalent focal length 1.000.

Relative aperture F/2.0.

35	Radius	Thickness or Separation	$\begin{array}{c} \text{Refractive} \\ \text{Index } n_{\scriptscriptstyle D} \end{array}$	Abbé V Number	Relative Partial Dispersion $e-g$ $\overline{\text{C-F}}$
· · · ·	$R_1 + .6432$ $R_2 + 1.599$	D ₁ .0845	1.644	48.3	1.02
40	$R_3 + .4175$	S ₁ .0053		-	_
	$ m R_4 \infty$	$D_2 .0950$	1.644	48.3	1.02
45	$R_5 + .2781$	D_{s} .0418	1.558	31.5	1.00
-	$R_6 = .3162$	S ₂ .1591			
-	$R_7 \propto$	D_4 .0398	1.651	33.5	1.07
50	R_s4158	D_{5} .1043	1.644	48.3	1.02
	R ₉ +3.167	S_{3} .0050		•	
55	$R_{10}8773$	D ₆ .0746	1.644	48.3	1.02

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 60 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 com- 65 pound 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.

5	Radius	Thickness or Separation	$\begin{array}{c} \text{Refractive} \\ \bullet \end{array}$ $\text{Index } n_{\scriptscriptstyle \mathrm{D}}$	Abbé V Number	Relative Partial Dispersion $e-g$ $\overline{C-F}$
10	$R_1 + .8106$ $R_2 + 1.653$	D ₁ .0671 S ₁ 0	1.613	59.6	1.00
15	$R_3 + .8284$ $R_4 + 1.650$	$D_2 .0597$ $S_2 .002$	1.613	59.6	1.00
20	$R_s + .442$ $R_s = \infty$	D _a .1474 D ₄ .0305	1.644 1.621	48.3 36.1	1.02
20	$R_7 + .2661$ R_83482 $R_9 - 1.169$	S_z .2033 D_s .0297	1,6634	21.3	.987
25	$R_{10}4854$ $R_{11} + 2.126$	D_{6} .1474 S_{4} .0019	1.644	48.3	1.02
30	$R_{12} = .7544$	D_{τ} .0813	1.644	48.3	1.02

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 35 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 40 (.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 simples convergent components and in

simple convergent components and in front of a third simple convergent com- 50 ponent.

	Equivalent focal length 1.000.			Relative aperture F/2.5.	
5					Relative Partial Dispersion
-	Radius	Thickness or Separation	$\begin{array}{c} \text{Refractive} \\ \text{Index } n_{\scriptscriptstyle \mathbf{D}} \end{array}$	Abbé V Number	$\frac{e-g}{\text{CF}}$
10	$R_1 + .6433$ $R_2 + 1.690$	D ₁ .0578	1.644	48.3	1.025
15	$R_{s} + .3707$ $R_{s} + 1.469$	D ₂ .0852	1.613	53.3	1.016
10	$R_{s} -2.444$ $R_{s} + .4130$	S ₂ .0416 D ₃ .0152	1.652	33.5	1.060
20	$R_{r} + 2.930$ $R_{s} + .4512$	S ₃ .0406 D ₄ .0155	1.641	29.9	.985
25	$R_{10} + .8520$ $R_{10}5847$	S_4 .0660 D_s .0568	1.644	48.3	1.025

This example uses sodium bromide for the divergent fourth element and dense flint glass for the divergent third element, 30 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

35 as a telephoto objective wherein known examples using glass throughout have suf-

fered 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 45 cemented in front of a convergent element.

EXAMPLE V.

	Equivalent focal length 1.000.			Relative aperture $F/5.6$.			
50					Relative Partial Dispersion		
	Radius	Thickness or Separation	$\begin{array}{c} \text{Refractive} \\ \text{Index } n_{\tt p} \end{array}$	Abbé V Number	$\frac{e-g}{\text{CF}}$		
55	$R_1 + .2075$ R_25768	D ₁ .0423	1.5732	51.9	1.012		
	$R_2 = 0.008$ $R_3 = 1.390$	D ₂ .0115	1.6634	21.3	.987		
60	$R_4 + .5585$	D0115	1.652	33.5	1.07		
-	R_s1308	S_1 .2460 D_4 .0082	1.509	64.3	.994		
65	$R_{z}6702$ $R_{z}2152$	D _s .0170	1.613	36.9	1.051		

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 15 doublet construction with the crystal as one of the elements, preferably the middle element, of the rear component.

EXAMPLE VI.

Tight attitude total length 1.000.	20	Equivalent	focal	length	1.000.
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Relative aperture F/1.4.

Radius	Thickness or Air Separation	$\begin{array}{c} \text{Refractive} \\ \text{Index } n_{\mathtt{p}} \end{array}$	Ablbé V Number	Relative Partia Dispersion $e-g$ $\overline{C-F}$
$R_1 + 2.312$	D 1019	1.710		
$R_a + 1.267$	D ₁ .1013	1.516	64.1	.988
$R_s + 1.447$	S. 1.395			
	D_2 .1391	1.6125	37.3	1.051
$R_4 + 6.031$	S0101			-
$R_s + .6427$	D_{s} .2432	1.6125	£9.6	.999
$ m R_c$ $ m extstyle e$	S ₂ .0137		-	
$R_{\tau} = 5.066$	-	1.00%9	20 -	
$R_s + 1.420$	D1619	1.6973	30.5	1.067
$R_{2} + .3746$	D_{5} .1721	1.6634	21.4	.988
	S_{4} .2343	-		
$R_{no} + .8120$	D_{c} .1391	1.6216	60.2	.998
$R_{n1} - 1.286$	· · · · · ·	AMPLE VII		.000
Equivalent focal length 1.000.			Relative a	aperture F/1.4.

Relative Partial Dispersion -g 50 Thickness or Refractive Abbé V Radius Air Separation Index $n_{\rm p}$ NumberC-F $R_1 + 1.066$ $D_1 .1081$ 1.6135 59.6.999 $R_2 + 7.262$ 55 $S_1 .0094$ $R_3 +$.4848 D_2 .2453 1.5732 51.91.012 $R_4 + 3.505$ S₂ .0110 $R_s - 25.80$ D_3 .1001 1.749227.8 1.078 $R_6 +$.9102 D_4 .1083 1.6634 21.4.988 \mathbf{R}_{7} + .295565 S₃ .1747 $R_8 +$.5238 D_5 .1081 1.61337.31.051 $R_9 - 1.428$

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 5 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 10 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 barrum crown glass, whilst 15 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 20 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 25 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 compo-30 nent.

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 35 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 40 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 in-45 vention, 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 inven-50 tion 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 55 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 num-65 ber 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 consist-ing 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 re- 95

fractive 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 100 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

105 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, 110 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 115 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 120 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 125 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 130

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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 re-

10 fractive 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

15 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.

20 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 25 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 30 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 35 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 40 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 45 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 50

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 55 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 60 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 65 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 70

20. An optical objective as claimed in Claim 17 or Claim 18, comprising an asymmetrical divergent component located behind two simple convergent components 75 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

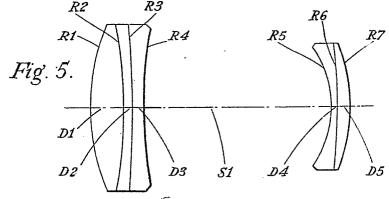
iodide crystal.

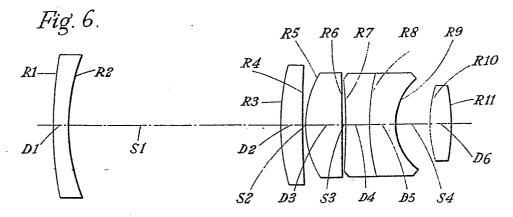
22. The optical objective substantially as described with reference to any one figure of the accompanying drawings and having numerical data substantially as set forth in the corresponding tables 90 herein.

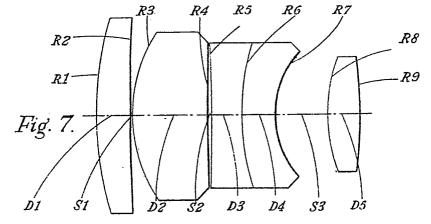
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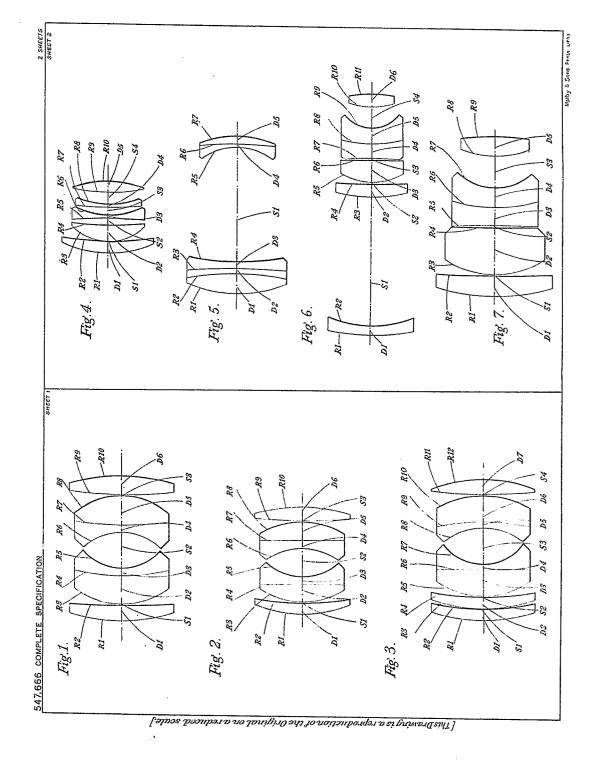
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