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(54) IMPROVEMENTS IN WIDE ANGLE LENSES

(71) We, OPTIGON RESEARCH AND DEVELOPMENT CORPORATION of P.O. Box 1740, Santa Monica, California, United States of America, a Corporation organized and existing under the laws of the State of California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to lenses, and more particularly to those known as wide angle lenses of the retrofocus type.

Wide angle lenses may be defined as those in which the diameter of the film or image frame of the camera with which the lens is used is substantially equal to or greater than the equivalent focal length of the lens. Moderately wide angle retrofocus objectives covering field angles of approximately 80° have been known for many years. Typically these lenses have been large in length and diameter resulting in considerable manufacturing expense and a lack of portability. In order to reduce the size, it is necessary to increase the lens element powers which normally increase the lens surface aberration contributions. When wide angle objectives of reduced size configuration are constructed to relative apertures of f/2.8, the need to correct large aperture dependence aberrations is apparent; however, when relative apertures of approximately f/2.0 or greater are desired, the amount of zonal spherical aberration and aperture dependent coma is considerably increased. Moreover, due to the large lens element powers, the amount of field curvature of third order and greater becomes excessive. Even though the aperture dependent aberrations may be well corrected, the zonal field curvature and astigmatism will severely limit resolution.

The present invention consists in a wide angle lens of the retrofocus type which comprises from the object end to the image end a first negative group, a second negative group in the form of a meniscus having a concave image side surface, a third positive group having a convex object side surface, a fourth positive group having a convex image side surface, a fifth negative group, and a sixth positive group having convex image and object side surfaces.

One embodiment of the present invention is a new and improved lens configuration for wide angle objectives which employs a new lens grouping arrangement which minimizes the lens element powers in order to obtain the necessary back focal distance and front vertex distance as required to be useful in single lens reflex cameras. The minimization of the lens group powers decreases the surface contributions to distortion and various aberrations.

Briefly stated, the present embodiment is a wide angle lens comprising a first lens group from the object end to the image and which is afocal, a second diverging group, third and fourth converging groups, a fifth diverging group and a sixth converging group. The lens groups and elements, and particularly the fourth group, have relative powers and configurations to achieve the objects of the invention, as hereinafter more specifically pointed out.

The lens is a lens of the retrofocus type having a large relative aperture with minimized field curvature and astigmatism and the capability of focusing to very close object distance without introduction of unacceptable field curvature and astigmatism.

The invention will now be described, by way of example, with reference to the accompany drawings, in which:

SPECIFICATION AMENDED - SEE ATTACHED SLIP

FIGS. 1—3 are side elevations of lens embodying the invention;

FIGS. 4 and 5 are curves illustrating the improved performance of the lens of Fig. 1;

FIGS. 6—10 are side elevations of additional lens embodying the invention; and

FIGS. 11 and 12 are curves illustrating the improved performance of the lens of Fig. 8.

In all lens designs, the elemental groupings and spacings thereof are chosen to minimize aberrations and distortion of the overall lens and generally provide a true image of an object. The lens groupings are chosen to provide a lens of given field angle or equivalent focal length for a specified image quality. Therefore, the contribution of each lens group or element in multi-element lens is incapable of precise definition inasmuch as all lens configurations are selected in view of the others to provide the desired result.

A lens embodying the invention as disclosed comprises six lens groups from the object end to the image end as follows:

I. A two element group of negative power.
II. A meniscus of negative power.
III. A positive element having a convex front surface.
IV. A positive element or doublet having a concave front surface and a convex rear surface.
V. A meniscus of negative power, and
VI. A positive doublet.

A first lens 10 embodying the invention is set forth in Fig. 1, and comprises nine lens elements L1—L9, arranged in six lens groups. The surfaces of the elements L1—L9 are defined on radii R1—R16 as shown. The first group viewed from the object end to the image end comprises elements L1 and L2 which are, as a combination, afocal with respect to the equivalent focal length (EFL) of the overall lens. The second group II is comprised of a meniscus L3 of negative power (diverging). The third group III is comprised of a bi-convex element L4 of positive power (converging). The fourth group IV is comprised of a contacting doublet L5 and L6 of positive power (converging). The fifth group V is comprised of a negative meniscus (diverging) and the sixth group VI is a contacting doublet of positive power (converging). This lens is defined by the data set forth in Table I.

A second lens 11 embodying the invention is set forth in Fig. 2 and comprises lens elements L1—L8, arranged in six groups of the same relative powers as the lens of Fig. 1. Lens 11 differs from lens 10 primarily in that Group IV comprises a single element L5, but which is still of positive power (converging). Lens 11 is defined by the data set forth in Table II.

Another lens 12 is shown in Fig. 3 and comprises the six groups I—VI of the same relative power as lens 11, having eight elements L1—L8. The lens surfaces are defined on radii R1—R15 as shown. Lens 12 differs from lens 11 primarily in that Group VI, elements L7 and L8, is comprised of a meniscus and a contacting bi-convex element in that order, rather than vice-versa, as lens 11. Lens 12 is defined by the data as set forth in Table III.

In the tables the index of refraction is denoted as N_d and the dispersion as referenced by the Abbe number is denoted by V_d.

Table I sets forth data on lens 10 of FIG. 1 scaled to an EFL of 28.7 mm for a 24 x 36 mm image frame, and having a relative aperture of F/1.9.

TABLE I.

FIGURE 1.

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
L1	R1	38.387mm			
	R2	18.755	2.435mm	1.5168	64.2
L2	R3	−119.389	8.5083		
	R4	−52.877	7.167	1.7995	42.3
L3	R5	18.178	4.72—0.20		
	R6	12.456	2.180	1.5831	59.5
L4	R7	49.0379	9.369		
	R8	−123.776	2.159	1.8306	36.5
L5	R9	−22.141	2.581		
L6	R10	−109.562	6.000	1.7470	27.5
	R11	−21.131	5.774	1.7620	40.3
L7	R12	55.725	0.135		
	R13	26.386	2.454	1.8467	23.8
L8	R14	76.751	2.239		
L9	R15	−22.374	6.000	1.8042	46.5
	R16	−54.363	1.500	1.8052	25.5

BFL = 38.8 mm

The aperture stop is located 8.4 mm after L3.

The spacing between elements L2 and L3 varies from 0.20 mm to 4.72 mm for focusing from infinity to 178.4 mm. Elements L3—L9 move in fixed relation as a group during focusing travel.

Table II sets forth data on lens 11 of FIG. 2 scaled to an EFL of 28.7 mm for a 24 x 36 mm image frame, and having a relative aperture of F/2.0.

TABLE II.

FIGURE 2.

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
L1	R1	38.570mm	2.435mm	1.5168	64.2
	R2	19.187	8.508		
L2	R3	−118.121	4.797	1.7995	42.3
	R4	−53.498	4.000—0.25		
L3	R5	18.556	2.180	1.5831	59.5
	R6	12.336	10.615		
L4	R7	50.120	2.159	1.8306	36.5
	R8	−160.5232	2.581		
L5	R9	−22.590	10.883	1.7600	47.5
	R10	−21.050	0.135		
L6	R11	51.8954	3.257	1.8467	23.8
	R12	26.298	2.239		
L7	R13	77.064	7.000	1.8042	46.5
	R14	−18.570			
L8	R15	−51.214	1.500	1.8052	25.5

BFL = 39.0 mm.

The aperture stop is located 9.55 mm behind L3.

Elements L3—L8 move in fixed relation as a group for focusing while L1 and L2 are stationary. The spacing between elements L2 and L3 varies from 0.25 mm to 4.00 mm for focusing from infinity to 178 mm.

Table III sets forth data on lens 12 of FIG. 3 scaled to an EFL of 28.7 mm for a 24 x 36 mm image frame and having a relative aperture of F/2.0.

TABLE III.

FIGURE 3.

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
L1	R1	39.897mm	2.435mm	1.520	65.6
	R2	19.832	8.500		
L2	R3	−111.180	5.835	1.802	47.5
	R4	−55.111	4.000—0.25		
L3	R5	17.557	2.180	1.807	44.3
	R6	12.193	10.789		
L4	R7	47.013	2.433	1.833	41.8
	R8	−138.976	3.390		
L5	R9	−23.286	9.700	1.837	51.9
	R10	−21.573	0.135		
L6	R11	−51.904	3.324	1.848	23.4
	R12	26.009	2.682		
L7	R13	85.346	1.000	1.848	23.4
L8	R14	31.429	4.000	1.776	50.6
	R15	−43.746			

BFL = 39.9 mm.

The aperture stop is located 10.79 mm behind L3.

The spacing between elements L2 and L3 varies between 0.25 mm and 4.00 mm for focusing from infinity to 178 mm.

Elements L3—L8 move in fixed relation as a group for focusing while L1 and L2 are stationary.

In the examples of Tables I—III, all lens have a rated EFL of 28 mm and a rated equivalent aperture of F/1.9, as scaled to a film or image frame size of 24 x 36 mm. The lenses may, of course, be scaled to other image frame sizes, and EFL's.

Figs. 4 and 5 exemplify plots of image height versus focal plane shift for the lens of Fig. 1, and a known wide angle lens scaled to 28 mm EFL and a stated relative aperture of F/2.0, respectively, as shown in U.S. Patent 3,736,049. Comparisons were made at a magnification of M = −.025 for a half image height of 20 mm, for both sagittal S and tangential T rays.

The curves of Fig. 4 are relatively close together evidencing essential elimination of astigmatism. The curves of Fig. 4 have less deviation from the vertical, and are generally flatter than those of Fig. 5, to evidence a substantial reduction in field curvature.

The lenses of Tables I, II and III are designed for the first group elements L1 and L2 to be stationary while the rear elements are shifted in fixed relation as a group for focusing as disclosed in copending application No. 36799/74 (Serial No. 1,484,321).

However, the lens Groups may also be arranged to move differentially as in the conventional wide angle objectives. For example, the entire objective may be shifted for focusing, while the fourth and fifth lens Groups move differentially in a well known manner. Also, the lens may be arranged to move only Groups V and VI for focusing, as hereinafter described.

Further examples of lenses embodying the invention are set forth in Figs. 6—10, and Tables IV—IX. In all of the examples, Group IV is an air spaced doublet L5, L6.

Table IV sets forth data on the lens 13 of Fig. 6 as scaled to an EFL of 28.5 mm for a 24 x 36 mm image plane, and having a relative aperture of F/1.9.

TABLE IV.

FIGURE 6.

Lens		Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	R_1	155.101			
L1			4.160	1.562	58.52
	R_2	−541.744			
			.300		
	R_3	29.242			
L2			3.000	1.487	70.4
	R_4	13.031			
			12.759		
	R_5	22.898			
L3			2.000	1.800	42.3
	R_6	15.520			
			8.692		
	R_7	48.249			
L4			3.200	1.785	25.7
	R_8	−70.561			
			1.967		
	R_9	−24.204			
L5			2.164	1.805	25.5
	R_{10}	−1430.264			
			.844		
	R_{11}	−94.529			
L6			5.504	1.800	42.3
	R_{12}	−19.767			
			3.550—1.028		
	R_{13}	45.215			
L7			2.580	1.847	23.8
	R_{14}	29.179			
			1.700		
	R_{15}	70.687			
L8			8.00	1.743	49.2
	R_{16}	−19.969			
L9			2.700	1.847	23.8
	R_{17}	−44.577			

The aperture stop is located 7.18 mm after L3. The BFL varies from 39.68 mm to 44.34 mm as the lens is focused from infinity to an object distance of 174.7 mm. All lens elements move for focusing and the space between Groups IV and V moves differentially as shown.

Table V sets forth data on a lens 14 substantially as shown in Fig. 7 scaled to an EFL of 28.6 mm for a 24 × 36 mm frame size and a relative aperture of F/1.9.

TABLE V.

FIGURE 7.

Lens		Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	R_1	42.160			
L1			5.700	1.487	70.4
	R_2	384.104			
			.300		
	R_3	35.935			
L2			2.800	1.487	70.4
	R_4	11.488			
			4.032		
	R_5	26.721			
L3			2.000	1.517	64.2
	R_6	15.510			
			14.343		
	R_7	39.692			
L4			3.200	1.689	31.2
	R_8	−925.392			
			2.973		
	R_9	−76.847			
L5			2.164	1.847	23.8
	R_{10}	97.091			
			1.750		
	R_{11}	−75.162			
L6			4.549	1.800	42.3
	R_{12}	−21.352			
			4.098—.100		
	R_{13}	37.634			
L7			2.700	1.722	29.2
	R_{14}	32.248			
			2.000		
	R_{15}	70.613			
L8			8.400	1.641	59.8
	R_{16}	−18.940			
L9			2.700	1.805	25.5
	R_{17}	−42.358			

The aperture stop is located 12.3 mm after L3. The BFL varies from 39.2 mm to 43.2 mm as the lens is focused from infinity to an object distance of 203 mm. Groups I—IV are stationary while Groups V and VI (elements L7—L9) move in fixed relation for focusing.

Table VI sets forth data on lens 15 of FIG. 8 scaled to an EFL of 35.0 mm for a 24 x 36 mm image frame, and a relative aperture of F/2.0.

TABLE VI.

FIGURE 8.

Lens		Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
L1	R_1	31.195	2.998	1.517	64.2
	R_2	20.569	7.074		
L2	R_3	–96.642	2.829	1.785	25.7
	R_4	–58.277	0.726		
L3	R_5	18.356	4.321	1.723	38.0
	R_6	12.649	11.925		
L4	R_7	53.996	2.800	1.831	36.5
	R_8	–172.838	3.000		
L5	R_9	–22.950	2.695	1.741	27.8
	R_{10}	–276.177	0.720		
L6	R_{11}	–76.849	6.081	1.757	47.7
	R_{12}	–19.800	2.000—0.20		
L7	R_{13}	51.599	3.000	1.847	23.8
	R_{14}	31.353	2.332		
L8	R_{15}	82.914	7.000	1.800	42.3
L9	R_{16}	–25.647	3.000		
	R_{17}	–57.034		1.805	25.5

BFL = 40.5.

The aperture stop is located 10.73 mm after element L3. The space between Groups IV and V varies as shown for close focus compensation at a linear rate as the lens focuses to 230.1 mm. The entire lens also shifts for focusing.

Table 7 sets forth data on lens 16 of FIG. 9 scaled to an EFL of 35.0 mm for a 24 x 36 mm image frame, and a relative aperture of F/1.9.

TABLE VII.

FIGURE 9.

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
L1	R1	−1598.84mm	4.160mm	1.750	35.0
	R2	−175.71	.300		
L2	R3	22.57	2.985	1.487	70.4
	R4	13.99	9.079		
L3	R5	23.40	5.005	1.700	47.8
	R6	15.49	8.869		
L4	R7	58.80	3.200	1.831	36.5
	R8	−100.28	2.385		
L5	R9	−24.54	2.358	1.741	27.8
	R10	−845.99	.680		
L6	R11	−102.81	6.778	1.757	47.7
	R12	−19.97	0.91—3.66		
L7	R13	58.83	3.000	1.847	23.8
	R14	32.65	1.700		
L8	R15	65.28	7.300	1.800	42.3
	R16	−27.00			
L9	R17	−79.24	0	1.805	25.5

BFL = 39.48 — 45.28 mm as lens is focused from infinity to 221.3 mm. The aperture stop is located 7.54 mm after element L3. The BFL varies from 39.48 mm to 45.28 mm as the lens is focused from infinity to 221.3 mm. The spacing between Groups IV and V also varies as shown.

Table VIII sets forth data on lens 17 of FIG. 10 scaled to an EFL of 35.0 mm for a 24 x 36 mm image frame, and a relative aperture of F/1.9.

TABLE VIII.

FIGURE 10.

Lens		Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
L1	R_1	30.600	7.000	1.487	70.4
	R_2	170.290	.300		
L2	R_3	34.231	2.985	1.487	70.4
	R_4	11.567	6.000		
L3	R_5	67.235	2.000	1.569	56.0
	R_6	25.201	6.171		
L4	R_7	46.077	3.200	1.806	40.7
	R_8	–644.608	7.931		
L5	R_9	–34.424	2.358	1.762	26.6
	R_{10}	829.911	1.350		
L6	R_{11}	–47.763	4.832	1.757	47.7
	R_{12}	–19.289	4.70—.10		
L7	R_{13}	41.514	3.000	1.667	33.1
	R_{14}	35.544	1.900		
L8	R_{15}	64.725	8.000	1.717	48.0
	R_{16}	–22.414			
L9	R_{17}	–56.648	2.700	1.805	25.5

The BFL varies from 39.56 mm to 44.16 mm as the lens is focused from infinity to 258 mm, and the spacing between Groups IV and V varies as shown. The aperture stop is located 1.59 mm behind element L4.

Table IX sets forth data on a lens substantially as shown in FIG. 7 scaled to an EFL of 28.5 mm for a 24 × 36 mm frame size and a relative aperture of F/1.9.

TABLE IX.

FIGURE 7.

Lens		Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
L1	R_1	54.600	5.700	1.487	70.4
	R_2	937.48	.300		
L2	R_3	28.640	2.800	1.487	70.4
	R_4	11.392	4.474		
L3	R_5	28.640	2.000	1.517	64.2
	R_6	15.990	13.502		
L4	R_7	41.450	3.200	1.689	31.2
	R_8	−840.70	3.342		
L5	R_9	−70.750	2.164	1.805	25.5
	R_{10}	106.030	1.900		
L6	R_{11}	−71.649	4.549	1.804	46.5
	R_{12}	−21.220	4.098—.10		
L7	R_{13}	48.140	2.700	1.741	27.8
	R_{14}	35.430	1.212		
L8	R_{15}	53.960	9.159	1.639	55.5
L9	R_{16}	−20.430	2.700	1.805	25.5
	R_{17}	−44.190			

The aperture stop is located 11.5 mm behind L3. Groups V and VI move from a BFL of 39.2 mm of 43.2 mm for focusing from infinity to 203 mm while Groups I—IV are fixed with respect to the film plane.

Figs. 11 and 12 exemplify further comparison of the focal plane shift of the lens of Fig. 8 and the lens of the previously mentioned patent at a magnification of M = −.025 for a half image height of 20 mm, for both sagittal S and tangential T rays.

The curves of Fig. 11 are relatively close together evidencing substantially less astimatism than Fig. 12. The curves of Fig. 11, particularly in the saggital have less deviation from the vertical, evidencing reduction in field curvature.

As previously mentioned, the contribution of each lens group to an overall lens is incapable of precise definition since properties of one or more elements and groups serve the same function and are complimenting and supplementing each other. However, in the new lens form described, Group IV is designed to provide certain contributions to the overall lens.

Group IV provides a substantial correction for the Petzval sum of the lens. The axial spacing of the front and rear surfaces contributes to correction of field curvature convex toward the object. Additionally, it provides positive power required to shorten the EFL of the overall lens while maintaining the required back focal length (BFL) to make the lens of the retrofocus type. The EFL of

Group IV (F_4) should have the following relation to the EFL of the overall lens (F_0).

$$2.5\ F_0 \leqq F_4 \leqq 6.5\ F_0$$

The foregoing is an important relation, and other preferred relationships exist which do not have the same criticality. The radius R_4 of the rear surface is less than F_0, or

$$F_0 > R_4$$

This relationship contributes to correction for distortion. The axial separation D_4 between front and rear surfaces is a substantial percentage of the EFL of the lens and preferably is in the range of

$$.45\ F_0 \geqq D_4 \geqq .20\ F_0$$

Additionally, to maintain the desired power contribution the combined EFL of Groups III and IV (F_{34}) is preferably

$$2.0\ F_0 \leqq F_{34} \leqq 1.0\ F_0$$

As shown Group IV may be a single element or a doublet, either cemented or air spaced. It might also be defined in three elements. The front surface of Group III, L4, is convex. However, the rear surface may be other than convex depending on the design.

Groups V and VI are of positive power of a magnitude determined by the power of the other elements but in the preferred designs have an EFL (F_{56})

$$4.0\ F_0 \geqq F_{56} \geqq 1.0\ F_0$$

while the EFL (F_6) of Group VI is

$$2.0\ F_0 > F_6 \geqq 1.0\ F_0$$

Group III is of positive power to supplement the positive power of Group IV and preferably has an EFL (F_3) range

$$2.5\ F_0 \geqq F_3 \geqq 1.2\ F_0$$

The ranges set forth above may be better appreciated in consideration with Table X which tabulates the ratio of the EFL of each group and combinations thereof to the overall EFL of the lens.

TABLE X.

RATIO OF EFL OF LENS GROUPS TO EFL OF LENS

TABLE	GROUP I	GROUP II	GROUP III	GROUP IV	GROUP V	GROUP VI	GROUPS V & VI	GROUPS I—IV	GROUPS III & IV
I	–11.541	–2.740	1.472	3.299	–2.124	1.4139	3.610	1.502	1.261
II	–10.770	–2.514	1.598	3.492	–2.307	1.373	3.030	1.730	1.332
III	–9.415	–2.105	1.478	3.410	–2.276	1.394	3.251	1.688	1.249
IV	–2.602	–2.391	1.285	5.325	–3.647	1.492	2.413	2.414	1.249
V	–2.282	–2.656	2.088	3.132	–13.743	1.854	2.178	3.202	1.446
VI	–15.020	–2.345	1.414	4.604	–2.866	1.250	2.103	2.172	1.312
VII	–3.718	–2.472	1.279	3.342	–3.061	1.324	2.279	2.094	1.121
VIII	–2.799	–2.052	1.518	3.732	–13,175	1.381	1.574	4.829	1.313
IX	–2.429	–2.589	2.200	2.952	–6.933	1.662	2.179	3.190	1.459

The lenses disclosed may be focused on an object as close as 6.25 EFL's or less than seven inches in the case of the lens of Table IV. In the case of the lens of Table I, the lens is focused to 6.37 EFL or 7.02 inches with minimal astigmatism and field curvature, as exemplified in Fig. 4.

Table XI exemplifies the close focusing capability of the various lens disclosed.

TABLE XI.

LENS	CLOSE FOCUS DISTANCE (FD)		FD/EFL
TABLE I	178mm	7.02 in.	6.20
II	178	7.02	6.20
III	178	7.02	6.20
IV	175	6.91	6.14
V	203	7.99	7.12
VI	230	9.06	6.57
VII	221	8.70	6.31
VIII	258	10.20	7.37
IX	203	7.99	7.12

It may thus be seen that some new wide-angle lenses of the retrofocus type according to the invention have a large relative aperture which will focus to an object distance of less than seven EFL's with minimal astigmatism and field curvature.

While preferred embodiments of the invention have been set forth for purposes of disclosure, other embodiments and modification to the disclosed embodiment of the invention may be derived by others skilled in the art. Accordingly, the appended claims are intended to cover all embodiments and applications of the invention and reversals thereof which do not depart from the scope of the invention.

In our co-pending Application No. 36799/74 (Serial No. 1,484,321) there is described and claimed a wide angle lens of the retrofocus type comprising a housing, a first lens grouping in said housing at the object end thereof the absolute value of the equivalent focal length of said first lens grouping being at least three times greater than the equivalent focal length of said lens, and a second lens grouping in said housing, said second grouping comprising a plurality of lens elements in fixed relation to each other, said second lens grouping being movable forwardly in said housing a predetermined distance for close focusing of said lens whilst said first grouping is stationary.

WHAT WE CLAIM IS:—

1. A wide angle lens of the retrofocus type which comprises from the object end to the image end a first negative group, a second negative group in the form of a meniscus having a concave image side surface, a third positive group having a convex object side surface, a fourth positive group having a convex image side surface, a fifth negative group, and a sixth positive group having convex image and object side surfaces.

2. The lens of claim 1 wherein the equivalent focal length of the fourth group is equal to or greater than two and one-half times the equivalent focal length of the overall lens.

3. The lens of claim 1 wherein the equivalent focal length of the fourth group is equal to or less than six and one-half times the equivalent focal length of the overall lens.

4. The lens of claim 1 further defined by

$$6.5\ F_0 \geqq F_4 \geqq 2.5\ F_0$$

where F_0 is the equivalent focal length of the overall lens and F_4 is the equivalent focal length of the fourth group.

Table XI exemplifies the close focusing capability of the various lens disclosed.

TABLE XI.

LENS	CLOSE FOCUS DISTANCE (FD)		FD/EFL
TABLE I	178mm	7.02 in.	6.20
II	178	7.02	6.20
III	178	7.02	6.20
IV	175	6.91	6.14
V	203	7.99	7.12
VI	230	9.06	6.57
VII	221	8.70	6.31
VIII	258	10.20	7.37
IX	203	7.99	7.12

It may thus be seen that some new wide-angle lenses of the retrofocus type according to the invention have a large relative aperture which will focus to an object distance of less than seven EFL's with minimal astigmatism and field curvature.

While preferred embodiments of the invention have been set forth for purposes of disclosure, other embodiments and modification to the disclosed embodiment of the invention may be derived by others skilled in the art. Accordingly, the appended claims are intended to cover all embodiments and applications of the invention and reversals thereof which do not depart from the scope of the invention.

In our co-pending Application No. 36799/74 (Serial No. 1,484,321) there is described and claimed a wide angle lens of the retrofocus type comprising a housing, a first lens grouping in said housing at the object end thereof the absolute value of the equivalent focal length of said first lens grouping being at least three times greater than the equivalent focal length of said lens, and a second lens grouping in said housing, said second grouping comprising a plurality of lens elements in fixed relation to each other, said second lens grouping being movable forwardly in said housing a predetermined distance for close focusing of said lens whilst said first grouping is stationary.

WHAT WE CLAIM IS:—

1. A wide angle lens of the retrofocus type which comprises from the object end to the image end a first negative group, a second negative group in the form of a meniscus having a concave image side surface, a third positive group having a convex object side surface, a fourth positive group having a convex image side surface, a fifth negative group, and a sixth positive group having convex image and object side surfaces.

2. The lens of claim 1 wherein the equivalent focal length of the fourth group is equal to or greater than two and one-half times the equivalent focal length of the overall lens.

3. The lens of claim 1 wherein the equivalent focal length of the fourth group is equal to or less than six and one-half times the equivalent focal length of the overall lens.

4. The lens of claim 1 further defined by

$$6.5\ F_0 \geqq F_4 \geqq 2.5\ F_0$$

where F_0 is the equivalent focal length of the overall lens and F_4 is the equivalent focal length of the fourth group.

5. The lens of claim 1 further defined by

$$2.0\ F_0 \geqq F_{34} \geqq 1.0\ F_0$$

where F_{34} is the combined equivalent focal length of the third and fourth groups, and F_0 is the equivalent focal length of the overall lens.

6. The lens of claim 4 further defined by the rear surface of said fourth group being defined on a radius R_4 where

$$R_4 < F_0$$

and F_0 is the equivalent focal length of the overall lens.

7. The lens of claim 1 further defined in that the first surface of said fourth group is concave and the distance D_4 between the first and last surface thereof is

$$.45\ F_0 \geqq D_4 \geqq .20\ F_0$$

where F_0 is the equivalent focal length of the overall lens.

8. The lens of claim 1 further defined by

$$2.0\ F_0 \geqq F_6 \geqq 1.0\ F_0$$

where F_0 is the equivalent focal length of the overall lens and F_6 is the equivalent focal length of the sixth group.

9. The lens of claim 1 further defined by

$$2.5\ F_0 \geqq F_3 \geqq 1.2\ F_0$$

where F_3 is the equivalent focal length of said third group, and F_0 is the equivalent focal length of the overall lens.

10. The lens of claim 1 defined by substantially the following data as scaled to an equivalent focal length of 28.7 mm.

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
L1	R1	38.387mm	2.435mm	1.5168	64.2
	R2	18.755	8.5083		
L2	R3	−119.389	7.167	1.7995	42.3
	R4	−52.877	4.72—0.20		
L3	R5	18.178	2.180	1.5831	59.5
	R6	12.456	9.369		
L4	R7	49.0379	2.159	1.8306	36.5
	R8	−123.776	2.581		
L5	R9	−22.141	6.000	1.7470	27.5
L6	R10	−109.562	5.774	1.7620	40.3
	R11	−21.131	0.135		
L7	R12	55.725	2.454	1.8467	23.8
	R13	26.386	2.239		
L8	R14	76.751	6.000	1.8042	46.5
L9	R15	−22.374	1.500	1.8052	25.5
	R16	−54.363			

Where L1—L9 are successive lens elements arranged in six groups, L1,L2; L3; L4; L5, L6, L7; and L8, L9; R1—R16 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens; N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1—L9.

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11. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 28.7 mm.

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
L1	R1	38.570mm	2.435mm	1.5168	64.2
	R2	19.187	8.508		
L2	R3	−118.121	4.797	1.7995	42.3
	R4	−53.498	4.000—0.25		
L3	R5	18.556	2.180	1.5831	59.5
	R6	12.336	10.615		
L4	R7	50.120	2.159	1.8306	36.5
	R8	−160.5232	2.581		
L5	R9	−22.590	10.883	1.7600	47.5
	R10	−21.050	0.135		
L6	R11	51.8954	3.257	1.8467	23.8
	R12	26.298	2.239		
L7	R13	77.064	7.000	1.8042	46.5
	R14	−18.570			
L8	R15	−51.214	1.500	1.8052	25.5

Where L1—L8 are successive lens elements arranged in six groups, L1, L2; L3; L4; L5; L6; L7, L8; R1—R15 are the radii of curvature of the successive lens surfaces according to the sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe numbers, respectively, of the elements L1—L8.

12. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 28.7 mm.

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
L1	R1	39.897mm	2.435mm	1.520	65.6
	R2	19.832	8.500		
L2	R3	−111.180	5.835	1.802	47.5
	R4	−55.111	4.000—0.25		
L3	R5	17.557	2.180	1.807	44.3
	R6	12.193	10.789		
L4	R7	47.013	2.433	1.833	41.8
	R8	−138.976	3.390		
L5	R9	−23.286	9.700	1.837	51.9
	R10	−21.573	0.135		
L6	R11	−51.904	3.324	1.848	23.4
	R12	26.009	2.682		
L7	R13	85.346	1.000	1.848	23.4
	R14	31.429	4.000	1.776	50.6
L8	R15	−43.746			

Where L1—L8 are successive lens elements arranged in six groups, L1, L2; L3; L4; L5; L6; L7, L8; R1—R15 are the radii of curvature of the successive lens surfaces according to the sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe numbers, respectively, of the elements L1—L8.

13. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 28.5 mm.

Lens		Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
L1	R_1	155.101	4.160	1.562	58.52
	R_2	−541.744	.300		
L2	R_3	29.242	3.000	1.487	70.4
	R_4	13.031	12.759		
L3	R_5	22.898	2.000	1.800	42.3
	R_6	15.520	8.692		
L4	R_7	48.249	3.200	1.785	25.7
	R_8	−70.561	1.967		
L5	R_9	−24.204	2.164	1.805	25.5
	R_{10}	−1430.264	.844		
L6	R_{11}	−94.529	5.504	1.800	42.3
	R_{12}	−19.767	3.550—1.028		
L7	R_{13}	45.215	2.580	1.847	23.8
	R_{14}	29.179	1.700		
L8	R_{15}	70.687	8.00	1.743	49.2
L9	R_{16}	−19.969	2.700	1.847	23.8
	R_{17}	−44.577			

Where L1—L9 are successive lens elements arranged in six groups, L1, L2; L3; L4; L5, L6; L7; L8, L9; R1—R17 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1—L9.

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14. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 28.6 mm.

Lens		Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
L1	R_1	42.160	5.700	1.487	70.4
	R_2	384.104	.300		
L2	R_3	35.935	2.800	1.487	70.4
	R_4	11.488	4.032		
L3	R_5	26.721	2.000	1.517	64.2
	R_6	15.510	14.343		
L4	R_7	39.692	3.200	1.689	31.2
	R_8	–925.392	2.973		
L5	R_9	–76.847	2.164	1.847	23.8
	R_{10}	97.091	1.750		
L6	R_{11}	–75.162	4.549	1.800	42.3
	R_{12}	–21.352	4.098—.100		
L7	R_{13}	37.634	2.700	1.722	29.2
	R_{14}	32.248	2.000		
L8	R_{15}	70.613	8.400	1.641	59.8
L9	R_{16}	–18.940	2.700	1.805	25.5
	R_{17}	–42.358			

Where L1—L9 are successive lens elements arranged in six groups, L1, L2; L3; L4; L5; L6; L7; L8, L9; R1—R17 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1—L9.

15. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 35.0 mm.

Lens		Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	R_1	31.195			
L1			2.998	1.517	64.2
	R_2	20.569			
			7.074		
	R_3	−96.642			
L2			2.829	1.785	25.7
	R_4	−58.277			
			0.726		
	R_5	18.356			
L3			4.321	1.723	38.0
	R_6	12.649			
			11.925		
	R_7	53.996			
L4			2.800	1.831	36.5
	R_8	−172.838			
			3.000		
	R_9	−22.950			
L5			2.695	1.741	27.8
	R_{10}	−276.177			
			0.720		
	R_{11}	−76.849			
L6			6.081	1.757	47.7
	R_{12}	−19.800			
			2.000—0.20		
	R_{13}	51.599			
L7			3.000	1.847	23.8
	R_{14}	31.353			
			2.332		
	R_{15}	82.914			
L8			7.000	1.800	42.3
	R_{16}	−25.647			
L9			3.000		
	R_{17}	−57.034		1.805	25.5

Where L1—L9 are successive lens elements arranged in six groups, L1, L2; L3; L4; L5, L6; L7; L8, L9; R1—R17 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1—L9.

16. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 35.0 mm.

Lens		Radius	Axial Distance Between Surfaces	N_d	V_d
L1	R1	−1598.84mm	4.160mm	1.750	35.0
	R2	−175.71	.300		
L2	R3	22.57	2.985	1.487	70.4
	R4	13.99	9.079		
L3	R5	23.40	5.005	1.700	47.8
	R6	15.49	8.869		
L4	R7	58.80	3.200	1.831	36.5
	R8	−100.28	2.385		
L5	R9	−24.54	2.358	1.741	27.8
	R10	−845.99	.680		
L6	R11	−102.81	6.778	1.757	47.7
	R12	−19.97	0.91—3.66		
L7	R13	58.83	3.000	1.847	23.8
	R14	32.65	1.700		
L8	R15	65.28	7.300	1.800	42.3
	R16	−27.00			
L9	R17	−79.24	0	1.805	25.5

Where L1—L9 are successive lens elements arranged in six groups, L1, L2; L3; L4; L5, L6; L7; L8, L9; R1—R17 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1—L9.

17. The lens of claim 1 defined substantially by the following data as scaled to an equivalent focal length of 35.0 mm.

Lens		Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	R_1	30.600			
L1			7.000	1.487	70.4
	R_2	170.290			
			.300		
	R_3	34.231			
L2			2.985	1.487	70.4
	R_4	11.567			
			6.000		
	R_5	67.235			
L3			2.000	1.569	56.0
	R_6	25.201			
			6.171		
	R_7	46.077			
L4			3.200	1.806	40.7
	R_8	−644.608			
			7.931		
	R_9	−34.424			
L5			2.358	1.762	26.6
	R_{10}	829.911			
			1.350		
	R_{11}	−47.763			
L6			4.832		
	R_{12}	−19.289		1.757	47.7
			4.70—.10		
	R_{13}	41.514			
L7			3.000	1.667	33.1
	R_{14}	35.544			
			1.900		
	R_{15}	64.725			
L8			8.000	1.717	48.0
	R_{16}	−22.414			
L9			2.700	1.805	25.5
	R_{17}	−56.648			

Where L1—L9 are successive lens elements arranged in six groups, L1, L2; L3; L4; L5, L6; L7; L8, L9; R1—R17 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1—L9.

18. The lens of claim 1 defined substantially by the following data is scaled to an equivalent focal length of 28.5 mm.

Lens		Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	R_1	54.600			
L1			5.700	1.487	70.4
	R_2	937.48			
			.300		
	R_3	28.640			
L2			2.800	1.487	70.4
	R_4	11.392			
			4.474		
	R_5	28.640			
L3			2.000	1.517	64.2
	R_6	15.990			
			13.502		
	R_7	41.450			
L4			3.200	1.689	31.2
	R_8	−840.70			
			3.342		
	R_9	−70.750			
L5			2.164	1.805	25.5
	R_{10}	106.030			
			1.900		
	R_{11}	−71.649			
L6			4.549	1.804	46.5
	R_{12}	−21.220			
			4.098—.10		
	R_{13}	48.140			
L7			2.700	1.741	27.8
	R_{14}	35.430			
			1.212		
	R_{15}	53.960			
L8			9.159	1.639	55.5
	R_{16}	−20.430			
L9			2.700	1.805	25.5
	R_{17}	−44.190			

Where L1—L9 are successive lens elements arranged in six groups, L1, L2; L3; L4; L5, L6; L7; L8, L9; R1—R17 are the radii of curvature of the successive lens surfaces according to sequence of the surfaces in the overall lens, N_d and V_d are the indexes of refraction and Abbe Numbers, respectively, of the elements L1—L9.

19. A wide angle lens constructed and arranged substantially as hereinbefore described and exemplified.

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