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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.

Wide angle lenses may be defined as those in which the diagonal of the film frame with which the camera is used is substantially equal to or greater than the effective focal length of the lens. Generally, wide angle objectives and particularly those of the retrofocus type are well corrected for ordinary aberrations for only one magnification. Wide angle lens of the retrofocus type are generally used with single lens reflex cameras and have a back focal length (BFL) greater than the equivalent focal length (EFL). This is generally dictated by design considerations which must permit room for the viewing mirror behind the last lens element.

Where the lens is designed for close focusing applications, the magnification will change slightly and such objectives then have considerably degraded performance due to the introduction of astigmatism, coma and other aberrations. One technique often employed to compensate for this change of aberration is to change an axial separation between lens elements as a function of focusing distance independent of focusing travel of the overall lens. While this technique has theoretical merit and can often be used to produce satisfactory results over a large range of focusing distances, the power of the lens elements for this type of objective is often large, and together with the nature of the lens element aberration contributions, the group of elements moving independently of the focusing travel is often very sensitive to deviations in mechanical centration. The resulting image is thus often degraded due to decentration more than to the effects of astigmatism, the dominant aberration due to focusing.

The present invention consists in 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.

By the term "lens grouping" is meant one or more groups of lenses.

One embodiment of the present invention is a new and improved wide angle lens of the retrofocus type which corrects the aberrations generally encountered in close focusing, decreases or eliminates the sensitivity to decentration resulting from focusing motion of the lens elements, and also provides a lens barrel in which the length is not elongated during focusing. This construction may be quite useful in environments potentially damaging to the lens.

Briefly stated, the present embodiment comprises a lens utilizing a front grouping of elements which are fixed in location with respect to the image plane and are generally afocal. The remaining lens elements move as a unit for focusing. Since the front element grouping in combination is nearly afocal, the sensitivity to

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decentration resulting from the focusing motion is considerably reduced. With the proper selection of lens elements the effect of focusing the rearward group is merely to provide a constant correction for astigmatism.

The lens is a new and improved wide angle lens of the retrofocus type which can be focused very close distances without degradation of the image and in which the front vertex distance of the lens does not change during focusing.

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

FIG. 1 is a representation of elements of a first lens embodying the invention;

FIG. 2 is a side elevation, partially in half section of a lens utilizing the elements of Fig. 1;

FIG. 3 is a side elevation, partially in half section of another lens utilizing the invention; and

FIG. 4 is a representation of another lens embodying the invention.

Reference is now made to Fig. 1 which exemplifies a wide angle lens of the retrofocus type adapted to be utilized with a 35 millimeter camera (24 millimeter x 36 millimeter frame size) and which has a relative aperture of f/1.9 and an equivalent focal length (EFL) of 28 millimeters.

The lens 10 comprises elements L1—L9 having surfaces defined by radii R1—R16 as shown. The aperture is placed between elements L3 and L4. Elements L1 and L2 form a first grouping made up of a single first group, which is fixed in relation to a lens housing and, hence, the film plane FP. The elements L3—L9 form a second grouping made up of five groups which are held in fixed relation to each other but move axially for focusing.

The lens of Fig. 1 comprises, from the object end, the first grouping made up of a first negative group L1, L2; and the second grouping made up of a second negative group L3 in the form of a meniscus having a convex object side surface; a third positive group L4 having a convex object side surface; a fourth positive group L5, L6 having a convex image side surface; a fifth negative group L7; and a sixth positive group L8, L9 having convex object and image side surfaces.

The lens of Fig. 1 for the frame size specified is defined substantially by the data of Table I, as scaled to an equivalent focal length of 28.7mm:

TABLE I

Lens		Radius	Axial Distance Between Surfaces	N _d	V _d
L1	R1	38.387mm		1.5168	64.2
	R2	18.755	2.435mm		
L2	R3	-119.389	8.5083	1.7995	42.3
	R4	-52.877	7.167		
L3	R5	18.178	4.00	1.5831	59.5
	R6	12.456	2.180		
L4	R7	49.0379	9.369	1.8306	36.5
	R8	-123.776	2.159		
L5	R9	-22.141	2.581	1.7470	27.5
	R10	-109.562	6.000		
L6	R11	-21.131	5.774	1.7620	40.3
	R12	55.725	0.135		
L7	R13	26.386	2.454	1.8467	23.8
	R14	76.751	2.239		
L8	R15	-22.374	6.000	1.8042	46.5
	R16	-54.363	1.500		
L9			41.687	1.8052	25.5

Film Plane

EFL=28.7mm

The aperture stop is located between elements L3 and L4. The focal length of elements L1 and L2 is -329.5mm, or nearly twelve times the EFL of the lens. The spacing between elements L2 and L3 varies from 0.20mm to 4.72mm for focusing from infinity to 178.4mm. N_d is the index of refraction and V_d is the Abbe number.

The lens disclosed may, of course, be scaled for other image frame sizes and EFL.

Fig. 2 exemplifies the lens 10 of Fig. 1 in a lens mount 11 which includes a lens barrel or housing 12, a lens mount 13, and a focusing ring 14. Barrel 12 is provided with a camera mount in the form of threads 15, and has a longitudinal slot 16 defined therein. A pin 17 is received in mount 13 and extends through slot 16 into barrel 12 into an annular groove 18 in ring 14. Ring 14 has internal threads 19 engaging mating external threads 20 on barrel 12. As ring 14 is rotated, pin 17 in slot 16 inhibits rotation of mount 13, and axial movement is imparted to mount 13 for focusing travel.

Fig. 3 exemplifies a scaled lens construction, where there is also no change in the front vertex distance of the lens during focusing. The first group comprising elements L1 and L2 is fixed in a lens barrel on housing 25, a movable lens mount 26 carrying a pin 27 therein which extends into an internal axially directed slot 28 in barrel 25. The image end of the barrel 25 is adapted to be coupled to a camera body 29 as by means of threads 30, mating with mounting threads 31 of the camera body. A focusing sleeve 32 is disposed within barrel 25, and has internal threads 33

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engaging external threads 34 on mount 26. A pin 35 carried by barrel 25 extends into an annular groove 36 in sleeve 32 and prevents axial motion thereof. A gear 37 is defined on the end of sleeve 32, and meshes with a pinion 38 on a shaft 39 journaled in body 29. A focusing knob 40 is coupled to shaft 39.

To focus the lens, knob 40 is rotated imparting rotational movement to pinion 38 and sleeve 32. As sleeve 32 rotates, mount 26 travels axially in barrel 25 over the focusing range of the lens.

The barrel 25 has a continuous uninterrupted outer surface with the exception of an aperture for pin 35, which may be suitably sealed. A seal 41 may be provided between the rear side of lens element L1 and barrel 35. Also a seal 42 may be provided in an annular groove 43 in mounting flange 44 on barrel 25.

This construction provides a sealed lens which may be utilized in underwater applications without the necessity of placing the camera body and lens in a sealed container.

Table II sets forth data of another lens embodying the invention as scaled to an equivalent focal length of 35mm for a 24 x 36mm frame size, and with a relative aperture of F/1.9. The lens of Table II is exemplified in Fig. 4. In this lens there is a first grouping made up of four groups and a second grouping made up of two groups. In the first grouping there is a first group L1,L2; a second group L3; a third group L4; and a fourth group L5,L6. In the second grouping there is a fifth group L7; and a sixth group L8,L9.

TABLE II

Lens		Radius (mm)	Axial Distance Between Surfaces (mm)	N _d	V _d
L1	R ₁	30.600			
	R ₂	170.290	7.000	1.487	70.4
L2	R ₃	34.231	.300		
	R ₄	11.567	2.985	1.487	70.4
L3	R ₅	67.235	6.000		
	R ₆	25.201	2.000	1.569	56.0
L4	R ₇	46.077	6.171		
	R ₈	-644.608	3.200	1.806	40.7
L5	R ₉	-34.424	7.931		
	R ₁₀	829.911	2.358	1.762	26.6
L6	R ₁₁	-47.763	1.350		
	R ₁₂	-19.289	4.832	1.757	47.7
L7	R ₁₃	41.514	4.70 - .10		
	R ₁₄	35.544	3.000	1.667	33.1
L8	R ₁₅	64.725	1.900		
	R ₁₆	-22.414	8.000	1.717	48.0
L9	R ₁₇	-56.648	2.700	1.805	25.5

The BFL varies from 39.56mm to 44.16mm as the lens is focused from infinity to 258mm, and the spacing between Groups IV and V varies as shown. The aperture stop is located 1.59mm behind element L4. Groups I—IV are fixed with respect to the film plane.

In this arrangement only the grouping of elements L7, L8 and L9 move while the grouping of elements L1—L6 as shown in Fig. 4 are stationary in the lens housing. There is thus no change in the front vertex distance and the lens barrel may be completely sealed.

Table III exemplifies a lens also as represented in Fig. 4 as scaled for a 28.5mm equivalent focal length for a 24 × 36mm image frame in which the grouping of elements L7, L8 and L9 move relative to the image frame while the grouping of elements L1—L6 are in fixed relation to the image frame and there is no change in the front vertex distance of the lens when focused as close as 203mm or 7.25 EFL's.

TABLE III

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

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

The lens groupings of the lenses are set forth in Table IV.

TABLE IV

Lens	Stationary Grouping	Movable Grouping
Table I	L1, L2	L3—L9
II	L1—L6	L7—L9
III	L1—L6	L7—L9

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The absolute value of the EFL (F_0) of the stationary grouping is afocal with respect to the EFL (F_0) of the overall lens. As used herein afocal refers to the EFL of the stationary grouping being at least three times the focal length of the overall lens or

$$|F_s| \geq 3F_0$$

It is preferred that the following relations are maintained:

$$3.7 F_0 \geq F_{56} \geq 1.5 F_0$$

where F_0 is the EFL of the lens and F_{56} is the combined equivalent focal length of Groups V and VI, and

$$1.5 F_0 \geq F_{34} \geq 1.0 F_0$$

where F_{34} is the combined equivalent focal length of Groups III and IV.

The disclosed lens have the following relationships:

LENS	F_1/F_0	F_{56}/F_0	F_{34}/F_0	Focuses To	
Table I	-11.54	3.61	1.26	$6.20F_0$	(7.01")
Table II	4.89	1.57	1.31	$7.12F_0$	(10.15")
Table III	3.19	2.18	1.46	$7.25F_0$	(7.99")

It is possible to focus even closer by moving the overall lens after the movable grouping has reached the end of its travel. This is merely a conjugate shift, which is accomplished after the primary focusing movement.

For example the lens of Table III can be arranged so that after L7-L9 move forward from an object distance of infinity to an object distance 209mm (8.23 EFL) through 3.9mm of forward travel, the entire lens may be moved 1.3mm to focus to an object distance 149.7mm or 5.89 EFL. This may easily be accomplished mechanically by making movement of the overall lens responsive to the moving group reaching the end of its close focusing travel.

The described arrangements provide wide angle lens of the retrofocus type which give excellent image quality while focusing to less than ten EFL's from the front element and capable of focusing within eight EFL's while maintaining a relatively small front vertex distance.

In our co-pending application No. 36800/74 (Serial No. 1,484,321) there is described and claimed 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.

WHAT WE CLAIM IS:—

1. 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.

2. A lens as claimed in claim 1, wherein said first and second groupings are movable toward an object in fixed relation after said predetermined forward movement of said second grouping.

3. A lens as claimed in claim 1 or 2, wherein said second lens grouping is moved for focusing by means within the housing.

4. A lens as claimed in claim 1, 2 or 3 in combination with a camera body, and means on said camera body coupled to said second lens grouping for providing focusing movement thereof.



The absolute value of the EFL (F_o) of the stationary grouping is afocal with respect to the EFL (F_o) of the overall lens. As used herein afocal refers to the EFL of the stationary grouping being at least three times the focal length of the overall lens or

$$|F_s| \geq 3F_o$$

It is preferred that the following relations are maintained:

$$3.7 F_o \geq F_{36} \geq 1.5 F_o$$

where F_o is the EFL of the lens and F_{36} is the combined equivalent focal length of Groups V and VI, and

$$1.5 F_o \geq F_{34} \geq 1.0 F_o$$

where F_{34} is the combined equivalent focal length of Groups III and IV.

The disclosed lens have the following relationships:

LENS	F/F_o	F_{36}/F_o	F_{34}/F_o	Focuses To	
Table I	-11.54	3.61	1.26	$6.20F_o$	(7.01")
Table II	4.89	1.57	1.31	$7.12F_o$	(10.15")
Table III	3.19	2.18	1.46	$7.25F_o$	(7.99")

It is possible to focus even closer by moving the overall lens after the movable grouping has reached the end of its travel. This is merely a conjugate shift, which is accomplished after the primary focusing movement.

For example the lens of Table III can be arranged so that after L7-L9 move forward from an object distance of infinity to an object distance 209mm (8.23 EFL) through 3.9mm of forward travel, the entire lens may be moved 1.3mm to focus to an object distance 149.7mm or 5.89 EFL. This may easily be accomplished mechanically by making movement of the overall lens responsive to the moving group reaching the end of its close focusing travel.

The described arrangements provide wide angle lens of the retrofocus type which give excellent image quality while focusing to less than ten EFL's from the front element and capable of focusing within eight EFL's while maintaining a relatively small front vertex distance.

In our co-pending application No. 36800/74 (Serial No. 1,484,321) there is described and claimed 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.

WHAT WE CLAIM IS:—

1. 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.

2. A lens as claimed in claim 1, wherein said first and second groupings are movable toward an object in fixed relation after said predetermined forward movement of said second grouping.

3. A lens as claimed in claim 1 or 2, wherein said second lens grouping is moved for focusing by means within the housing.

4. A lens as claimed in claim 1, 2 or 3 in combination with a camera body, and means on said camera body coupled to said second lens grouping for providing focusing movement thereof.



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5. A lens as claimed in claim 1 or 2, wherein said first grouping is made up of a single group which comprises a first diverging element and a second converging element.

6. A lens as claimed in claim 5, wherein both of said first and second elements are meniscus.

7. A lens as claimed in claim 1 or 2, wherein said first grouping is arranged in four lens groups, the first and second groups being diverging, the third and fourth converging, and said second grouping comprises a divergent meniscus and a bi-convex doublet.

8. A wide angle lens of the retrofocus type as claimed in claim 1 or 2, wherein said first and second groupings are formed by a plurality of lens groups which are provided in said housing and comprise from the object end to the image end, a first negative group, a second negative group in the form of a meniscus having a convex object 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, said first group is in said first grouping, means for moving said second grouping maintain all groups therein in fixed relation to each other relative to said first grouping while said first grouping remains stationary in said housing to focus said lens to within ten equivalent focal lengths of said lens.

9. A lens as claimed in claim 8, wherein said second grouping is formed by said second, third, fourth, fifth and sixth groups.

10. A lens as claimed in claim 8, wherein said second grouping is formed by said fifth and sixth groups.

11. A lens as claimed in claim 8, wherein

$$1.5 F_o \geq F_{34} \geq 1.0 F_o$$

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

12. A lens as claimed in claim 8, wherein

$$3.7 F_o \geq F_{56} \geq 1.5 F_o$$

where F_{56} is the combined equivalent focal length of the fifth and sixth groups and F_o is the equivalent focal length of the overall lens.

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13. A lens as claimed in claim 8, defined substantially by the following data where the elements L1 and L2 comprise said first grouping:

	Lens	Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d	
5		R1	38.387mm			
	L1	R2	18.755	2.435mm	1.5168	64.2
			8.5083			
10	L2	R3	-119.389	7.167	1.7995	42.3
		R4	-52.877	4.00		
	L3	R5	18.178	2.180	1.5831	59.5
15		R6	12.456	9.369		
	L4	R7	49.0379	2.159	1.8306	36.5
		R8	-123.776	2.581		
20	L5	R9	-22.141	6.000	1.7470	27.5
	L6	R10	-109.562	5.774	1.7620	40.3
25		R11	-21.131	0.135		
	L7	R12	55.725	2.454	1.8467	23.8
		R13	26.386	2.239		
30	L8	R14	76.751	6.000	1.8042	46.5
	L9	R15	-22.374	1.500	1.8052	25.5
35		R16	-54.363			

Where L1—L9 are lens elements from the object to the image end, R1—R16 are radii of the surfaces of the lens elements, N_d is the index of refraction and V_d is the Abbe number of elements L1—L9.



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14. A lens as claimed in claim 8 defined substantially by the following data:

	Lens	Radius (mm)		Axial Distance Between Surfaces (mm)	N_d	V_d	
	L1	R_1	30.600	7.000	1.487	70.4	5
		R_2	170.290				
10	L2	R_3	34.231	2.985	1.487	70.4	10
		R_4	11.567				
15	L3	R_5	67.235	2.000	1.569	56.0	15
		R_6	25.201				
20	L4	R_7	46.077	3.200	1.806	40.7	20
		R_8	-644.608				
25	L5	R_9	-34.424	2.358	1.762	26.6	25
		R_{10}	829.911				
30	L6	R_{11}	-47.763	4.832	1.757	47.7	30
		R_{12}	-19.289				
35	L7	R_{13}	41.514	3.000	1.667	33.1	35
		R_{14}	35.544				
	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	

Where L1—L9 are lens elements from the object to the image end, R_1 — R_{17} are the radii of the surfaces of the lens elements, N_d is the index of refraction and V_d is the Abbe number of elements L1—L9.



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15. A lens as claimed in claim 8, defined substantially by the following data:

	Lens	Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d	
5	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	
10		R_4 11.392	4.474			10
	L3	R_5 28.640	2.000	1.517	64.2	
		R_6 15.990	13.502			15
15	L4	R_7 41.450	3.200	1.689	31.2	
		R_8 840.70	3.342			
20	L5	R_9 -70.750	2.164	1.805	25.5	20
		R_{10} 106.030	1.900			
25	L6	R_{11} -71.649	4.549	1.804	46.5	25
		R_{12} -21.220	4.098 - .10			
	L7	R_{13} 48.140	2.700	1.741	27.8	
30		R_{14} 35.430	1.212			30
	L8	R_{15} 53.960	9.159	1.639	55.5	
		R_{16} -20.430	2.700	1.805	25.5	35
35	L9	R_{17} -44.190				

Where L1—L9 are lens elements from the object to the image end, R_1 — R_{17} are the radii of the surfaces of the lens elements, N_d is the index of refraction and V_d is the Abbe number of elements L1—L9.

16. A wide angle lens of the retrofocus type constructed and arranged substantially as hereinbefore described with reference to and as illustrated in, the accompanying drawings.

MATHYS & SQUIRE,
Chartered Patent Agents,
10 Fleet Street,
London, EC4Y 1AY.
Agents for the Applicants.

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