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IMPROVEMENTS IN OR RELATING TO ZOOM LENSES

Photographic lenses having a zoom ratio of substantially five to one typically suffer from excessive size, weight, and complexity which make these lenses impractical for use in what is commonly referred to as 35mm photography; that is, an image frame of 24 x 36mm.

Many examples of zoom lenses covering a normal to telephoto range are disclosed in the prior art. Most of these are of the mechanically compensated type with two moving groups. A maximum zoom ratio usually attainable in such a lens of reasonably small size is a three to one. However, once the zoom ratio extends over a three to one range, the front vertex distance of the lens as well as the diameter thereof begins to grow very quickly with increased zoom ratio. In the case of most lenses, compromise is achieved between the optical performance of the lens and its physical characteristics.

There have been attempts to provide zoom lenses having a large zoom ratio and a small relative aperture. However, none of them is really a compact lens allowing for convenient handling and operation.

Reducing the overall length of the lens usually requires increasing the power of the zooming and stationary groups in the lens. This consequently leads to increased surface aberrational contributions and adversely affects the performance and manufacturability of the lens. The faster the lens, that is, the lower the relative aperture, the more difficult it is to reduce its size because of increased surface aberrational contributions produced by the large apertures. The optical designer has to be very

careful not to design a lens of theoretically high optical capability which will be impossible to produce economically because of sensitivity to manufacturing variations.

The relative aperture of the lens is commonly designated by the ratio of the equivalent focal length (EFL) of the lens to the diameter of the entrance pupil of this lens. It is well known that if the location of the aperture stop of the lens is allowed to move axially with change of EFL, such construction can help to reduce the size of the front group by altering the location of the entrance pupil of the lens as a function of EFL, and still allow for a reasonably high speed of the lens.

According to the present invention there is provided a zoom lens comprising from the object side a first positive grouping movable axially for focusing; a second negative grouping, said second and third groupings being simultaneously movable axially but in opposite directions to vary the equivalent focal length of said lens, said third grouping comprising object and image side sub-groupings of positive optical power, said image side sub-grouping having a telephoto ratio of 0.75 to 1.4 and the ratio of the equivalent focal length of the object side sub-grouping to that of the image side sub-grouping being from 1.0 to 3.1.

One embodiment of the invention is a new and improved zoom lens design having a large zooming ratio while maintaining a relatively small absolute diameter and a short front vertex distance (FVD). Briefly stated, the lens comprises three lens groupings. The first or front lens grouping is of positive optical power and is used for focusing by limited axial movement

thereof. However, it is not moved axially in the zooming mode. A second movable group of negative power moves toward the image plane as the focal length is varied from the lower value to the upper value. A third group of positive power moves in the direction opposite to the motion of the second group during zooming. The aperture stop is located within this third movable

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group and for simplicity of mechanical construction of the lens may move together with the grouping as a whole. Further, the third grouping can be further divided into two sub-groupings, both the first and second sub-groupings being of positive power. The rear sub-grouping achieves a favorable balance of aberration correction while maintaining minimum size and weight of the lens by having a ratio of front vertex distance (FVD) to equivalent focal length (EFL) between 0.75 and 1.4 and is comprised of three groups, positive, positive, and negative.

The various groups and groupings of the lens also have certain optical relationships as hereinafter pointed out.

Lenses embodying the invention may have zooming ranges of substantially five to one, with semi-field angles of about 26° at the lower EFL ranging to less than 6° in the extreme telephoto position. For 35mm photography, this will provide a lens with a rated EFL range of 40 - 200mm.

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

FIGS. 1a-1b, 2a-2b, 3a-3b, 4a-4b, 5a-5b, 6a-6b, 7a-7b, 8a-8b,

9a-9b and 10a-10b are diagrammatic views of lenses embodying the invention where each lens is shown in different operating position in each pair of figures related by the same numeral.

A lens embodying the invention may be considered to have three major groupings, GPI, GPII, and GPIII. Grouping GPIII will be described as having sub-groupings SGIIIIa and SGIIIIb. Within sub-grouping SGIIIIb will be described a lens comprised of three groups G31, G32, and G33 which are of positive, positive, negative power, successively from the object to image side.

10 All elements of a lens are identified by the reference L followed by successive numerals from the object end to the image end. All radii of the lens elements are from a point on the optical axis A of a lens and are identified by the reference R followed by successive numerals from the first object end lens surface to the last image end lens surface. The radii are positive
15 when struck from the right and negative when struck from the left.

The spacings D1, D2, and D3 in the drawings are the spacings which vary in axial dimension as the lens groupings move during a change in EFL. FP indicates the focal or image plane of the lens.

20 Each lens is shown in its minimum EFL position by a figure number followed by (a), and its maximum EFL position by a figure number followed by (b).

A lens embodying the invention, as shown in FIGS. 1a and 1b, comprises a first grouping GPI of positive power which is movable
25 for focusing, but stationary during zooming and comprises elements L1, L2, and L3; a second negative grouping GPII of negative power which moves toward the image plane as the equivalent focal length of the lens is increased and comprises elements L4, L5, and L6; and a third positive grouping GPIII which moves toward the object as the
30 equivalent focal length is increased, and comprises elements L7-L13.

L1, a bi-concave element, and L2, a bi-convex element form a doublet of overall negative power due to the large index of refraction of L1. L3, a bi-convex element, renders GPI of overall positive power.

5 Elements L4 and L5 are a doublet of overall negative power with L5 bi-concave. Grouping GPII further includes bi-concave element L6.

In the examples and FIGS. 1a and 1b, Grouping GPIII comprises two sub-groupings SGIIIIa and SGIIIIb. Sub-grouping SGIIIIa is of
10 positive power comprising a positive element L7 convex to the object with a large image side radius surface, and a very weak doublet L8, L9. Sub-grouping SGIIIIb comprises a positive group G31 in the form of an element having a convex object side surface and an image side surface of much greater radius; a positive
15 group G32 comprising elements L11 and L12; and a negative group G33 in the form of a negative meniscus L13, concave to the object.

To maintain the compact size and yet to allow for reasonably loose tolerances in manufacturing of this lens, the power of the sub-grouping SGIIIIb should satisfy the following condition:

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$$0.75 < \frac{FVD_{IIIIb}}{f_{IIIIb}} < 1.4$$

Front vertex distance or FVD_{IIIIb} refers to the distance of the first object side surface of the rear sub-grouping SGIIIIb to the focal plane when this sub-grouping alone is focused at infinity.

If the upper limit is increased, the size of the lens becomes
25 too big to allow for a compact, easy-to-handle package. On another hand, when the above-mentioned ratio becomes smaller than the lower limit, then the individual lens elements become very sensitive to manufacturing variations leading to increased difficulties producing the lens.

To achieve a favorable balance of aberrations, the sub-grouping SGIIIb is comprised of three groups G31, G32, and G33 of positive, positive, and negative optical power wherein the last group has meniscus shape concave towards the object.

5 Group G32 generally serves as an aberration corrector and may have a wide range of powers as hereinafter made apparent. Also, the absolute ratio of the power of groups G31 to G33 is of importance, as hereinafter pointed out.

FIGS. 1a and 1b illustrate a lens embodying the invention at its extreme lower and upper equivalent focal lengths respectively. The axial spaces D1, D2, and D3 vary to change the EFL as hereinafter stated.

10 A lens as shown in FIGS. 1a and 1b, which has a zoom range to subtend semi-field angles of 22.8° to 6.3° as scaled to an image frame of 24mm x 36mm, and an EFL of 51.5mm to 195mm is set forth in Table I. BFL is the back focal length.

TABLE I

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction n_d	Abbe No. v_d
L1	R1 = -331.909	2.000	1.847	23.8
L2	R2 = 77.893	8.325	1.531	50.9
L3	R3 = -105.577	0.200	1.741	35.1
L4	R4 = 75.550	5.264	1.847	23.8
L5	R5 = -738.126	1.000 (D1)	1.697	55.5
L6	R6 = -273.757	4.990	1.847	23.8
L7	R7 = -39.174	2.000	1.697	55.5
L8	R8 = 74.538	4.086	1.608	40.0
L9	R9 = -53.121	1.500	1.587	51.7
L10	R10 = 148.879	49.510 (D2)	1.847	23.8
L11	R11 = 46.961	4.902	1.517	69.7
L12	R12 = -929.669	0.200	1.804	46.5
L13	R13 = 726.860	6.485	1.648	33.8
	R14 = -31.445	11.397	1.834	37.3
	R15 = -260.591	10.825 (D3)		
	R16 = 23.960	8.148		
	R17 = 249.885	2.692		
	R18 = 64.858	1.500		
	R19 = 16.770	0.467		
	R20 = 18.004	6.440		
	R21 = -46.653	2.692		
	R22 = -18.862	1.500		
	R23 = -106.740	40.106		
	BFL =			

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In the foregoing Table I, the iris defining the aperture stop is located between elements L6 and L7 and moves with sub-grouping SGIIIIa. Positive radii are struck from the right and negative radii are struck from the left.

The spacings of the groupings at different equivalent focal lengths are given below in Table II.

<u>Spacing</u>	<u>TABLE II</u>			
	<u>EFL</u>			
	51.5mm	85.00mm	135.00mm	195.00mm
D1	1.000mm	15.525mm	25.714mm	31.992mm
D2	49.310mm	31.944mm	15.651mm	2.000mm
D3	10.825mm	5.460mm	2.224mm	.500mm
f/No.	2.88	3.35	3.73	4.12

The relative aperture as exemplified by f/No. varies from 2.9 at the lower EFL to 4.1 at the higher EFL due to the moving aperture stop, while the iris diameter stays fixed.

Thirteen examples of the invention are disclosed, and for purposes of comparison, the organization of the elements are set forth below.

<u>TABLE</u>		<u>TABLE III</u>					
	<u>GP1</u>	<u>GP11</u>	<u>SGIIIIa</u>	<u>SGIIIIb</u>	<u>G31</u>	<u>G32</u>	<u>G33</u>
I	L1-L3	L4-L6	L7-L9	L10-L13	L10	L11, L12	L13
IV & VI	L1-L3	L4-L6	L7-L9	L10-L14	L10	L11, L12	L13, L14
X	L1-L3	L4-L7	L8-L10	L11-L15	L11	L12, L13	L14, L15
VIII	L1-L3	L4-L6	L7, L8	L9-L12	L9	L10, L11	L12
XII & XIV	L1-L3	L4-L6	L7-L9	L10-L14	L10	L11, L12	L13, L14
XVI	L1-L3	L4-L6	L7-L9	L10-L14	L10	L11, L12	L13, L14
XVIII	L1-L3	L4-L6	L7-L9	L10-L13	L10	L11, L12	L13
XX	L1-L3	L4-L6	L7-L9	L10-L14	L10	L11, L12	L13, L14
XXII	L1-L3	L4-L6	L7-L10	L10-L14	L10	L11, L12	L13
XXIV & XXV	L1-L3	L4-L6	L7-L9	L10-L15	L10, L11	L12, L13	L14, L15

Another embodiment of the invention is set forth in FIGS. 2a and 2b. The structural form of the lenses differs in that grouping

GPI has a first bi-convex element L1 followed by a bi-convex doublet L3, L4. Grouping GPII comprises a first bi-concave element L4 followed by a negative doublet L5, L6 with L5 bi-concave. Group G32 comprises a negative meniscus L11 and a spaced bi-convex element L12. Group G33 comprises a bi-concave element L13 and a bi-convex element L14.

The prescriptions of two lenses of this form are set forth in Tables IV and V. In both examples, the lens sub-tends a semi-field angle varying from 22.8° to 6.3° , and is scaled for a 24 x 36mm image frame with an EFL range of 51.5mm to 195.5mm.

TABLE IV
Axial Distance
Between Surfaces
(mm)

Element	Radius of Curvature (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 91.606	6.157	1.517
	R2 = -204.977	0.200	69.7
L2	R3 = 99.209	6.256	1.487
L3	R4 = -121.897	2.000	1.847
	R5 = -1311.231	1.000 (D1)	23.8
L4	R6 = -207.668	1.500	1.713
	R7 = 39.369	4.571	53.9
L5	R8 = -48.686	2.000	1.697
L6	R9 = 39.043	4.988	1.847
	R10 = -564.889	46.831 (D2)	23.8
L7	R11 = 54.481	5.338	1.607
	R12 = -374.746	0.200	56.7
L8	R13 = 77.405	7.895	1.581
L9	R14 = -36.501	1.500	1.847
	R15 = 194.707	9.109 (D3)	23.8
L10	R16 = 26.911	8.076	1.525
	R17 = -1041.865	9.346	60.0
L11	R18 = 52.178	1.838	1.559
	R19 = 21.897	3.425	64.4
L12	R20 = 28.087	5.298	1.627
	R21 = -62.138	2.562	34.6
L13	R22 = -23.600	1.500	1.834
	R23 = 28.021	0.445	37.3
L14	R24 = 28.914	4.385	1.619
	R25 = -118.264		35.4
BFL = 38.539			

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TABLE V

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction n_d	Abbe No. v_d
L1	R1 = 101.687			
	R2 = -198.419	7.471	1.487	70.4
L2	R3 = 95.447	0.200		
	R4 = -139.520	7.353	1.487	70.4
L3	R5 = -5325.160	2.000	1.805	25.5
	R6 = -190.980	2.883 (D1)		
L4	R7 = 48.001	1.500	1.773	49.7
	R8 = -58.215	5.742		
L5	R9 = 42.255	2.000	1.697	55.5
L6	R10 = 2180.742	4.992	1.847	23.8
	R11 = 154.385	50.035 (D2)		
L7	R12 = -536.964	3.104	1.847	23.8
	R13 = 34.221	0.200		
L8	R14 = -42.312	8.851	1.487	70.4
L9	R15 = 124.660	1.500	1.805	25.5
	R16 = 27.114	5.006 (D3)		
L10	R17 = 167.817	5.691	1.581	40.9
	R18 = 35.204	6.077		
L11	R19 = 22.920	1.500	1.847	23.8
	R20 = 36.325	1.620		
L12	R21 = -83.500	6.578	1.541	47.2
	R22 = -18.143	8.928		
L13	R23 = 114.343	1.500	1.834	37.3
	R24 = 278.786	0.617		
L14	R25 = -35.211	3.152	1.847	23.8
	BFL = 38.552			

In Table IV the iris defining the aperture stop is located between elements L6 and L7, and moves with sub-grouping SGIIIa.

The spacings of the groupings at different equivalent focal lengths are given below in Table VI.

TABLE VI

Spacing	EFL			
	51.5mm	85.00mm	135.00mm	195.00mm
D1	1.000mm	13.307mm	22.522mm	27.537mm
D2	46.831mm	30.407mm	14.997mm	2.000mm
D3	9.109mm	4.571mm	2.208mm	.500mm
f/No.	2.9	3.35	3.73	4.1

In Table V, the iris defining the aperture stop is located between elements L10 and L11 and moves with sub-grouping SGIIb.

The spacings of the groupings at different equivalent focal lengths are given below in Table VII.

TABLE VII

Spacing	EFL			
	51.5mm	85.00mm	135.00mm	195.00mm
D1	2.883mm	14.285mm	23.334mm	28.899mm
D2	50.035mm	31.496mm	15.039mm	1.000mm
D3	5.006mm	2.782mm	.994mm	.500mm
f/No.	2.95	3.5	3.7	4.1

Another embodiment of the invention as shown in FIGS. 3a and 3b utilizes only twelve elements L1-L12. This embodiment differs primarily in that sub-groupings SGIIa comprises only a bi-convex doublet L7, L8. Also, the forward components L10, L11 of group G3 are a doublet comprising a forward (object side) bi-convex element L10, and a rear meniscus L11. Grouping GPI again comprises three elements, but here in the form of a convex object side meniscus L1 and a bi-convex element L2 forming a doublet, followed by a positive meniscus L3, convex to the object.

The prescription of this lens is set forth in Table VIII. The lens subtends a semi-field angle of 22.8° to 6.3° , and is scaled for an image plane of 24 x 36mm with an EFL range of 51.5mm to 195mm.

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TABLE VIII

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction n_d	Abbe No. v_d
L1	R1 = 311.481			
L2	R2 = 68.476	2.000	1.847	23.8
	R3 = -108.672	9.718	1.589	62.6
L3	R4 = 50.060	0.200		
	R5 = 84.784	4.222	1.690	31.0
L4	R6 = 508.164	2.822 (D1)		
L5	R7 = -47.257	5.563	1.847	23.8
	R8 = 41.931	2.000	1.696	55.1
L6	R9 = -38.143	5.239		
	R10 = Infinity	1.500	1.711	55.9
L7	R11 = 59.518	47.717 (D2)		
L8	R12 = -30.945	7.648	1.571	51.1
	R13 = -106.827	1.500	1.831	24.2
L9	R14 = 22.295	4.906 (D3)		
	R15 = 85.618	7.351	1.487	70.4
L10	R16 = 54.725	18.021		
L11	R17 = -16.627	5.731	1.631	34.2
	R18 = -68.855	1.500	1.806	40.7
L12	R19 = -19.620	2.363		
	R20 = -53.856	1.500	1.806	40.7
		BFL = 38.547		

In the foregoing Table VIII, the iris defining the aperture stop is located between elements L6 and L7. Positive radii are struck from the right and negative radii are struck from the left.

5 The spacings of the groupings at different equivalent focal lengths are given below in Table IX.

TABLE IX

		EFL			
<u>Spacing</u>		51.5mm	85.00mm	135.00mm	195.00mm
10	D1	2.822mm	12.015mm	25.282mm	29.739mm
	D2	47.717mm	30.486mm	15.603mm	2.000mm
	D3	4.906mm	1.699mm	.788mm	.500mm
	f/No.	2.8	3.3	3.6	4.0

FIGS. 4a and 4b disclose an embodiment of the invention where
 15 the grouping GPI takes the same form as in FIGS. 2a-2b. However, grouping GPII includes a positive meniscus L5 behind the bi-concave element L4. Group G32 of sub-grouping SGIIb comprises a bi-convex doublet L12, L13 followed by bi-concave element L14 and bi-convex element L15 of overall combined negative power.

20 This lens as further set forth in Table X has a lower EFL which is less than the diagonal of the image frame. The lens subtends semi-field angles of 27.8° to 6.3° , and is scaled for a 24 x 36mm image frame, with an EFL range of 41.00mm to 195.00mm.

TABLE X

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 87.088	6.073	1.487	70.4
	R2 = -357.220			
L2	R3 = 81.894	0.200	1.517	69.7
	R4 = -113.558	6.904		
L3	R5 = -741.212	2.000	1.805	25.5
	R6 = -145.203	1.000 (D1)		
L4	R7 = 29.227	2.000	1.850	32.2
	R8 = -40.720	5.027		
L5	R9 = -28.743	3.218	1.617	36.6
	R10 = -34.696	0.329		
L6	R11 = 30.644	2.000	1.620	60.3
	R12 = -836.811	4.602		
L7	R13 = 244.236	47.970 (D2)	1.847	23.8
	R14 = -159.720	3.347		
L8	R15 = 37.449	0.200	1.487	70.4
	R16 = -59.792	7.464		
L9	R17 = 128.574	1.500	1.847	23.8
	R18 = 34.377	14.245 (D3)		
L10	R19 = 125.375	7.312	1.694	53.3
	R20 = 40.777	12.722		
L11	R21 = 17.194	1.500	1.834	37.3
	R22 = -45.367	8.377		
L12	R23 = -23.943	4.500	1.529	51.6
	R24 = 50.260	1.500		
L13	R25 = 56.060	0.724	1.850	32.2
	R26 = -75.126	3.971		
L14		1.847	23.8	
L15				
BFL = 38.556				

In the foregoing Table X, the iris defining the aperture stop is located between elements L7 and L8 and moves with sub-grouping SGIIIa. Positive radii are struck from the right and negative radii are struck from the left.

5 The variable spacings of the groupings at different equivalent focal lengths are given below in Table XI.

TABLE XI

		EFL			
<u>Spacing</u>		41.0mm	85.00mm	135.00mm	195.00mm
10	D1	1.000mm	17.567mm	26.928mm	31.136mm
	D2	47.970mm	26.960mm	13.815mm	2.000mm
	D3	14.245mm	4.978mm	2.626mm	.500mm
	E/No.	2.95	3.5	3.7	4.1

FIGS. 5a and 5b illustrate another lens embodying the invention
15 where GP1 comprises a bi-convex doublet L1, L2 with L1 being a negative meniscus, and L2 is a positive with its shortest radius being convex to the object. Group G32 comprises a negative meniscus L11, and a bi-convex element L12 of overall positive power. Group G33 is a doublet comprising a bi-concave element
20 L13 and a bi-convex element L14 of overall negative power.

Prescriptions of two lenses of this form are set forth in Tables XII and XIII. Both lenses subtend semi-field angles of 22.8° to 6.3°, and are scaled to an image frame of 24 x 36mm, with an EFL range of 51.5mm to 195.0mm.

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TABLE XII

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction n_d	Abbe No. v_d
L1	R1 = 51.685	2.000	1.728	28.7
L2	R2 = 55.419	11.322	1.487	70.4
	R3 = -300.792	0.200		
L3	R4 = 70.392	4.236	1.487	70.4
	R5 = 260.451	2.174 (D1)		
L4	R6 = -218.893	1.500	1.773	49.6
	R7 = 33.369	5.032		
L5	R8 = -50.332	1.500	1.697	55.5
L6	R9 = 29.315	5.544	1.847	23.8
	R10 = 372.944	39.191 (D2)		
L7	R11 = 278.949	3.349	1.785	25.7
	R12 = -112.134	0.200		
L8	R13 = 37.648	8.126	1.487	70.4
L9	R14 = -46.741	1.500	1.728	28.7
	R15 = 130.107	12.937 (D3)		
L10	R16 = 30.554	5.344	1.589	61.3
	R17 = 161.993	9.765		
L11	R18 = 53.104	1.500	1.805	25.5
	R19 = 26.732	0.998		
L12	R20 = 35.956	4.621	1.603	60.7
	R21 = -86.528	10.000		
L13	R22 = -20.688	1.200	1.773	49.6
L14	R23 = 36.746	6.262	1.673	32.2
	R24 = -36.746			
		BFL = 38.550		

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TABLE XIII

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction n_d	Abbe No. V_d
L1	R1 = 100.000	2.000	1.847	23.8
L2	R2 = 61.777	8.540	1.487	70.4
	R3 = -139.015	0.200		
L3	R4 = 57.007	4.333	1.487	70.4
	R5 = 141.831	1.774 (D1)		
L4	R6 = -219.606	1.500	1.773	49.7
	R7 = 42.712	4.608		
L5	R8 = -50.056	2.000	1.697	55.5
L6	R9 = 39.784	4.992	1.847	23.8
	R10 = -1453.300	47.246 (D2)		
L7	R11 = 93.289	3.836	1.805	25.5
	R12 = -218.835	0.200		
L8	R13 = 37.170	7.645	1.487	70.4
L9	R15 = -60.263	1.500	1.847	23.8
	R15 = 74.160	8.989 (D3)		
L10	R16 = 28.233	5.691	1.583	45.7
	R17 = 161.805	8.196		
L11	R18 = 41.946	1.500	1.847	23.8
	R19 = 23.983	1.133		
L12	R20 = 33.166	4.571	1.532	48.8
	R21 = -115.744	11.000		
L13	R22 = -18.977	1.500	1.834	37.3
	R23 = 73.633	0.505		
L14	R24 = 94.636	5.041	1.785	25.7
	R25 = -31.880			
	BFL =	38.550		

In the foregoing Table XII, the iris defining the aperture stop is located between elements L6 and L7. Positive radii are struck from the right and negative radii are struck from the left.

The spacings of the groupings at different equivalent focal lengths are given below in Table XIV.

TABLE XIV

	Spacing	EFL			
		51.5mm	85.00mm	135.00mm	195.00mm
10	D1	2.174mm	12.738mm	18.123mm	22.250mm
	D2	39.191mm	25.950mm	12.813mm	2.000mm
	D3	12.937mm	8.055mm	3.253mm	.500mm
	f/No.	2.95	3.5	3.7	4.1

In the foregoing Table XIII, the iris defining the aperture stop is located between elements L10 and L11 and moves with sub-grouping SGIIIb. Positive radii are struck from the right and negative radii are struck from the left.

The spacings of the groupings at different equivalent focal lengths are given below in Table XV.

TABLE XV

	Spacing	EFL			
		51.5mm	85.00mm	135.00mm	195.00mm
20	D1	1.774mm	12.804mm	23.690mm	28.070mm
	D2	47.246mm	30.473mm	15.272mm	2.000mm
	D3	8.989mm	4.084mm	2.537mm	.500mm
	f/No.	2.95	3.5	3.7	4.1

FIGS. 6a and 6b exemplify another embodiment of the invention which differs from the others primarily in that group G33 is a negative meniscus L14, concave to the object. Group G32 comprises a positive meniscus L11, a negative
5 meniscus L12 fairly strongly concave to the image and a bi-convex positive element L13.

The lens subtends semi-field angles of 22.8° to 6.3° .
A prescription of the lens as scaled to an image frame of
24 x 36mm with an EFL range of 51.5mm to 195.00mm is given in
10 Table XVI.

TABLE XVI

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction n_d	Abbe No. V_d
L1	R1 = 94.324			
	R2 = -225.278	6.157	1.517	69.7
L2	R3 = 107.461	0.200		
L3	R5 = -125.129	6.256	1.487	70.4
	R5 = -998.950	2.000	1.847	23.8
L4	R6 = -175.603	1.000 (D1)		
	R7 = 42.006	1.500	1.713	53.9
L5	R8 = -55.596	4.571		
L6	R9 = 38.480	2.000	1.697	55.5
	R10 = -2603.400	4.988	1.847	23.8
L7	R11 = 57.230	46.933 (D2)		
	R12 = -355.668	5.338	1.607	56.7
L8	R13 = 97.881	0.200		
L9	R15 = -38.031	7.895	1.581	40.9
	R15 = 383.703	1.500	1.847	23.8
L10	R16 = 26.072	10.275 (D3)		
	R17 = 264.855	8.076	1.517	69.7
L11	R18 = 57.188	11.774		
	R19 = 157.667	2.581	1.487	70.4
L12	R20 = 132.141	0.588		
	R21 = 17.553	1.500	1.786	43.9
L13	R22 = 18.852	0.559		
	R23 = -54.308	6.418	1.648	33.8
L14	R24 = -20.096	2.694		
	R25 = -96.886	1.500	1.800	42.3
	BFL =	38.540		

The lens of the foregoing Table XVI has an iris defining an aperture stop between elements L6 and L7 which moves with sub-grouping SGIIla. Positive radii are struck from the right and negative radii are struck from the left.

5 The spacings of the movable elements at different EFL's are given below.

TABLE XVII

		EFL			
Spacing		51.5mm	85.00mm	135.00mm	195.00mm
10	D1	1.000mm	13.937mm	23.707mm	29.111mm
	D2	46.933mm	30.323mm	14.940mm	2.000mm
	D3	10.275mm	5.303mm	2.400mm	.500mm
	f/No.	2.8	3.35	3.73	4.12

FIGS. 7a and 7b show an embodiment of the invention where
 15 grouping GPI includes a doublet comprising negative meniscus L1 and bi-convex element L2, followed by bi-convex element L3. Grouping GPII comprises bi-concave element L4 and a bi-concave doublet L5, L6. Grouping GPIII includes a first sub-grouping SGIIla comprising a positive element L7, and convex-concave
 20 doublet L8, L9; and sub-grouping SGIIlb which comprises a bi-convex element L10, a negative meniscus L11 convex to the object side with a bi-convex element L12, and finally a negative meniscus L13 convex to the image side.

This lens as further set forth in Table XVIII has a lower
 25 EFL of 51.5mm and an upper EFL of 150mm. The exemplified lens subtends semi-field angles of 22.8° to 8.2° as scaled to an image frame of 24 x 36mm.

TABLE XVIII

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 43.818	2.00	1.805	25.5
	R2 = 30.325			
L2	R3 = 660.800	9.03	1.487	70.4
	R4 = 57.757			
L3	R5 = -2198.63	4.58	1.487	70.4
	R6 = -172.476			
L4	R7 = 23.666	2.00(D1)	1.786	43.9
	R8 = -37.599			
L5	R9 = 27.572	1.50	1.487	70.4
	R10 = 215.640			
L6	R11 = 58.063	4.19	1.847	23.8
	R12 = 451.184			
L7	R13 = 40.879	28.88(D2)	1.785	25.7
	R14 = -30.890			
L8	R15 = 179.032	2.76	1.487	70.4
	R16 = 26.196			
L9	R17 = -122.438	.20	1.805	25.3
	R18 = 54.654			
L10	R19 = 17.104	6.43	1.487	70.4
	R20 = 17.908			
L11	R21 = -77.945	1.50	1.834	37.3
	R22 = -17.046			
L12	R23 = -40.228	0.37	1.626	35.5
L13		5.14	1.743	49.2
		5.29		
		1.50		
		38.50(D4)		

In the foregoing Table XVIII the iris defining the aperture is located between elements L6 and L7 and moves with sub-grouping SGIIIa. Positive radii are struck from the right and negative radii are struck from the left.

- 5 The variable spacings of the grouping at different EFL are given below in Table XIX.

TABLE XIX

		EFL			
<u>Spacing</u>		51.5mm	75mm	100mm	145mm
10	D1	2.0mm	10.19mm	12.71mm	16.24mm
	D2	27.88mm	19.27mm	11.31mm	1.00mm
	D3	4.64mm	2.98mm	1.75mm	0.50mm
	D4	38.50mm	40.58mm	47.24mm	55.28mm
	f/No.	3.2	3.3	3.7	4.1

- 15 Another lens having fourteen elements and embodying the invention shown in FIGS. 8a-8b has the same general configuration as shown in FIGS. 5a and 5b with the exception that element L3 is bi-convex. This lens is set forth in Table XX. This lens has a lower EFL less than the diagonal of the image
- 20 plane. This lens subtends semi-field angles of 29.6° to 8.4° . This lens as scaled to EFL's of 38.0mm to 146.0mm for an image frame of 24 x 36mm is defined as follows:

27
TABLE XX

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction n_d	Abbe No. v_d
L1	R1 = 84.075	2.000	1.824	32.4
L2	R2 = 35.070	10.644	1.487	70.4
	R3 = Infinity	0.200		
L3	R4 = 42.216	7.293	1.640	60.2
	R5 = -551.202	1.417 (D1)		
L4	R6 = 3577.318	1.500	1.773	49.6
	R7 = 22.455	4.403		
L5	R8 = -36.651	1.500	1.697	55.5
L6	R9 = 23.130	4.494	1.847	23.8
	R10 = 305.162	27.789 (D2)		
L7	R11 = 182.035	3.349	1.805	25.5
	R12 = -83.526	.200		
L8	R13 = 31.013	6.560	1.487	70.4
L9	R14 = -39.407	1.500	1.789	27.5
	R15 = 83.438	19.239 (D3)		
L10	R16 = 24.898	5.344	1.592	60.5
	R17 = 131.219	4.888		
L11	R18 = 51.764	1.500	1.805	25.5
	R19 = 22.511	1.477		
L12	R20 = 32.129	6.196	1.599	62.1
	R21 = -44.403	6.00		
L13	R22 = -18.935	1.200	1.764	47.9
L14	R23 = 31.004	7.807	1.692	36.9
	R24 = -31.715	BFL = 38.572		

In the foregoing Table XX, the iris defining the aperture stop is located between elements L6 and L7 and moves with sub-grouping SGIIa. Positive radii are struck from the right and negative radii are struck from the left.

- 5 The variable spacings of the grouping at different EFL's are given below in Table XXI.

TABLE XXI

		EFL			
<u>Spacing</u>		38.0mm	70.0mm	110.0mm	146.0mm
10	D1	1.417mm	12.00mm	17.61mm	20.09mm
	D2	28.58mm	16.89mm	8.25mm	2.80mm
	D3	19.24mm	10.30mm	4.49mm	.50mm
	f/No.	2.95	3.32	3.7	4.1

- Another lens embodying the invention shown in FIGS. 9a and 9b has the same overall configuration as shown in FIGS. 7a and 7b. However, the lens as set forth in Table XXII has no relative movement between the sub-groupings of Grouping GPIII during zooming. This lens has elements L1-L13 as more specifically set forth in Table XXII.

- 20 The lens of Table XXII has an EFL range of 51.5mm to 145.0mm as scaled to an image frame of 24 x 36mm with semi-field angles of 22.8° to 8.5° .

TABLE XXII

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 154.274	2.000	1.805	25.5
L2	R2 = 60.625	7.482	1.603	60.7
L3	R3 = -166.752	0.200		
	R4 = 49.425	4.711	1.487	70.4
	R5 = 976.009	2.000 (D1)		
L4	R6 = -111.965	1.500	1.834	37.3
	R7 = 29.937	4.683		
L5	R8 = -40.282	1.500	1.487	70.4
L6	R9 = 34.267	4.190	1.847	23.8
	R10 = -661.409	37.179 (D2)		
L7	R11 = 58.780	3.370	1.785	25.7
	R12 = 588.325	0.200		
L8	R13 = 40.593	6.062	1.518	59.0
L9	R14 = -38.790	1.500	1.805	25.5
	R15 = 60.207	0.200		
L10	R16 = 29.884	4.661	1.603	60.7
	R17 = Infinity	15.024		
L11	R18 = 47.488	1.500	1.834	37.3
	R19 = 17.934	0.309		
L12	R20 = 18.509	5.462	1.632	34.8
	R21 = -62.404	6.267		
L13	R22 = -19.946	1.500	1.834	37.3
	R23 = -58.480			

BFL = 38.590

In the foregoing Table XXII, the iris defining the aperture stop is located between elements L6 and L7, and moves with grouping GPIII. Positive radii are struck from the right and negative radii are struck from the left.

5 The variable spacings of the grouping at different EFL's are given in Table XXIII.

TABLE XXIII

		EFL			
<u>Spacing</u>		51.5mm	65.00mm	80.00mm	145.00mm
10	D1	2.00mm	5.63mm	9.14mm	16.17mm
	D2	37.8mm	29.28mm	21.50mm	2.00mm
	f/No.	3.2	3.48	3.61	4.12

Another embodiment of the invention as shown in FIGS. 10a and 10b utilizes fifteen elements L1-L15. This embodiment differs primarily in that group G31 of sub-grouping SGIIla comprises an additional element in the form of a positive meniscus L11, convex to the object. Groupings GPI and GP2 and sub-grouping SGIIla again each comprise three elements.

The prescriptions of two lenses of this form are set forth in Tables XXIV and XXV. In the example of Table XXIV, the lens sub-tends a semi-field angle varying from 22.7° to 6.4° and is scaled for a 24 x 36mm image frame with an EFL range of 51.53mm to 194.98mm. In the example of Table XXV, the lens sub-tends a semi-field angle varying from 22.8° to 6.4° , and is scaled for a 24 x 36mm image frame with an EFL range of 51.44mm to 194.05mm.

TABLE XXIV

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction n_d	Abbe No. v_d
L1	R1 = 61.614	3.000	1.805	25.5
	R2 = 43.179			
L2	R3 = -262.146	11.800	1.487	70.4
	R4 = 57.758			
L3	R5 = 84.442	3.500	1.487	70.4
	R6 = -1317.271			
L4	R7 = 36.278	1.500	1.804	46.5
	R8 = -44.483			
L5	R9 = 34.734	1.500	1.773	49.6
	R10 = -219.127			
L6	R11 = 234.035	5.000	1.847	23.8
	R12 = -89.453			
L7	R13 = 43.887	3.250 (D2)	1.699	30.1
	R14 = -58.165			
L8	R15 = 117.280	3.350	1.487	70.4
	R16 = 43.796			
L9	R17 = 1423.188	0.200	1.785	26.1
	R18 = 25.838			
L10	R19 = 64.901	5.600	1.487	70.4
	R20 = 27.729			
L11	R21 = 18.696	4.495	1.805	25.5
	R22 = 72.878			
L12	R23 = -31.396	2.000	1.487	70.4
	R24 = -23.175			
L13	R25 = 43.273	8.570	1.804	46.5
	R26 = 46.400			
L14	R27 = -124.368	2.125	1.805	25.5
L15		1.200	1.805	25.5
		0.571	1.805	25.5
		3.900	1.805	25.5

TABLE XXV

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 76.881	3.000	1.805	25.5
	R2 = 48.966			
L2	R3 = -164.561	12.250	1.487	70.4
	R4 = 45.744	0.210		
L3	R5 = 64.414	3.500	1.517	64.2
	R6 = 230.226	30.449 (D1)		
L4	R7 = 32.025	1.500	1.713	53.9
	R8 = -39.590	5.200		
L5	R9 = 36.704	1.500	1.773	49.6
	R10 = -235.177	5.000		
L6	R11 = -166.537	3.750 (D2)	1.847	23.8
	R12 = -72.127	2.800		
L7.	R13 = 46.928	0.200	1.785	26.1
	R14 = -50.494	7.300		
L8	R15 = 526.365	1.500	1.487	70.4
	R16 = 64.334	1.010 (D3)		
L9	R17 = -211.416	4.200	1.785	26.1
	R18 = 29.665	0.200		
L10	R19 = 76.428	5.450	1.487	70.4
	R20 = 26.516	9.370		
L11	R21 = 19.733	2.000	1.847	23.8
	R22 = 64.036	6.680		
L12	R23 = -30.409	5.200	1.487	70.4
	R24 = -25.289	1.280		
L13	R25 = 52.130	1.200	1.804	46.5
	R26 = 62.262	3.230		
L14	R27 = -189.602	4.280	1.805	25.5

(63)

In the foregoing Table XXIV the iris defining the aperture stop is located between elements L6 and L7, and moves with sub-groupings SGIIa. Positive radii are struck from the right and negative radii are struck from the left.

5 The spacings of the groupings at different equivalent focal lengths are given below in Table XXVI.

TABLE XXVI

		EFL			
Spacing		51.53mm	85.07mm	135.12mm	194.98mm
10	D1	32.12mm	27.15mm	15.69mm	2.71mm
	D2	3.25mm	13.17mm	24.65mm	37.62mm
	D3	1.00	6.00mm	12.30mm	22.24mm
	f/No.	2.91	3.40	3.75	4.15

In Table XXV, the iris defining the aperture stop is located between elements L6 and L7 and moves with sub-grouping SGIIa. Positive radii are struck from the right and negative radii are struck from the left.

The spacings of the groupings at different equivalent focal lengths are given below in Table XXVII.

20

TABLE XXVII

		EFL			
Spacing		51.44mm	84.39mm	133.96mm	194.05mm
	D1	30.45mm	25.55mm	15.16mm	2.64mm
	D2	3.75mm	13.95mm	26.33mm	40.44mm
25	D3	1.01mm	7.12mm	13.68mm	22.38mm
	f/No.	<u>2.91</u>	<u>3.40</u>	<u>3.75</u>	<u>4.15</u>

TABLE XXVIII

Table	f_I	f_{II}	f_{IIIa}	f_{IIIb}	fg_{31}	fg_{32}	fg_{33}	Zoom Ratio	$\left \frac{\phi_{G1}}{\phi_{G3}} \right $	Telephoto Ratio	Telephoto Ratio SGIIb
I	1.98	-0.71	1.98	1.83	0.98	1.28	-0.53	3.79	0.54	0.9	0.81
IV	1.80	-0.62	1.96	1.66	0.97	1.02	-0.52	3.79	0.54	0.9	0.85
VIII	1.86	-0.62	2.17	1.53	1.15	1.51	-0.75	3.79	0.65	0.87	0.92
X	2.07	-0.66	2.30	2.10	1.61	1.70	-1.02	4.76	0.63	0.97	0.94
XII	1.47	-0.49	1.63	1.65	1.22	2.13	-1.04	3.79	0.85	0.9	0.93
V	1.90	-0.65	2.13	1.53	1.06	2.13	-0.86	3.79	0.81	0.9	0.9
XIII	1.72	-0.61	1.85	1.69	1.12	3.22	-1.12	3.79	1.00	0.9	0.89
XVI	1.89	-0.65	1.95	1.73	1.07	1.42	-0.62	3.79	0.58	0.9	0.85
XXII	1.62	-0.51	1.76	1.60	1.33	2.03	-1.64	3.84	1.27	1.13	1.01
XVIII	1.26	-0.46	1.11	1.11	-0.86	1.92	-0.79	2.82	0.92	0.99	0.96
XX	1.32	-0.55	3.02	0.99	0.96	1.24	-0.71	2.82	0.74	1.03	1.1
XXIV	1.89	-0.56	1.72	1.59	0.86	1.68	-0.69	3.78	0.80	0.94	0.90
XXV	1.88	-0.58	1.97	1.58	0.96	1.30	-0.69	3.77	0.73	0.99	0.93

34

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TABLE XXIX

TABLE	f_I/FVD	$ f_{II}/FVD $	f_{IIIa}/FVD	f_{IIIb}/FVD
I	0.58	0.21	0.58	0.54
IV	0.53	0.18	0.57	0.49
5 VIII	0.56	0.19	0.66	0.46
X	0.45	0.14	0.50	0.45
XII	0.43	0.14	0.48	0.48
V	0.56	0.19	0.62	0.45
XIII	0.50	0.18	0.54	0.50
10 XVI	0.55	0.19	0.57	0.51
XXII	0.37	0.12	0.41	0.37
XVIII	0.45	0.16	0.40	0.40
XX	0.45	0.19	1.04	0.34
XXIV	0.53	0.16	0.48	0.45
15 XXV	0.50	0.15	0.53	0.42

Tables XXVIII and XXIV show the focal lengths of the various groupings, sub-groupings and groups as follows, as well as other parameters where

- 20 FVD is the front vertex distance related to unity EFL at the lower limit EFL of the lens,
- f_I is the EFL of grouping GPI related to unity EFL at the lower limit EFL of the lens,
- f_{II} is the EFL of grouping GPII related to unity EFL at the lower limit EFL of the lens,
- 25 f_{IIIa} is the EFL of sub-grouping SGIIIa related to unity EFL at the lower limit EFL of the lens,
- f_{IIIb} is the EFL of sub-grouping SGIIIb related to unity EFL at the lower limit EFL of the lens,
- 30 f_{G31} is the EFL of group G31 related to unity EFL

at the lower limit EFL of the lens,
 f_{G32} is the EFL of group G32 related to unity EFL
 at the lower limit EFL of the lens,
 f_{G33} is the EFL of group G33 related to unity EFL
 at the lower limit EFL of the lens,

Telephoto Ratio is the ratio of the front vertex distance of the lens to the upper EFL of the lens,

Zoom Ratio is the ratio of the higher EFL of the lens to the lower EFL,

10 $\left| \frac{\phi_{G1}}{\phi_{G3}} \right|$ is the absolute ratio of the power of group G31 to the power of group G33,

Telephoto Ratio SG_{IIIb} is the ratio of the front vertex distance of sub-grouping SG_{IIIb} to its equivalent focal length.

15 It will be noted that in all cases $\left| \frac{\phi_{G1}}{\phi_{G3}} \right|$ is substantially equal to or greater than .5. Otherwise stated,

$$\frac{\phi_{G1}}{\phi_{G3}} \geq .5$$

In all examples given, it has been found that the object side surface of G33 should be concave to introduce the proper
 20 aberration corrections. If the foregoing ratio decreases below the expressed value, the aberration contribution of the object side surface of group G33 may become unacceptably large.

Usually $\left| \frac{\phi_{G1}}{\phi_{G3}} \right|$ will be less than 1.45.

All lens examples will focus to a magnification of 1:4 at
 25 the longest focal length by virtue of the structure of the overall lens and the front focusing grouping GP1. The smaller the value of f_1 the shorter the travel of grouping GP1 to focus at close objects. As shown by the examples, the following relation is preferred to achieve this result.

30 $2.5f_I > f_{IIIa} \geq .9 f_I$

where f_{IIIa} and f_I are as previously defined.

Also for proper aberration correction, the EFL f_{IIIa} of sub-grouping SGIIIa should be substantially the same as or greater than the EFL f_{IIIb} of sub-grouping SGIIIb or

$$3.2 f_{IIIb} > f_{IIIa} \gtrsim f_{IIIb}$$

This relationship further permits the lens to close focus to magnifications of 1:4 with relatively small axial movement of grouping GPI. For example, the lens of Table XII may focus this close with only 7.05mm of axial extension.

With reference to Table XXIX the following relations are obtained:

$$.3 \leq f_I/FVD \leq .6$$

$$.10 \leq |f_{II}/FVD| \leq .25$$

$$.3 \leq f_{IIIa}/FVD \leq 1.2$$

$$.3 \leq f_{IIIb}/FVD \leq .6$$

where f_I , f_{II} , f_{IIIa} , f_{IIIb} , and FVD are as previously defined.

As shown by the various examples, various lens forms may be made within the scope of the invention. Accordingly, the appended claims are intended to cover all modifications of the disclosed embodiments as well as other embodiments thereof which do not depart from the spirit and scope of the invention.

CLAIMS:

1. A zoom lens comprising from the object side a first positive grouping movable axially for focusing, a second negative grouping and a third positive grouping, said second and third groupings being simultaneously movable axially but in opposite directions to vary the equivalent focal length of said lens, said third grouping comprising object and image side sub-groupings of positive optical power, said image side sub-grouping having a telephoto ratio of 0.75 to 1.4 and the ratio of the equivalent focal length of the object side sub-grouping to that of the image side sub-grouping being from 1.0 to 3.1.
2. A lens as claimed in claim 1 where said image side sub-grouping comprises three groups which from the object side are of positive, positive, and negative optical powers successively.
3. A lens as claimed in claim 2, wherein said sub-groupings move at different rates as the equivalent focal length of said lens is varied.
4. A lens as claimed in claim 2 or 3, wherein the optical power of said first group of said sub-grouping has an absolute ratio to the optical power of said third group of said sub-grouping of .5 or greater.



5. A lens as claimed in claim 4, wherein said ratio has an upper limit of 1.45.

6. A lens as claimed in any one of claims 2 to 5, wherein the object side surface of said third group is concave.

5 7. A lens as claimed in any one of claims 2 to 6, wherein said third grouping has a first sub-grouping on the object side with equivalent focal length f_{IIIa} and

$$\frac{f_{IIIa}}{f_I} \geq .9$$

where f_I is the equivalent focal length of the first grouping.

10 8. A lens as claimed in any one of claims 2 to 7, wherein

$$2.5 > \frac{f_{IIIa}}{f_I} \geq .9$$

9. A lens as claimed in claim 2, wherein

$$3.2 \quad f_{IIIB} > f_{IIIa} \geq f_{IIIB}$$

15 where f_{IIIa} is the equivalent focal length of the first sub-grouping and f_{IIIB} is the equivalent focal length of the second sub-grouping.

10. A lens as claimed in any one of the preceding claims, wherein said first grouping comprises an object side doublet which is a negative meniscus and a bi-convex element, followed
20 by a positive meniscus.

11. A lens as claimed in any one of the preceding claims, wherein the front grouping is a doublet comprising a bi-concave element and a bi-convex element, followed by a bi-convex element.

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- 12. A lens as claimed in any one of the preceding claims,
wherein the doublet is of negative optical power.
- 13. A lens as claimed in any one of the preceding claims,
wherein said third grouping has a first object side sub-
5 grouping of positive power and said sub-grouping comprises from
the object side a positive element and a doublet comprising a
bi-concave element and a bi-convex element.
- 14. A lens as claimed in any one of the preceding claims,
wherein the second grouping has a first object side group
10 comprising a negative element, and a doublet concave to the
object side and convex to the image side.
- 15. A lens as claimed in any one of the preceding claims,
wherein the second grouping is, from the object side, a
doublet comprising a bi-convex element and a bi-concave element
15 followed by a negative element having a concave object side
surface.
- 16. A lens as claimed in any one of the preceding claims,
wherein the second grouping comprises from the object side a
negative optical power element, a positive meniscus element
20 concave to the object side, and a doublet concave to the
object side and convex to the image side.
- 17. A lens as claimed in any one of the preceding claims,
wherein said first sub-grouping comprises a doublet having a
bi-convex element and a negative element.
- 25 18. A lens as claimed in any one of the preceding claims,



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wherein said first sub-grouping is a doublet in the form of a negative meniscus and a bi-convex element, from the object side.

5 19. A lens as claimed in any one of the preceding claims, wherein said first sub-grouping comprises a positive single element and a weak optical power doublet which includes a bi-convex element.

20. A lens as claimed in claim 1, where said sub-groupings move at different rates as the equivalent focal length of the 10 lens is changed.

21. A lens as claimed in claim 1, wherein the telephoto ratio of said image side sub-grouping is less than 1.

22. The lens of claim 1 wherein:

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$$\begin{array}{rclclcl} .3 & \leq & fI/FVD & \leq & .6 \\ .10 & \leq & |fII/FVD| & \leq & .25 \\ .3 & \leq & fIIIa/FVD & \leq & 1.2 \\ .3 & \leq & fIIb/FVD & \leq & .6 \end{array}$$

20 Where fI is the effective focal length of said first grouping, fII is the equivalent focal length of said second grouping, fIIIa is the equivalent focal length of said object side sub-grouping, fIIb is the equivalent focal length of said image side sub-grouping, and FVD is the front vertex distance of the lens.



23. A lens according to claim 1 having semi-field angles of 22.8° to 6.3° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = -331.909	2.000	1.847	23.8
	R2 = 77.893			
L2	R3 = -105.577	8.325	1.531	50.9
	R4 = 75.550			
L3	R5 = -738.126	5.264	1.741	55.1
	R6 = -273.757			
L4	R7 = -39.174	4.990	1.847	23.8
	R8 = 74.538			
L5	R9 = -53.121	4.086	1.697	55.5
	R10 = 148.879			
L6	R11 = 46.961	49.510	1.697	55.5
	R12 = -929.669			
L7	R13 = 726.860	4.902	1.608	40.0
	R14 = -31.445			
L8	R15 = -260.591	6.485	1.587	51.7
	R16 = 23.960			
L9	R17 = 249.885	10.825	1.847	23.8
	R18 = 64.858			
L10	R19 = 16.770	8.148	1.517	69.7
	R20 = 18.004			
L11	R21 = -46.653	11.397	1.804	46.5
	R22 = -18.862			
L12	R23 = -106.740	0.467	1.648	33.8
L13		6.440	1.648	33.8
L13		2.692	1.834	37.3
L13		1.500	1.834	37.3

Where L1-L13 are lens elements from the object end to the image end successively. R1-R23 are the radii of the element surfaces successively from the object to image end. N_d is the index of refraction of the elements, and V_d is the dispersion of the elements as measured by the Abbe number.



24. A lens according to claim 1 having semi-field angles of 22.8° to 6.3° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 91.606	6.157	1.517	69.7
	R2 = -204.977	0.200		
L2	R3 = 99.209	6.256	1.487	70.4
	R4 = -121.897	2.000	1.847	23.8
L3	R5 = -1311.231	1.000		
	R6 = -207.668	1.500	1.713	53.9
L4	R7 = 39.369	4.571		
	R8 = -48.686	2.000	1.697	55.5
L5	R9 = 39.043	4.988	1.847	23.8
	R10 = -564.889	46.831		
L6	R11 = 54.481	5.338	1.607	56.7
	R12 = -374.746	0.200		
L7	R13 = 77.405	7.895	1.581	40.9
	R14 = -36.501	1.500	1.847	23.8
L8	R15 = 194.707	9.109		
	R16 = 26.911	8.076	1.525	60.0
L9	R17 = -1041.865	9.346		
	R18 = 52.178	1.838	1.559	64.4
L10	R19 = 21.897	3.425		
	R20 = 28.087	5.298	1.627	34.6
L11	R21 = -62.138	2.562		
	R22 = -23.600	1.500	1.854	37.3
L12	R23 = 28.021	0.445		
	R24 = 28.914	4.385	1.619	35.4
L13	R25 = -118.264			

Where L1-L14 are lens elements from the object end to the image end successively. R1-R25 are the radii of the element surfaces successively from the object to image end. N_d is the index of refraction of the elements, and V_d is the dispersion of the elements as measured by the Abbe number.



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25. A lens according to claim 1 having semi-field angles of 22.8° to 6.3° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 311.481	2.000	1.847	23.8
	R2 = 68.476			
L2	R3 = -108.672	9.718	1.589	62.6
	R4 = 50.060			
L3	R5 = 84.784	0.200	1.690	31.0
	R6 = 508.164			
L4	R7 = -47.257	4.222	1.847	23.8
	R8 = 41.931			
L5	R9 = -38.143	2.822	1.696	55.1
	R10 = Infinity			
L6	R11 = 59.518	47.717	1.711	53.9
	R12 = -30.945			
L7	R13 = -106.827	7.648	1.571	51.1
	R14 = 22.295			
L8	R15 = 85.618	1.500	1.831	24.2
	R16 = 54.725			
L9	R17 = -16.627	4.906	1.487	70.4
	R18 = -68.855			
L10	R19 = -19.620	7.351	1.631	34.2
	R20 = -53.856			
L11		18.021	1.806	40.7
L12		5.731	1.806	40.7

Where L1-L12 are lens elements from the object end to the image end successively. R1-R20 are the radii of the element surfaces successively from the object to image end. N_d is the index of refraction of the elements, and V_d is the dispersion of the elements as measured by the Abbe number.

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26. A lens according to claim 1 having semi-field angles of 27.8° to 6.3° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 87.088	6.073	1.487	70.4
	R2 = -357.220			
L2	R3 = 81.894	0.200	1.517	69.7
	R4 = -113.558	6.904		
L3	R5 = -741.212	2.000	1.805	25.5
	R6 = -145.203	1.000		
L4	R7 = 29.227	2.000	1.850	32.2
	R8 = -40.720	5.027		
L5	R9 = -28.743	3.218	1.617	36.6
	R10 = -34.696	0.329		
L6	R11 = 30.644	2.000	1.620	60.3
	R12 = -836.811	4.602		
L7	R13 = 244.236	47.970	1.847	23.8
	R14 = -159.720	3.347		
L8	R15 = 37.449	0.200	1.847	23.8
	R16 = -59.792	7.464		
L9	R17 = 128.574	1.500	1.847	23.8
	R18 = 34.377	14.245		
L10	R19 = 125.375	7.312	1.694	53.3
	R20 = 40.777	12.722		
L11	R21 = 17.194	1.500	1.834	37.3
	R22 = -45.367	8.377		
L12	R23 = -23.943	4.500	1.529	51.6
	R24 = 50.260	1.500		
L13	R25 = 56.060	0.724	1.850	32.2
	R26 = -75.126	3.971		
L14			1.847	23.8

Where L1-L15 are lens elements from the object end to the image end successively. R1-R26 are the radii of the element surfaces successively from the object to image end. N_d is the index of refraction of the elements, and V_d is the dispersion of the elements as measured by the Abbe number.



27. A lens according to claim 1 having semi-field angles of 22.8° to 6.3° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 51.685	2.000	1.728	28.7
	R2 = 35.419			
L2	R3 = -300.792	11.322	1.487	70.4
	R4 = 70.392	0.200		
L3	R5 = 260.451	4.236	1.487	70.4
	R6 = -218.893	2.174		
L4	R7 = 33.369	1.500	1.773	49.6
	R8 = -50.332	5.032		
L5	R9 = 29.315	1.500	1.697	55.5
	R10 = 372.944	5.544	1.847	23.8
L6	R11 = 278.949	39.191		
	R12 = -112.134	3.349	1.785	25.7
L7	R13 = 37.648	0.200		
	R14 = -46.741	8.126	1.487	70.4
L8	R15 = 130.107	1.500	1.728	28.7
	R16 = 30.554	12.937		
L9	R17 = 161.993	5.344	1.589	61.3
	R18 = 53.104	9.765		
L10	R19 = 26.732	1.500	1.805	25.5
	R20 = 35.956	0.998		
L11	R21 = -86.528	4.621	1.603	60.7
	R22 = -20.688	10.000		
L12	R23 = 36.746	1.200	1.773	49.6
	R24 = -36.746	6.262	1.673	32.2

Where L1-L14 are lens elements from the object end to the image end successively. R1-R24 are the radii of the element surfaces successively from the object to image end. N_d is the index of refraction of the elements, and V_d is the dispersion of the elements as measured by the Abbe number.



28. A lens according to claim 1 having semi-field angles of 22.8° to 6.3° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
1	R1 = 101.637	7.471	1.487	70.4
	R2 = -198.419			
	R3 = 95.447	0.200		
2	R4 = -139.520	7.353	1.487	70.4
	R5 = -5325.160	2.000	1.805	25.5
3	R6 = -190.880	2.883	1.773	49.7
	R7 = 48.001	1.500		
	R8 = -58.215	5.742		
4	R9 = 42.255	2.000	1.697	55.5
	R10 = 2180.742	4.992	1.847	23.8
5	R11 = 154.385	50.035	1.847	23.8
	R12 = -536.964	3.104		
	R13 = 34.221	0.200		
6	R14 = -42.312	8.851	1.487	70.4
	R15 = 124.660	1.500	1.805	25.5
7	R16 = 27.114	5.006	1.581	40.0
	R17 = 167.817	5.691		
	R18 = 35.204	6.077		
8	R19 = 22.920	1.500	1.847	23.8
	R20 = 36.325	1.620	1.541	47.2
9	R21 = -83.500	6.578		
	R22 = -18.143	8.928	1.834	37.3
10	R23 = 114.343	1.500		
	R24 = 278.786	0.617	1.847	23.8
11	R25 = -35.211	3.152		

Where L1-L14 are lens elements from the object end to the image end successively. R1-R25 are the radii of the element surfaces successively from the object to image end. N_d is the index of refraction of the elements, and V_d is the dispersion of the elements as measured by the Abbe number.





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29. A lens according to claim 1 having semi-field angles of 22.8° to 6.3° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 100.000	2.000	1.847	23.8
L2	R2 = 61.777	8.540	1.487	70.4
	R3 = -139.015	0.200		
L3	R4 = 57.007	4.333	1.487	70.4
	R5 = 141.831	1.774		
L4	R6 = -219.606	1.500	1.773	49.7
	R7 = 42.712	4.608		
L5	R8 = -50.056	2.000	1.697	55.5
L6	R9 = 39.784	4.992	1.847	23.8
	R10 = -1453.300	47.246		
L7	R11 = 93.289	3.836	1.805	25.5
	R12 = -218.835	0.200		
L8	R13 = 37.170	7.645	1.487	70.4
L9	R15 = -60.263	1.500	1.847	23.8
	R15 = 74.160	8.989		
L10	R16 = 28.233	5.691	1.583	45.7
	R17 = 161.805	8.196		
L11	R18 = 41.946	1.500	1.847	23.8
	R19 = 23.983	1.133		
L12	R20 = 33.166	4.571	1.532	48.8
	R21 = -115.744	11.000		
L13	R22 = -18.977	1.500	1.834	37.3
	R23 = 73.633	0.505		
L14	R24 = 94.636	5.041	1.785	25.7
	R25 = -31.880			

Where L1-L14 are lens elements from the object end to the image end successively. R1-R25 are the radii of the element surfaces successively from the object to image end. N_d is the index of refraction of the elements, and V_d is the dispersion of the elements as measured by the Abbe number.

30. A lens according to claim 1 having semi-field angles of 22.8° to 6.3° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 94.324			
	R2 = -225.278	6.157	1.517	69.7
L2	R3 = 107.461	0.200		
	R5 = -125.129	6.256	1.487	70.4
L3	R5 = -998.950	2.000	1.847	23.8
	R6 = -175.603	1.000		
L4	R7 = 42.006	1.500	1.713	53.9
	R8 = -55.596	4.571		
L5	R9 = 38.480	2.000	1.697	55.5
	R10 = -2603.400	4.988	1.847	23.8
L7	R11 = 57.230	46.933		
	R12 = -355.668	5.338	1.607	56.7
L8	R13 = 97.881	0.200		
	R15 = -38.031	7.895	1.581	40.9
L9	R15 = 383.703	1.500	1.847	23.8
	R16 = 26.072	10.275		
L10	R17 = 264.855	8.076	1.517	69.7
	R18 = 57.188	11.774		
L11	R19 = 157.667	2.581	1.487	70.4
	R20 = 132.141	0.588		
L12	R21 = 17.553	1.500	1.786	43.9
	R22 = 18.852	0.559		
L13	R23 = -54.308	6.418	1.648	33.8
	R24 = -20.096	2.694		
L14	R25 = -96.886	1.500	1.800	42.3

Where L1-L14 are lens elements from the object end to the image end successively. R1-R25 are the radii of the element surfaces successively from the object to image end. N_d is the index of refraction of the elements, and V_d is the dispersion of the elements as measured by the Abbe number.



31. A lens according to claim 1 having semi-field angles 22.8° to 8.2° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 43.818	2.00	1.805	25.5
	R2 = 30.325			
L2	R3 = 660.800	9.03	1.487	70.4
	R4 = 57.757			
L3	R5 = -2198.63	4.58	1.487	70.4
	R6 = -172.476			
L4	R7 = 23.666	1.50	1.786	43.9
	R8 = -37.599			
L5	R9 = 27.572	1.50	1.487	70.4
	R10 = 215.640			
L6	R11 = 58.063	4.19	1.847	23.8
	R12 = 451.184			
L7	R13 = 40.879	.88	1.785	25.7
	R14 = -30.890			
L8	R15 = 179.032	2.76	1.785	25.7
	R16 = 26.196			
L9	R17 = -122.438	.20	1.785	25.7
	R18 = 54.654			
L10	R19 = 17.104	6.43	1.487	70.4
	R20 = 17.908			
L11	R21 = -77.945	1.50	1.805	25.3
	R22 = -17.046			
L12	R23 = -40.228	4.64	1.487	70.4
L13		5.72	1.487	70.4
		11.13	1.834	37.3
		0.37	1.626	35.5
		5.14	1.626	35.5
		5.29	1.626	35.5
		1.50	1.743	49.2

Where L1-L13 are lens elements from the object end to the image end successively. R1-R23 are the radii of the element surfaces successively from the object to image end. N_d is the index of refraction of the elements, and V_d is the dispersion of the element as measured by the Abbe number.



32. A lens according to claim 1 having semi-field angles of 29.6° to 8.4° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 84.075	2.000	1.824	32.4
	R2 = 35.070			
L2	R3 = Infinity	10.644	1.487	70.4
	R4 = 42.216	0.200		
L3	R5 = -551.202	7.293	1.640	60.2
	R6 = 3577.318	1.417		
L4	R7 = 22.455	1.500	1.773	49.6
	R8 = -36.651	4.403		
L5	R9 = 23.130	1.500	1.697	55.5
	R10 = 305.162	4.494		
L6	R11 = 182.035	27.789	1.847	23.8
	R12 = -83.526	3.349		
L7	R13 = 31.013	.200	1.805	25.5
	R14 = -39.407	6.560		
L8	R15 = 83.438	1.500	1.487	70.4
	R16 = 24.898	19.239		
L9	R17 = 131.219	5.344	1.789	27.5
	R18 = 51.764	4.888		
L10	R19 = 22.511	1.500	1.592	60.5
	R20 = 32.129	1.477		
L11	R21 = -44.403	6.196	1.599	62.1
	R22 = -18.935	6.00		
L12	R23 = 31.004	1.200	1.764	47.9
	R24 = -31.715	7.807		
L13			1.692	36.9

Where L1-L14 are lens elements from the object end to the image end successively. R1-R24 are the radii of the element surfaces successively from the object to image end. N_d is the index of refraction of the elements, and V_d is the dispersion of the elements as measured by the Abbe number.



33 A lens according to claim 1 having semi-field angles of 22.8° to 8.5° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe No. V_d
L1	R1 = 154.274	2.000	1.805	25.5
	R2 = 60.625	7.482	1.603	60.7
L2	R3 = -166.752	0.200		
	R4 = 49.425	4.711	1.487	70.4
L3	R5 = 976.009	2.000		
	R6 = -111.965	1.500	1.834	37.3
L4	R7 = 29.937	4.683		
	R8 = -40.282	1.500	1.487	70.4
L5	R9 = 34.267	4.190	1.847	23.8
	R10 = -661.409	37.179		
L7	R11 = 58.780	3.370	1.785	25.7
	R12 = 588.325	0.200		
L8	R13 = 40.593	6.062	1.518	59.0
	R14 = -38.790	1.500	1.805	25.5
L9	R15 = 60.207	0.200		
	R16 = 29.884	4.661	1.603	60.7
L10	R17 = Infinity	15.024		
	R18 = 47.488	1.500	1.834	37.3
L11	R19 = 17.934	0.309		
	R20 = 18.509	5.462	1.632	34.8
L12	R21 = -62.404	6.267		
	R22 = -19.946	1.500	1.834	37.3
L13	R23 = -58.480			

Where L1-L13 are lens elements from the object end to the image end successively. R1-R23 are the radii of the element surfaces successively from the object to image end. N_d is the index of refraction of the elements; and V_d is the dispersion of the elements as measured by the Abbe number.



34. A lens according to claim 1 having semi-field angles of 22.7° to 6.4° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction n_d	Abbe V_d
L1	R1 = 61.614	3.000	1.805	25.5
	R2 = 43.179			
L2	R3 = -262.146	11.800	1.487	70.4
	R4 = 57.758			
L3	R5 = 84.442	0.200	1.487	70.4
	R6 = -1317.271			
L4	R7 = 36.278	32.117	1.804	46.5
	R8 = -44.483			
L5	R9 = 34.734	1.500	1.773	49.6
	R10 = -219.127			
L6	R11 = 234.035	5.000	1.847	23.8
	R12 = -89.453			
L7	R13 = 43.887	3.250	1.699	30.1
	R14 = -58.165			
L8	R15 = 117.280	3.350	1.487	70.4
	R16 = 43.796			
L9	R17 = 1423.188	1.500	1.785	26.1
	R18 = 25.838			
L10	R19 = 64.901	1.000	1.487	70.4
	R20 = 27.729			
L11	R21 = 18.696	4.495	1.805	25.5
	R22 = 72.878			
L12	R23 = -31.396	8.570	1.487	70.4
	R24 = -23.175			
L13	R25 = 43.273	4.900	1.804	46.5
	R26 = 46.400			
L14	R27 = -124.368	1.200	1.805	25.5
L15		0.571		
L16		3.900		

Where L1-L15 are lens elements from the object end to the image end successively. R1-R27 are the radii of the element surfaces successively from the object to image end. n_d is the index of refraction of the elements, and V_d is the dispersion of the elements as measured by the Abbe number.





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35. A lens according to claim 1 having semi-field angles of 22.8° to 6.4° as scaled to a 24 x 36mm image frame defined substantially as follows:

Element	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Index of Refraction N_d	Abbe N_v
L1	R1 = 76.881	3.000	1.805	25.5
	R2 = 48.966			
L2	R3 = -164.561	12.250	1.487	70.4
	R4 = 45.744			
L3	R5 = 64.414	3.500	1.517	64.2
	R6 = 230.226			
L4	R7 = 32.025	1.500	1.713	53.9
	R8 = -39.590			
L5	R9 = 36.704	5.200	1.773	49.6
	R10 = -235.177			
L6	R11 = -166.537	3.750	1.847	23.8
	R12 = -72.127			
L7	R13 = 46.928	2.800	1.785	26.1
	R14 = -50.494			
L8	R15 = 526.365	0.200	1.487	70.4
	R16 = 64.334			
L9	R17 = -211.416	4.200	1.487	70.4
	R18 = 29.665			
L10	R19 = 76.428	5.450	1.487	70.4
	R20 = 26.516			
L11	R21 = 19.733	9.370	1.487	70.4
	R22 = 64.036			
L12	R23 = -30.409	2.000	1.847	23.8
	R24 = -25.289			
L13	R25 = 52.130	6.680	1.487	70.4
	R26 = 62.262			
L14	R27 = -189.602	5.200	1.487	70.4
L15		1.280	1.804	46.5
		3.230	1.805	25.5
		4.280	1.805	25.5

Where L1-L15 are lens elements from the object end to the image end successively. R1-R27 are the radii of the element surfaces successively from the object to image end. N_d is the index of refraction of the elements, and V_d is the dispersion of the elements as measured by the Abbe number.

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36. A zoom lens constructed, arranged and adapted to operate substantially as hereinbefore described with reference to, and as illustrated in, the accompanying drawings.

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