

SPECIFICATION

Improvements in zoom lenses

5 This invention relates to zoom lenses.

In recent years, zoom lenses which have lower EFL's in the wide angle range have been developed which have focal length variations of about 3:1 or less, and a field of view in excess of 70 degrees. However, known lens often have excessive spherical aberration at the long focal length position as the zoom range is extended. Thus, the field of view of such lenses is restricted on the longer field length of the range to an angle which is greater than 20 degrees. While these known design types can be modified to cover greater focal length ranges, the resulting designs for well corrected lenses are undesirably large in diameter and in length.

A wide angle lens may be defined as one whose EFL is shorter than the diagonal of the image frame of the lens. When designing a very wide angle to long focus zoom lens, difficulty resides in obtaining sufficient optical power of the individual lens groups to achieve a reasonably small overall length and diameter. If the optical powers of the lens groups are allowed to be small, then the dimensions of the lens necessarily becomes large, but the aberration corrections are not difficult to correct. However, if the optical power of the lens groups become strong, the aberrations become correspondingly more difficult to correct.

According to the present invention there is provided a zoom lens having equivalent focal lengths ranging from a dimension below the diagonal of the image frame of the lens to a dimension at least twice the diagonal of the image frame, comprising from the object end a first positive group, a second negative group and a third positive group, at least two of said groups being axially movable to vary the equivalent focal length of said lens, said second negative group having an absolute optical power greater than said first and third groups, said second group having object side elements of negative power and image side elements of positive power, where:

$$.40 > \frac{K_{22}}{K_{21}} > .20$$

and where K_{21} is the absolute sum of the powers of the negative elements of the second group, and K_{22} is the optical power of the positive component of the second group.

According to the invention there is also provided a zoom lens comprising from the object end a first positive group, a second negative group and a third positive group, at least two of said groups being relatively axially movable to vary the equivalent focal length of the lens, said second group having an absolute optical power greater than said first and third groups, and

$$.40K_M < K_1 < 1.0K_M$$

$$2.0K_M < K_2 < 4.8K_M$$

$$.60K_M < K_3 < 1.5K_M$$

where:

K_M is the geometric mean of the optical powers of said lens at the extremes of its equivalent focal lengths, and

K_1 , K_2 and K_3 are the optical powers of the first, second, and third groups, respectively.

One lens embodying the present invention is a compact zoom objective lens with aberrations well corrected, and capable of angular coverage from a field wider than 70 degrees, while providing a large zoom ratio. The lens subtends a field angle well below the diagonal of its image frame to a field substantially two to three times the diagonal of the image frame. The lens has a short front vortex distance FVD in relation to focal length, and a focal length range as great as 5:1, with an angular coverage field in excess of 70 degrees at its lower equivalent focal length (EFL). The optical power of the second group is considerably larger than previously known zoom lenses, and the overall form of the lens is designed to obtain the necessary aberration corrections. This embodiment comprises either three or four basic groups. The aperture defining diaphragm is located near the middle of the lens assembly so as to enable the lens to be of minimum size. In the four-group system, a first positive group moves axially for focusing and the other three groups move for zooming. The diaphragm may move with the movable components, may be fixed causing the relative aperture to vary, or the opening of the diaphragm may be varied with EFL to maintain a constant relative aperture. In the four-group embodiment, the second group is of negative optical power and the third and fourth groups are of positive power. The first focusing group is of a given positive power. This first group has sufficient power to reduce the diameter of the axial beam presented to the strong negative second group, but must have better aberration correction than would be provided by simpler forms. Hence, the second component group includes a rear positive doublet. Since the negative power of the second group is relatively large, some aberrations remain which vary as the focal length is adjusted. The third group is selected to reduce these aberrations and a fourth group may be added to form the final image and contribute to correction of aberrations. Alternatively, the fourth group may not be used in which case the third group is

designed to finally correct aberrations and aid in maintaining the image of the focal plane.

Preferred forms of zoom lenses, with a focal length varying from a relatively wide field through "normal" to a long focus field, are designed to result in a relatively small overall length and a small diameter front element. These elements enable a more compact configuration than would be expected for a lens having the same zoom ratio, the degree of optical corrections, and the large field of view. Generally, it is difficult to provide a lens with an EFL ranging from a wide angle field to an extended zoom range while maintaining compactness and cost effectiveness. However, lenses embodying the invention accomplish such features.

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

Figures 1, 2, 3, 4 and 5 are side illustrations of lenses embodying the invention with the optical groups thereof positioned for the shorter EFL of the lens; and

Figures 1a, 2a, 3a, 4a, and 5a are side elevations of the lenses of Figures 1-5, respectively, with the optical groups positioned for the longer EFL of the lens.

Referring to Figures 1 and 1a, a compact variable focal length or zoom lens of four groups is shown. The embodiment of Figures 1 and 1a represents a lens of approximately 5:1 zoom ratio. In these lenses, primarily intended for use on a camera of the 35mm format, the angular coverage extends from a wide angle through "normal" to moderate telephoto.

In the drawings, the reference L followed by an arabic numeral designates lens progressively from the object end to the image end of the lens. The reference S followed by an arabic numeral designates lens surfaces progressively from the object to the image end of the lens. The various lens groups are designated by the reference G followed by an arabic numeral progressively from the object to image end of the lens. The axial spaces which vary with change in EFL are designated by the reference Z. The reference D represents the aperture defining mechanism, and FP indicates the film or focal plane. In the following description, the various groups G include the elements L as shown in Table 1.

TABLE I

	G1	G2	G3	GR
TABLE II	L1,L2,L3	L4-L7	L8,L9	L10-L15
TABLE IV	L1,L2,L3	L4-L7	L8,L9	L14-L15
TABLE VI	L1,L2,L3	L4-L7	L8,L9	L10-L13
TABLE VIII	L1,L2,L3	L4-L7	L8,L9	L10-L13
TABLE X	L1,L2,L3	L4-L7	L8,L9	L10-L14
TABLE XII	L1,L2,L3	L4-L7		L8-L14

A four-group system, as exemplified in Figures 1 and 1a, includes a first positive group G1 which moves axially only for focusing. The axial positions of the remaining groups are varied as the focal length of the objective is changed. A diaphragm D is positioned between the second and third groups to enable the lens size to be kept to a minimum, or it may be fixed in axial position. If fixed in position, the relative aperture varies as the focal length is changed. However, a diaphragm adjustable as the focal length changes, can be incorporated to maintain the relative aperture constant as the lens is zoomed from one end of its EFL range toward the other end.

In the embodiment shown in Figures 1 and 1a, the first group is of positive power and comprises a negative meniscus element L1, a bi-convex element L2 and a positive meniscus element L3.

Air spaced from the first group is a second group G2 of negative power which is movable as the focal length of the lens is varied. This group comprises a negative meniscus element L4 convex to the object, followed by a negative bi-concave element L5, a bi-convex doublet of positive power comprising a bi-convex element L6, and a meniscus L7.

A third positive group G3 in the form of air-spaced doublet elements L8, L9 is arranged for movement relative to the second group. Element L8 is a thin negative meniscus element. Element L9 is a bi-convex element of positive power. This group moves with a reversing motion, as hereinafter set forth, as the focal length of the lens is varied. This third group provides aberration compensation.

The fourth or last group GR includes a plurality of doublets air spaced one from the other, but movable together during variation of the EFL of the lens. Elements L10, L12, and L14 are meniscus elements of negative power, which are mated respectively with bi-convex elements L11, L13, and L15 of positive power to provide three bi-convex lenses of positive power.

A lens embodying the invention may have a zoom ratio of essentially five to one. In a 24 x 36mm image frame format (43.3 diagonal), examples are given of 25.5mm to 125.00mm EFL. However, the invention is equally applicable to providing well corrected lenses of smaller zoom ranges from an EFL substantially below the diagonal of the image frame (about .66) to an EFL of two or more times the diagonal of the image frame.

To achieve a lens which satisfies the objectives of the invention, certain parameters have been determined.

The second group G2 is of strong relative negative power to provide compactness of the overall lens, both as to length and diameter, but requires positive corrections in the form of the doublet L6, L7 (Figures 1 and 1a).

An important condition of the lens is the relation of combined power of the two negative elements of group G2 to the positive power component. It has been determined that:

$$|.20K_{21}| < K_{22} < |.40K_{21}|$$

where K_{22} is the power of the positive component of G2, and

K_{21} is the sum of the absolute power of the negative elements of Group G2.

This is the most important parameter to maintain compactness. Other parameters determined during the design of lenses embodying the invention may best be expressed in terms of the geometric mean power of the lenses. The geometric mean power K_M of a zoom lens is expressed as:

$$K_M = \sqrt{K_S \times K_L}$$

where K_S is the power of the lens at its shorter EFL extreme, and

K_L is the power of the lens at its longer EFL extreme.

In Tables II, IV, VI, VIII and X, K_M is .0177, and in Table VI, K_M is .0193.

The power K_1 of the first Group G1 should be:

$$.40 K_M < K_1 < 1.0 K_M$$

where the lens comprise three groups as exemplified in Tables XII and Figures 5 and 5a, and where the lens comprises four groups as shown in Tables II, IV, VI, VIII, and X.

$$.70 K_M < K_1 < 1.0 K_M$$

Also, the power K_3 of the third group should be:

$$1.5 K_M > K_3 > .6 K_M$$

and the absolute power of the second negative group should be:

$$4.0 K_M < |K_2| < 2.0 K_M$$

Six examples of lenses embodying the foregoing parameters are set forth in the following tables and described in conjunction with the drawings.

In the following prescription tables, the index of refraction of each element is given as N_D , and the dispersion as measured by the Abbe number is given by V_D . Zoom spacings Z are given in odd numbered tables following each prescription table.

In the lens of Figures 1 and 1a, and Table I, group G1 moves axially only for focusing. As the EFL of the lens is varied from the lower limit to the upper limits, group G2 moves toward the image end, group G3 has reversing motion, and group GR moves toward the object end. The aperture defining mechanism is positioned just in front of group G3.

A lens embodying the invention as scaled to an image frame of 24×36 mm, and EFL's of 25.5mm (76 degree field) to 122.70 degrees (18 degrees field) with relative aperture of f/3.0 to f/4.6 is substantially described in Table II.

TABLE II

Lens	Surface	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Nd	Vd
L1	S1	185.9987			
	S2	49.6058	3.000	1.847	23.8
L2	S3	51.2413	1.768		
	S4	-323.9418	11.700	1.743	49.2
L3	S5	37.4951	.150		
	S6	70.1003	6.000	1.806	40.7
L4	S7	118.4422	Z1		
	S8	13.2349	2.000	1.850	32.2
L5	S9	-49.699	6.735		
	S10	42.7192	2.000	1.835	43.0
L7	S11	24.7201	.100		
	S12	-13.4465	7.641	1.689	31.2
	S13	-223.5334	2.000	1.713	53.9
	Aperture		Z2		
L8	S14	47.1016	Z3		
	S15	25.6722	1.500	1.847	23.8
L9	S16	31.4590	1.409		
	S17	-100.8025	4.300	1.762	40.3
L10	S18	40.3475	Z4		
	S19	25.3014	2.000	1.847	23.8
L11	S20	-95.3470	7.000	1.589	41.0
	S21	59.5290	.150		
L12	S22	20.2397	2.500	1.835	43.0
	S23	-564.7725	6.100	1.488	70.4
L14	S24	220.4092	7.154		
	S25	28.9627	2.500	1.850	32.2
L15	S26	-83.7917	6.100	1.488	70.4

The spacing of the various groups of Figures 1 and 1a and Table II during zooming are set forth below in Table III:

TABLE III

EFL	Z1	Z2	Z3	Z4	f/No.	
5						5
25.5mm	1.20mm	20.61mm	6.71mm	19.73mm	3.30	
40.0	7.76	16.97	.50	10.93	4.35	
85.0	25.12	4.38	4.88	.50	4.10	
125.0	29.66	1.70	.50	.50	4.60	
10						10

The space Z3 is the spacing between surface S16 and the diaphragm D.

Another embodiment of the invention has the elemental configuration showing in Figures 1 and 1a.

Here the aperture defining diaphragm is located after group G2 and axially fixed. This lens, scaled to a 24 × 36mm image frame, and has an EFL range of 25.5 to 125mm and subtends semi-fields of 9.1 degrees to 38 degrees is substantially described in Table IV.

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TABLE IV

Lens	Surface	Radius of Curvature (mm)	Axial Distance Between Surfaces (mm)	Nd	Vd
L1	S1	414.835			
	S2	50.369	3.500	1.847	23.8
L2	S3	52.721	1.768		
	S4	-203.797	11.700	1.743	49.2
	S5	41.688	.150		
L3	S6	103.130	6.00	1.806	40.7
	S7	302.316	Z1		
L4	S8	14.793	2.00	1.850	32.2
	S9	-64.865	8.400		
L5	S10	44.117	2.000	1.840	42.8
	S11	28.093	.100		
L6	S12	-19.503	7.700	1.739	28.3
	S13	349.480	2.000	1.651	59.0
L8	Aperture		Z2		
	S14	42.981	Z3		
	S15	26.354	1.200	1.847	23.8
	S16	31.399	1.858		
	S17	-199.096	3.300	1.790	41.4
L10	S18	28.676	Z4		
	S19	20.560	2.000	1.862	23.3
L11	S20	-128.190	4.500	1.547	27.8
	S21	70.468	8.039		
L12	S22	25.194	2.500	1.619	20.3
	S23	-132.809	6.100	1.488	70.3
L14	S24	2798.444	1.984		
	S25	21.735	2.500	1.863	37.4
L15	S26	-70.988	6.100	1.482	71.2

The spacing of the various groups of Table IV during zooming as set forth below in Table V.

TABLE V

EFL	Z1	Z2	Z3	Z4	F/No	
5 25.5mm	1.21mm	29.85mm	3.63mm	13.92mm	3.30	5
40.0	8.70	22.03	.50	6.60	3.90	
85.0	26.4	4.89	6.98	.03	3.44	
125.0	29.6	1.700	.50	.50	4.30	

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A third embodiment of the invention is shown in Figures 2 and 2a, and has a movable aperture defining mechanism between groups G2 and G3.

The front group G comprises a positive cemented doublet L1, L2, and a positive meniscus L3 convex to the object. Groups G2 and G3 have the same configurations previously described. Group GR comprises a first 15 positive doublet L10 and L11, and a second positive doublet L12 and L3.

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As the EFL varies, from the lower limit to the upper limit group G2 moves toward the image end. Group G3 moves first toward the aperture, then reverses and then back toward the aperture.

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This lens is scaled to an image frame of 24 x 36mm, having EFL's of 25.5mm to 125mm and subtending semi-angles of 9 degrees to 76 degrees is substantially described in Table VI.

TABLE VI

5 Lens	Surface	Radius Curvature (mm)	Axial Distance Between Surfaces (mm)	Nd	Vd	5
L1	S1	272.365				
	S2	49.902	3.50	1.762	27.3	
10 L2	S3	-348.735	9.70	1.673	51.4	10
	S4	41.575	.15			
L3	S5	88.688	6.00	1.806	40.7	
	S6	119.038	Z1			15
L4	S7	15.309	2.00	1.857	32.0	
	S8	-59.323	8.40			20
L5	S9	85.381	2.00	1.840	42.8	
	S10	31.319	.07			25
L6	S11	-25.034	7.70	1.762	27.3	
	S12	110.053	2.00	1.697	55.5	
30	Aperture		Z2			30
	S13	54.083	Z3			
L8	S14	27.576	1.20	1.847	23.8	
	S15	29.890	.43			35
L9	S16	-163.620	3.30	1.806	40.7	
	S17	47.088	Z4			40
L10	S18	20.204	2.00	1.847	23.8	
	S19	-192.570	4.50	1.650	39.3	
L11	S20	253.894	14.66			45
	S21	25.299	2.49	1.790	43.7	
L12	S22	-47.350	6.10	1.488	70.4	
						50

The spacing of the various groups is set forth below in Table VII.

TABLE VII

EFL	Z1	Z2	Z3	Z4	f/No.
25.5mm	.50mm	30.83mm	4.37mm	17.60mm	3.65
40.1	8.94	22.56	0.00	11.67	3.65
85.0	25.93	5.72	3.95	1.33	3.65
125.0	30.70	.78	.15	.40	3.65

In another embodiment shown in Figures 3 and 3a, elements L14 and L5 of group G4 remain stationary during zooming. Groups G1, G2 and G3 have the configuration shown in Figures 2 and 2a. Group GR comprises a first positive cemented doublet L10, L11 of negative meniscus — bi-convex form, a second doublet L12, L13 of the same form, a positive element L14 and a negative meniscus L15 concave to the object.

The diaphragm is stationary and arranged to maintain the relative aperture constant during variations of EFL.

This lens scaled to an image frame of $24 \times 36\text{mm}$, and having EFL's of 25.5 to 125.0mm, and subtending semi-field angles of 9.1 degrees to 38 degrees is substantially described in Table VIII.

TABLE VIII

5 Lens	Surface	Radius Curvature (mm)	Axial Distance Between Surfaces (mm)	Nd	Vd	5
L1	S1	445.579				
	S2	46.817	3.50	1.847	23.8	
10 L2	S3	-323.931	9.70	1.806	40.7	10
	S4	44.318	.15			
L3	S5	98.638	6.00	1.827	39.5	
	S6	152.122	Z1			15
L4	S7	16.665	2.00	1.840	42.8	
	S8	-66.642	8.40			20
20 L5	S9	58.409	2.00	1.840	42.8	
	S10	32.864	.50			
L6	S11	-30.877	7.70	1.733	28.1	25
	S12	197.121	2.00	1.700	55.3	
30	Aperture		Z2			30
	S13	40.025	Z3			
L8	S14	24.132	1.20	1.847	23.8	
	S15	28.626	1.30			35
L9	S16	-425.010	3.30	1.806	40.7	
	S17	41.374	Z4			40
L10	S18	28.237	2.00	1.854	23.6	
	S19	-456.281	4.50	1.732	52.0	
45 L11	S20	-209.078	3.24			45
	S21	20.252	2.49	1.785	48.8	
L12	S22	-38.872	6.10	1.475	70.3	50
	S23	-1513.366	Z5			
L14	S24	-26.320	6.10	1.488	70.4	
	S25	-24.591	2.50			55
L15	S26	-56.837	2.50	1.832	30.6	
						60

The spacing of the groups during zooming is set forth in Table IX.

TABLE IX

	EFL	Z1	Z2	Z3	Z4	Z5	f/No.
5	25.5mm	.50mm	29.37mm	4.79mm	.54mm	16.63mm	3.65
	40.4	8.08	21.73	.01	11.28	10.71	3.65
	85.0	26.28	3.80	6.22	13.44	2.08	3.65
	125.0	29.60	.43	.01	21.38	.40	3.65

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Another embodiment of the invention shown in Figures 4 and 4a has groups G1, G2 and G3 as previously described. Group GR comprises three positive doublets L10, L11; L12, L13; and L14, L15 which move with variation of EFL. The aperture defining diaphragm is positioned between groups G2 and G3 and is arranged to change absolute aperture with EFL to provide a constant relative aperture.

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This lens as scaled for an image frame of 24×36 mm, with EFL's of 25.5mm to 125.0mm and subtending semi-angles of 9 degrees to 38 degrees is substantially described in Table X.

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TABLE X

5 Lens	Surface	Radius Curvature (mm)	Axial Distance Between Surfaces (mm)	Nd	Vd	5
L1	S1	86.919				
	S2	51.507	3.50	1.847	23.8	
10 L2	S3	586.863	9.15	1.569	63.1	10
	S4	44.013	.15			
L3	S5	120.989	6.00	1.773	49.6	
	S6	107.542	Z1			15
L4	S7	15.311	2.00	1.857	32.0	
	S8	-68.184	8.00			20
L5	S9	35.639	2.00	1.839	42.0	
	S10	25.449	.01			25
L6	S11	-22.645	7.70	1.722	29.2	
	S12	-4941.359	2.00	1.773	49.6	
L7	S13	42.644	Z2			30
	S14	23.589	1.20	1.589	61.2	
L8	S15	27.132	.43			35
	S16	1101.577	3.30	1.655	33.7	
L9	S17	29.676	Z3			40
	S18	26.206	2.00	1.76	26.6	
L10	S19	-46.160	14.92	1.807	35.5	
	S20	-50.914	.00			45
L11	S21	14.786	2.40	1.847	23.8	
	S22	-27.371	9.73	1.488	70.4	
L12	S23	-16.837	2.04			50
	S24	32.237	1.60	1.488	70.4	
L13	S25	-34.016	8.50	1.650	39.3	
						55

TABLE XI

EFL	Z1	Z2	Z3	f/No.
5 25.5mm	.10	24.34	19.35	3.65
40.0	7.04	14.78	11.84	3.65
85.0	26.64	5.97	1.89	3.65
125.0	28.77	.10	.45	3.65

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- 10 Another embodiment of the invention comprises three groups G1, G2, and GR, as shown in Figures 5 and 5a. Groups G1 and G2 are constructed as previously described. Group GR comprises a bi-convex positive doublet L8, L9; a positive meniscus L10; a bi-concave element L11; a positive meniscus L12 concave to the object; and a positive bi-convex doublet L13, L14. In this embodiment all three groups move with change in EFL. As the EFL is increased group G1 moves toward the object end, group G2 moves toward the image end
- 15 and group GR moves toward the object end. The aperture defining mechanism D is axially fixed in position. A lens of this embodiment scaled for an image plane of 24×36 mm, EFL's of 25.5 to 104.8mm, and subtending semi-field angles of 10.8 degrees is substantially described in Table XII.

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TABLE XII

5 Lens	Surface	Radius Curvature (mm)	Axial Distance Between Surfaces (mm)	Nd	Vd	5
L1	S1	343.179	4.00	1.805	25.5	10
	S2	87.924				
L2	S3	-412.177	.15	1.691	57.7	15
	S4	72.251				
L3	S5	145.982	.21	1.804	46.5	20
	S6	68.558				
L4	S7	19.481	2.00	1.834	37.3	25
	S8	-91.032				
L5	S9	41.216	4.69	1.762	26.6	30
	S10	40.739				
L6	S11	-19.592	2.00	1.834	37.3	35
	S12	-689.714				
L7	S13	35.503	.22	1.805	25.5	40
	S14	22.130				
L8	S15	-538.122	.15	1.713	53.9	45
	S16	41.920				
L9	S17	526.965	4.00	1.713	53.9	50
	S18	-37.060				
L10	S19	47.131	1.50	1.570	42.6	55
	S20	-103.372				
L11	S21	-26.839	5.29	1.623	60.1	55
	S22	60.673				
L12	S23	-18.358	6.33	1.488	70.4	55
	S24	-73.946				
L13	S25	10.00	1.80	1.834	37.3	55
	S26	-18.358				
L14	S27	10.00	1.80	1.834	37.3	55
	S28	-18.358				

The spacings of the various groups with variation in EFL are given in Table XIII.

TABLE XIII

EFL	Z1	Z2	FVD	f/No.
25.5mm	.10mm	31.93mm	159.7mm	3.7
40.0	6.64	16.07	164.5	3.7
85.0	28.06	2.66	193.6	3.7
105.0	45.2	.39	204.6	3.7

The powers K_1 , K_2 , K_3 and K_4 of the various groups G_1 , G_2 , G_3 , and G_4 , respectively, are set forth in Table XIV:

TABLE XIV

5 Lens	K_1	K_2	K_3	K_R	5
Table II	.0156	-.0645	.0173	.0131	
Table IV	.0159	-.0576	.0172	.0099	
10 Table VI	.0138	-.0535	.0170	.0127	10
Table VIII	.0143	-.0539	.0167	.0119	
Table X	.0147	-.0607	.0126	.0192	
Table XII	.0085	-.0417		.0260	

15 The powers K_{21} of the negative elements K_{21} of group G_2 and the power K_{22} of the positive are set forth in Table XV together with the absolute ratio of the positive to the negative:

TABLE XV

20 Lens	K_{21}	K_{22}	K_{22}/K_{21}	20
Table II	-.0939	.0294	.31	
Table IV	-.0871	.0287	.33	
Table VI	-.0724	.0210	.29	
25 Table VIII	-.0718	.0202	.28	25
Table X	-.0838	.0268	.32	
Table XII	-.0601	.0166	.27	

30 The ratio of the absolute power of each group to the geometric mean of the powers of the lens at the extreme EFL's is given in Table XVI.

TABLE XVI

35	K_1/K_M	K_2/K_M	K_3/K_M	K_R/K_M	35
Table II	.88	3.64	.98	.74	
Table IV	.89	3.25	.97	.60	
Table VI	.80	3.02	.96	.72	
Table VIII	.81	3.05	.94	.67	
40 Table X	.83	3.42	.71	1.08	40
Table XII	.44	2.16		1.46	

CLAIMS

- 45 1. A zoom lens having equivalent focal lengths ranging from a dimension below the diagonal of the image frame of the lens to a dimension at least twice the diagonal of the image frame, comprising from the object end a first positive group, a second negative group and a third positive group, at least two of said groups being axially movable to vary the equivalent focal length of said lens, said second negative group 50 having an absolute optical power greater than said first and second groups, said second group having object side elements of negative power and image side elements of positive power, where:

$$.40 < \frac{K_{21}}{K_{22}} > .20$$

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and where K_{21} is the absolute sum of the powers of the negative elements of the second group, and K_{22} is the optical power of the positive component of the second group.

2. A lens as claimed in claim 1, wherein said second group from the object end comprises a negative 60 meniscus convex to the object end, a bi-concave element, and a positive, bi-convex doublet.

3. A lens as claimed in claim 1 or 2, further including a positive fourth group.

4. A lens as claimed in claim 1, 2 or 3, where during variations of focal length from the lower extreme to the upper extreme, said second group moves from the object end toward the image end, said third group moves initially toward the image end and thereafter toward the object and then the image end, and at least a 65 portion of said fourth group moves toward the object end.

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The powers K_1 , K_2 , K_3 and K_4 of the various groups G_1 , G_2 , G_3 , and G_4 , respectively, are set forth in Table XIV:

TABLE XIV

Lens	K_1	K_2	K_3	K_R
Table II	.0156	-.0645	.0173	.0131
Table IV	.0159	-.0576	.0172	.0099
Table VI	.0138	-.0535	.0170	.0127
Table VIII	.0143	-.0539	.0167	.0119
Table X	.0147	-.0607	.0126	.0192
Table XII	.0085	-.0417		.0260

The powers K_{21} of the negative elements K_{21} of group G_2 and the power K_{22} of the positive are set forth in Table XV together with the absolute ratio of the positive to the negative:

TABLE XV

Lens	K_{21}	K_{22}	K_{22}/K_{21}
Table II	-.0939	.0294	.31
Table IV	-.0871	.0287	.33
Table VI	-.0724	.0210	.29
Table VIII	-.0718	.0202	.28
Table X	-.0838	.0268	.32
Table XII	-.0601	.0166	.27

The ratio of the absolute power of each group to the geometric mean of the powers of the lens at the extreme EFL's is given in Table XVI.

TABLE XVI

	K_1/K_M	K_2/K_M	K_3/K_M	K_R/K_M
Table II	.88	3.64	.98	.74
Table IV	.89	3.25	.97	.60
Table VI	.80	3.02	.96	.72
Table VIII	.81	3.05	.94	.67
Table X	.83	3.42	.71	1.08
Table XII	.44	2.16		1.46

CLAIMS

1. A zoom lens having equivalent focal lengths ranging from a dimension below the diagonal of the image frame of the lens to a dimension at least twice the diagonal of the image frame, comprising from the object end a first positive group, a second negative group and a third positive group, at least two of said groups being axially movable to vary the equivalent focal length of said lens, said second negative group having an absolute optical power greater than said first and second groups, said second group having object side elements of negative power and image side elements of positive power, where:

$$.40 < \frac{K_{21}}{K_{22}} > .20$$

and where K_{21} is the absolute sum of the powers of the negative elements of the second group, and K_{22} is the optical power of the positive component of the second group.

2. A lens as claimed in claim 1, wherein said second group from the object end comprises a negative meniscus convex to the object end, a bi-concave element, and a positive, bi-convex doublet.

3. A lens as claimed in claim 1 or 2, further including a positive fourth group.

4. A lens as claimed in claim 1, 2 or 3, where during variations of focal length from the lower extreme to the upper extreme, said second group moves from the object end toward the image end, said third group moves initially toward the image end and thereafter toward the object and then the image end, and at least a portion of said fourth group moves toward the object end.

5. A lens as claimed in claim 2 or 3, where said first and fourth groups move in fixed relation to each other.

6. A lens as claimed in claim 1, 2 or 3, where the power K_1 of said first group is:

$$.40K_M < K_1 < 1.0K_M$$

where K_M is the geometrical mean power of said lens at the extremes of its equivalent focal lengths.

7. A lens as claimed in claim 1 or 2, further including a fourth positive group and the power K_1 of said first group is:

$$.70K_M < K_1 < 1.0K_M$$

where K_M is the geometrical mean power of said lens at the extremes of its equivalent focal lengths.

8. A lens as claimed in any of the preceding claims, where said third group has an optical power K_3 and

$$1.5K_M > K_3 > .60K_M$$

and K_M is the geometrical mean power of said lens at the extremes of its equivalent focal lengths.

9. A lens as claimed in any of the preceding claims, wherein said third group includes a bi-convex doublet of positive power and

$$.60K_M < K_3 < 1.5K_M$$

where K_M is the geometrical mean power of said lens at the extremes of its equivalent focal lengths and K_3 is the power of said third group.

10. A lens as claimed in any of the preceding claims, where an aperture defining means is positioned between said second and third groups.

11. A zoom lens as claimed in any of the preceding claims, where said second group has an absolute optical power greater than said first and third groups, and

$$.40K_M < K_1 < 1.0K_M$$

$$2.0K_M < K_2 < 4.8K_M$$

$$.60K_M < K_3 < 1.5K_M$$

where:

K_M is the geometric mean of the optical powers of said lens at the extremes of its equivalent focal lengths, and

K_1 , K_2 and K_3 are the optical powers of the first, second, and third groups, respectively.

