Kreitzer

[45] Reissued Date of Patent: May 16, 1989

[54] ZOOM LENS	3,918,797
[75] Inventor: Melvyn H. Kreitzer, Cincinnati, Ohio	3,961,845 3,975,089
[73] Assignee: Vivitar Corporation, Chatsworth, Calif.	4,149,774 4,172,635
[21] Appl. No.: 659,334	FORE
[22] Filed: Oct. 10, 1984	1547127 363501 1437620
Related U.S. Patent Documents	Primary Exam
Reissue of: [64] Patent No.: 4,256,381	Assistant Exan Attorney, Agen
Issued: Mar. 17, 1981 Appl. No.: 117,369	[57]
Filed: Jan. 31, 1980	A lens of vari
[51] Int. Cl. ⁴	lens groups loo ing means mov and a lens grou
[58] Field of Search	the aperture
[56] References Cited	means and the either be static
U.S. PATENT DOCUMENTS	focal length.

3,840,290 10/1974 Betensky et al. 350/427

3,918,797	11/1975	Takano	350/427
3,961,845	6/1976	Doi et al.	350/427
3,975,089	8/1976	Betensky	350/427
•		Hirano	
, ,		Ogino	

FOREIGN PATENT DOCUMENTS

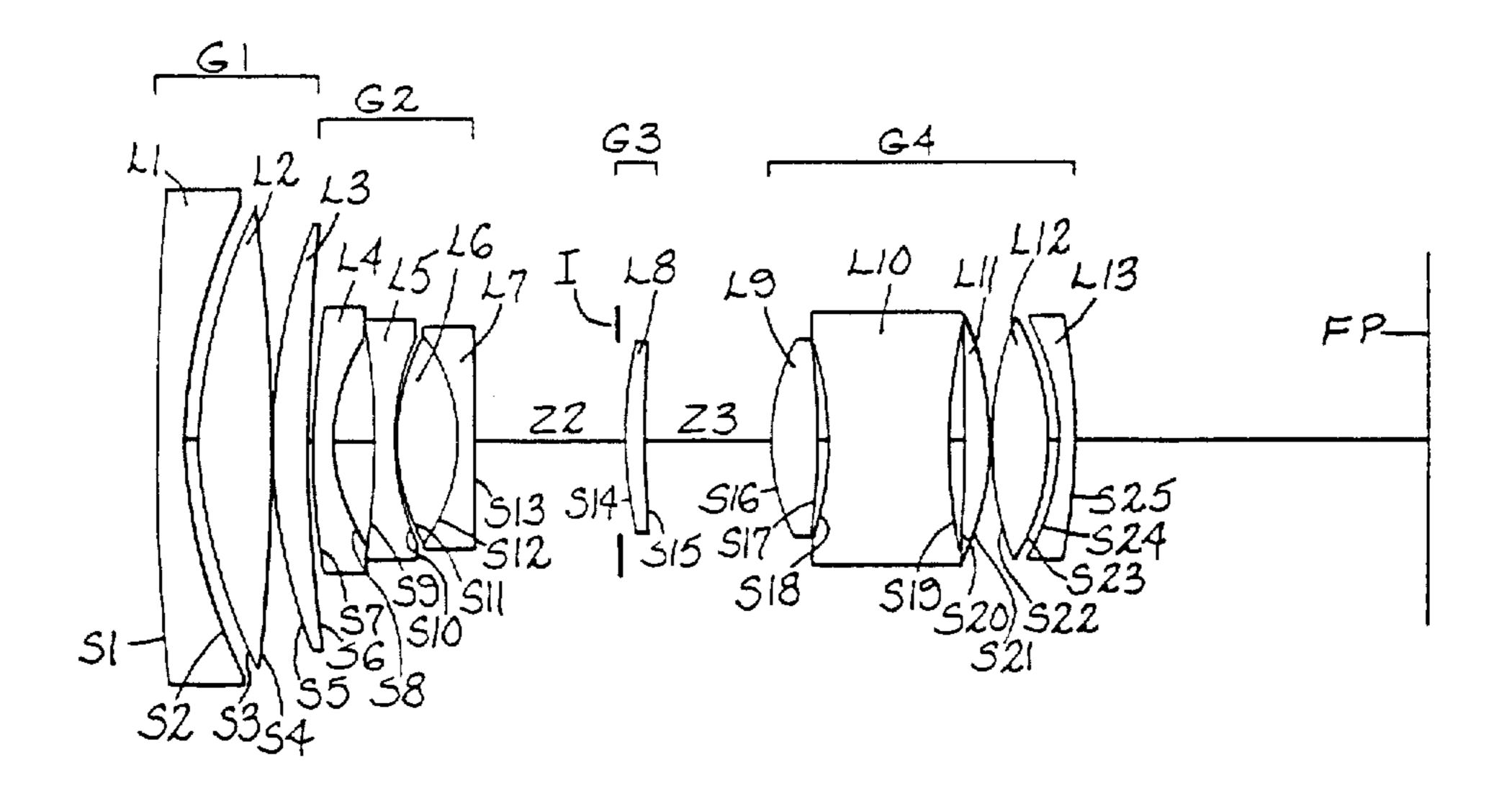
1547127 8/1970 Fed. Rep. of Germany. 363501 9/1962 Switzerland. 1437620 6/1976 United Kingdom.

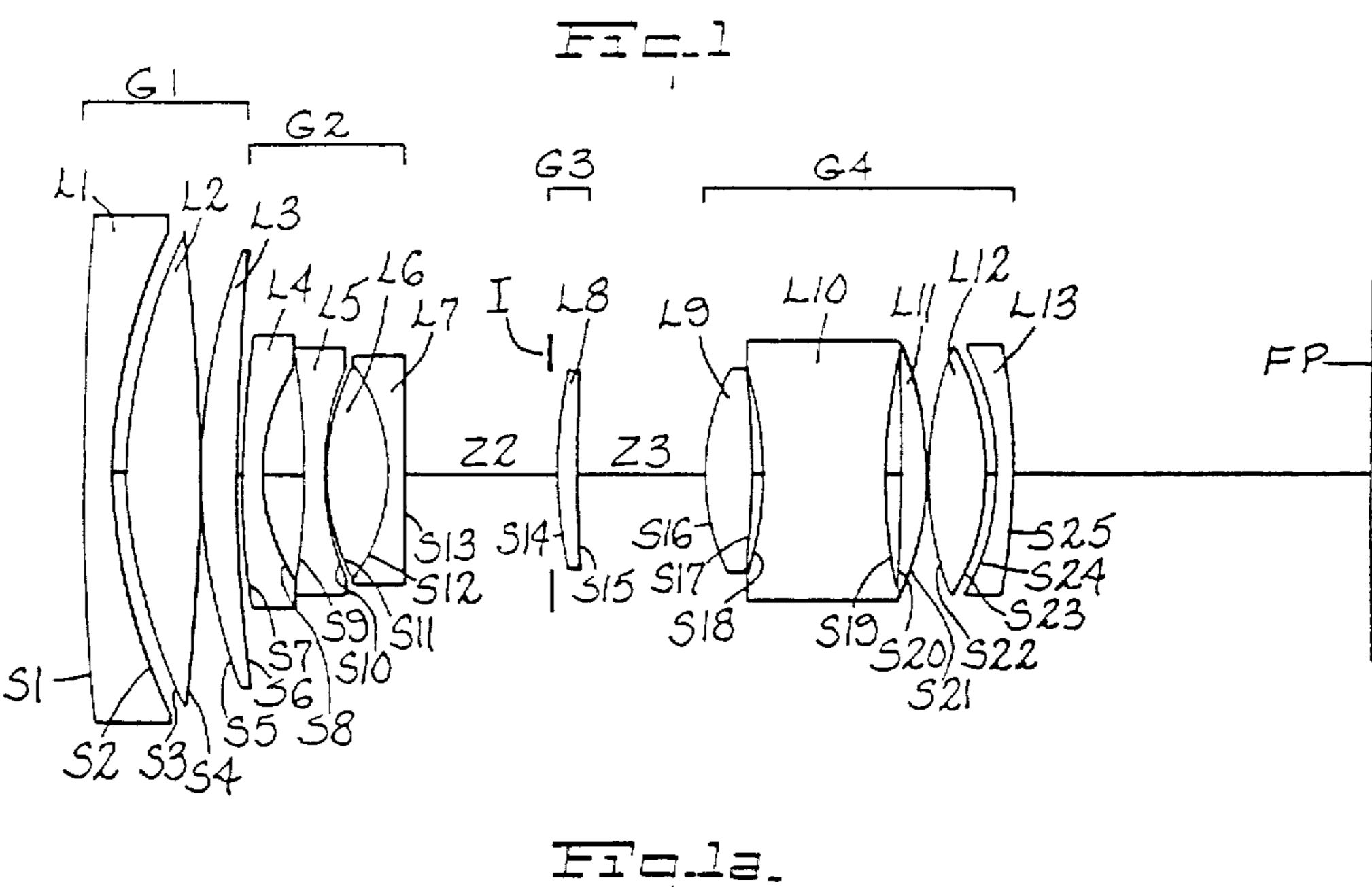
Primary Examiner—John K. Corbin Assistant Examiner—Scott J. Sugarman Attorney, Agent, or Firm—Costas & Montgomery

[57] ABSTRACT

A lens of variable equivalent focal length where two lens groups located on either side of an aperture defining means move relative to the aperture defining means, and a lens group of positive power is positioned close to the aperture defining means. The aperture defining means and the associated positive power group may either be stationary or move with change in equivalent focal length.

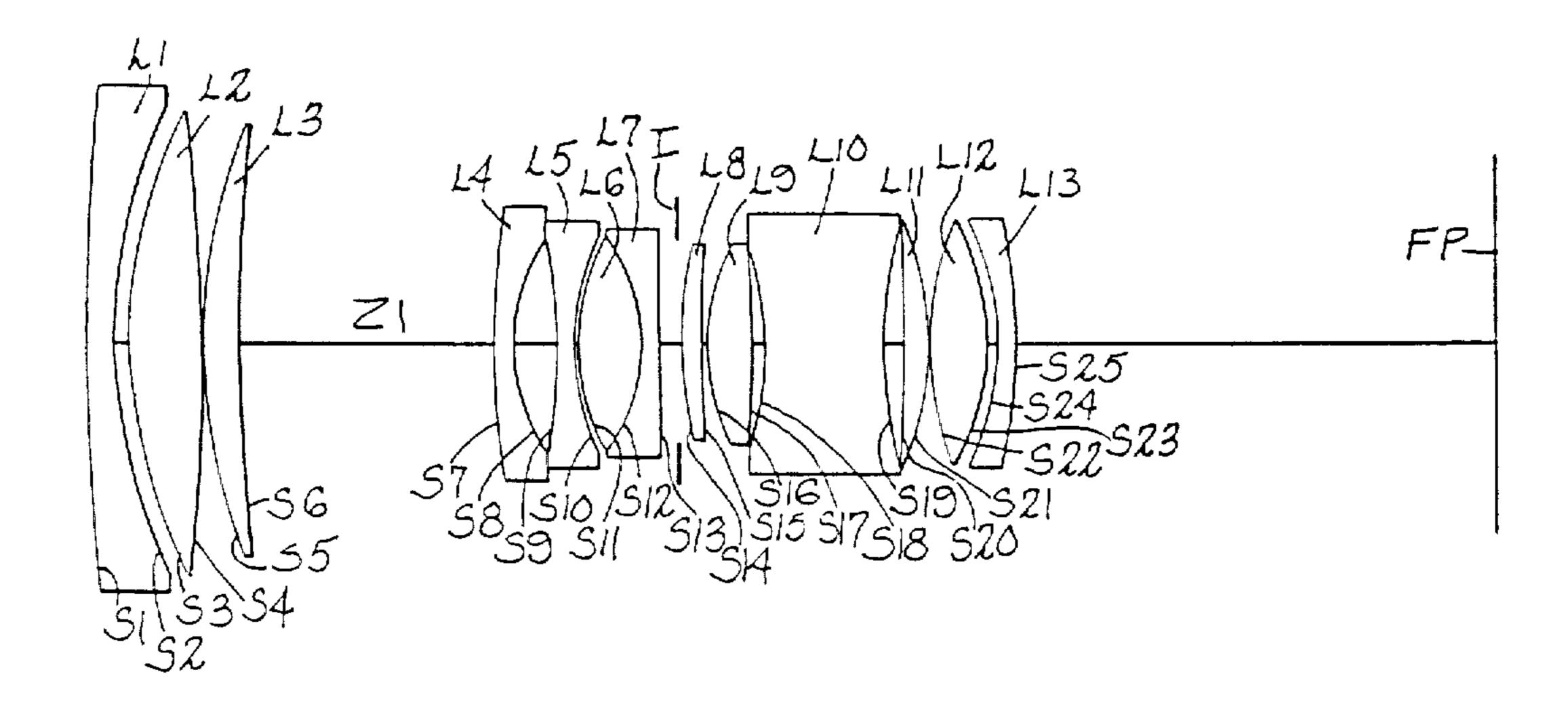
27 Claims, 2 Drawing Sheets

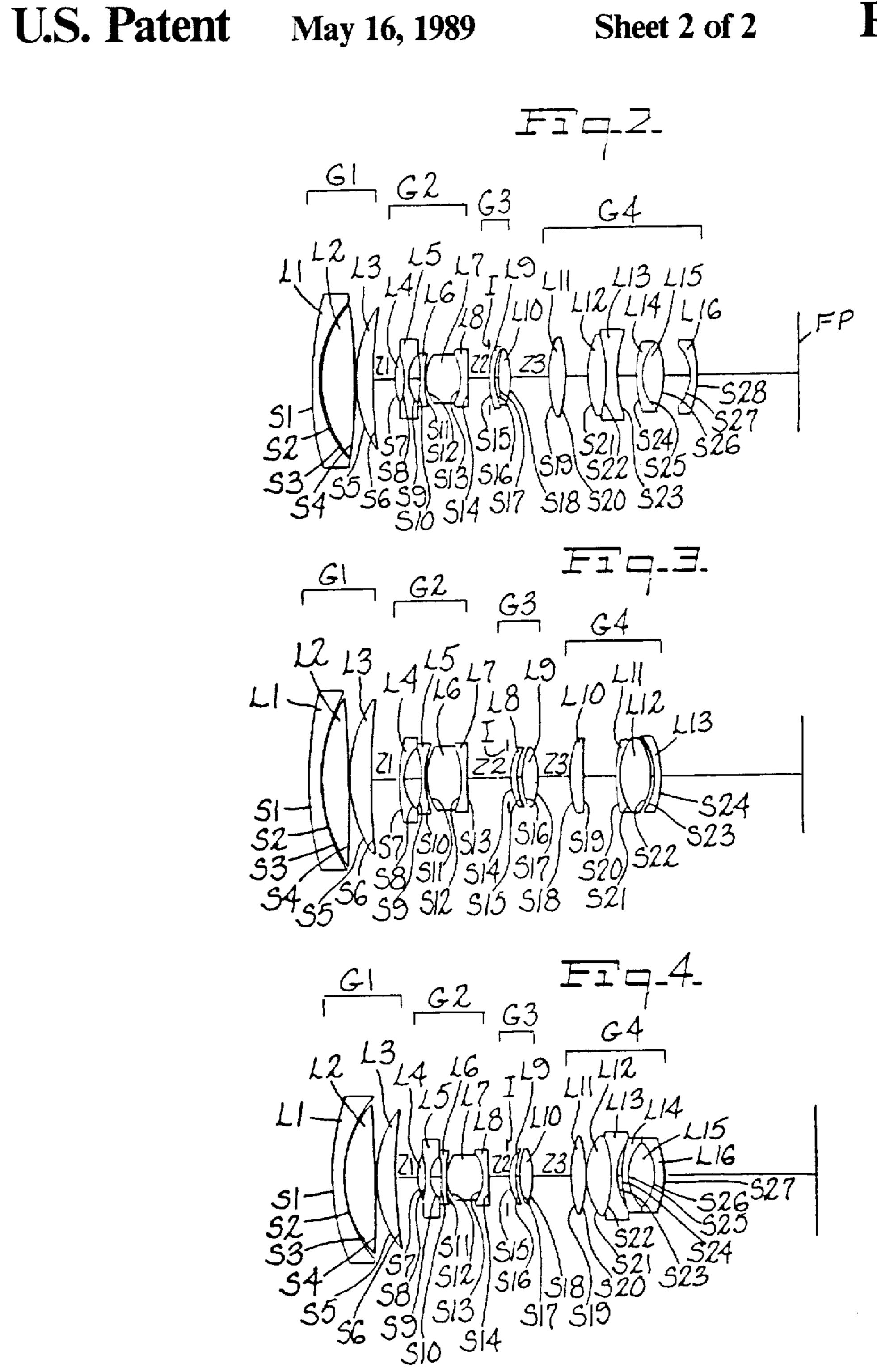




May 16, 1989







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ZOOM LENS

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specifica-5 tion; matter printed in italics indicates the additions made by reissue.

FIELD OF THE INVENTION

This invention relates to zoom lenses, and more particularly relates to such lenses having a range of equivalent focal lengths which subtend the dimension of the diagonal of the image plane of the lens.

BACKGROUND OF THE INVENTION

A lens having an equivalent focal length less than the diagonal of its image plane may be classified as a wide angle lens. Zoom lenses which have a range from wide angle to a long focus or so-called telephoto equivalent focal length (EFL) present different design criteria when considered from the extremes of the EFL's.

A wide angle lens of about 70° field is not difficult to design. Such design generally includes a negative front group and a positive rear group where the back focal length of the lens is greater than the EFL. Such lens is often termed a retrofocus or reverse telephoto lens. An example of an excellent optic of this category is shown in U.S. Pat. No. 4,099,849 and is marketed as a Vivitar Series I, 28 mm f/1.9 lens. On the other hand, lenses having an EFL several times the diagonal of the image frame present other design considerations. Examples of a well corrected telephoto lens are given in U.S. Pat. No. 3,942,876, and have been marketed as Vivitar Series I lenses at 135 mm f/2.3, and 200 mm f/3.0. A comparison of such lens shows completely different design configurations and considerations.

Where the EFL range of a zoom lens is to cross the so-called wide angle definition, a more sophisticated lens design is demanded requiring more lens elements 40 and movements of various lens groups. An example is shown in U.S. Pat. No. 3,975,089, and has been marketed as a Vivitar Series I 35-85 mm f/2.8 lens.

Few zoom lenses have been designed and marketed having a lower EFL in the wide angle range and having 45 a zoom range of greater than 3:1, and then the actual EFL extremities are subject to a five percent marking tolerance. In such zoom lenses, the spherical [abberrations] aberrations become excessive as the longer EFL is attempted to be increased and/or attempt is made to 50 increase the relative aperture.

Without size and cost constraints, these problems can be overcome by any experienced optical designer. However, there are presently few, if any, commercially acceptable zoom lenses, from the standpoint of compact 55 size, relative aperture, zoom range, and good quality available from a wide angle range with a rated zoom range of three to one or over for the 24×36 mm image frame format.

However, Ellis I. Betensky in U.S. patent application 60 Ser. No. 070,749, now U.S. Pat. No. 4,299,454, has disclosed a new configuration for a zoom lens which permits a zoom range of almost five to one from a field angle of over seventh degrees. Such lenses comprise a front positive group, a strong negative second group, a 65 third positive group and in some cases, a fourth positive group. Three of these groups may be movable to vary the EFL of the lens.

The present invention provides an improvement over and to the foregoing Betensky lens in that it permits a larger aperture for a given physical size of the lens, or alternatively a reduction in physical size for a given relative aperture.

SUMMARY OF THE INVENTION

Briefly stated, the invention provides a zoom lens comprising a front positive group, a second negative group and a rear positive group in which a positive power lens group is positioned very closely adjacent the aperture defining means between the second and rear groups. The lens and aperture defining means may be stationary, or may move in fixed spaced relation as the EFL is varied. This positive optical power at the aperture permits a larger relative aperture by alleviating the limiting factor of spherical aberration at the longer EFL's. The positive component reduces the marginal ray height of the ray bundle at and past the aperture defining means. The optical power of this positive group is related to other parameters of the lens as hereinafter described.

A first embodiment of a lens embodying the invention comprises a first positive group, a second negative group, the aperture defining means followed by a third positive group in fixed relation to the aperture defining means, and a fourth positive group. During variation of focal length, the first and fourth groups move simultaneously in one direction and the second group moves in the opposite direction; for focusing all groups move in fixed relation. In [a] another embodiment of the invention, the aperture defining means and the third group move in fixed relation, and only the first group moves for focusing.

An object of this invention is to provide a new and improved zoom lens of the type described of compact size and/or large relative aperture.

The features of the invention which are believed to be novel are particularly pointed out and distinctly claimed in the concluding portion of this specification. However, the invention both as to its organization and operation together with further objects and advantages thereof may best be appreciated by reference to the following detailed description taken in conjunction with the drawings [, in which:].

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1 and 1a are schematic side elevations of one lens form embodying the invention; and

FIGS. 2, 3, and 4 are schematic side elevations of other embodiments of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

A lens embodying the invention as shown in FIGS. 1 and 1a comprises from the object end thirteen elements L1-L13 in four groups G1-G4.

Group G1 comprises a negative meniscus L1, a bi-However, Ellis I. Betensky in U.S. patent application 60 convex element L2, a positive meniscus L3, and is of er. No. 070,749, now U.S. Pat. No. 4,299,454, has overall positive power.

Group G2 comprises a negative meniscus L4, a biconcave element L5, and a relatively thick positive doublet shown as a biconvex element L6, and a negative element L7. The doublet L6, L7 is convex to the object and has a large radius image side surface which may be convex or concave to the image as shown by the prescriptions, infra.

S22

S23

S24

S25

Surface

S1

S2

S3

S4

L12

L13

TABLE I-continued

Group G3, as shown in FIG. 1, comprises a single element L8 very closely spaced to the aperture defining means or iris I. Component L8 is convex to the object and has an image side surface defined on a very large radius R_I relative to the object side radius R_O .

Group G4 comprises a biconvex element L9, a relatively thick biconcave element L10, a positive meniscus L11 convex to the image, a biconvex element L12, and a negative meniscus convex to the image.

As will hereinafter be made apparent, the third group 10 bears a certain relationship to other parameters of the lens:

$0.3 < (K_3/K_GZ_R) < 0.15$	
where	15
K ₃ is the optical power of the group G3	
Z_R is the zoom ratio of the lens, and	
K _G is the geometric mean power of the lens, and	
$K_G = \sqrt{K_L K_S}$	20
where	20
77 ' .1 C.1 1 1	

 K_L is the power of the lens at the longest equivalent focal length, and

 K_S is the power of the lens at the shortest equivalent focal length.

Three examples of the lenses substantially as shown in FIGS. 1 and 1a are set forth in Tables I-III. In these examples and as shown in FIGS. 1 and 1a, groups G1 and G4 move together toward the object as the EFL increases, group G2 moves toward the image and group 30 G3 and the aperture defining means remains stationary with respect to the focal plane FP.

In the following three examples, the prescriptions are for lenses having a 24×36 mm image frame; an equivalent focal length (EFL) range of 28.6 mm to 87.0 mm; 35 and relative apertures which vary from f/2.9 to f/3.9 from the lower EFL to the higher EFL.

In Tables I-III, the lens elements are identified from the object to the image end by L1-L13, the lens element surfaces are S1-S25, the index of refraction is N_D, and 40 Lend the lens element dispersion as measured by the Abbe Number is V_D. The movements of the various groups are shown by the data under the heading Zoom Data for various EFL's, Z1, Z2 and Z3 are the axial spaces between groups as shown on the drawings. FVD is the 45 front vertex distance of the lens, and BFL is the back focal length of the lens. The relative aperture at the

vario	us EFL's	is given un	ider the heading	f/No.				S 5	52.91			
			BLEI			ŧο	L3	S 6	120.92	4.30	1.834	37.3
Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_{d}	V_d	- 50	L4	S 7	70.22	Z1 2.00	1.805	25.5
-	S1	878.67				-		S8	17.07	5.10		
L1	S2	53.00	3.00	1.805	25.5	55	T.5	\$9	-64.49	2.00	1.500	41 1
	S 3	54.94	1.80				22	S10	25.54		1.589	61.3
L2			8.70	1.786	43.9			S 11	22.97	0.50		
	S4	- 2 9 5.19	0.15				L6	S12	 18.35	7.17	1.699	30.1
L3	S5	49.87			4.	60	L7		10.33	7.17	1.699	30.1
L 3	S6	100.18	4.30	1.835	43.0			S13	158.15	Z 2		
	S 7	83.91	Z 1					aperture				
L4	S8		2.00	1.850	32.2			S14	61.35	1.30		
		17.34	4.80			65	L8	S15	 697.26	2.23	1.723	38.0
L5	S9	— 116.10	2.00	1.835	43.0					Z 3		
	\$10	33.18		1.000	45.0		L9	S16	31.91	4.79	1.658	57.3

			Continued		
	S 11	25.25	.20		,
L6	311	25.25	11.54	1 779	707
20	S12	—17.23	11.54	1.728	28.3
L7	S 13	- 826.07	1.50	1.835	43.0
			Z 2		
	apertur	е			
	S 14	55.92	1.00		
L8	314	33.92	2.23	1.667	48.3
	S15	1165.66	4.40	1.007	70,5
	244		Z 3		
L9	S16	28.44	4.70		7 0.6
L	S17	-41.59	4.79	1.613	58.6
	4	*****	0.79		
	S18	28.11			
L10	610	20.61	12.00	1.593	35.6
	S19	38.61	2.68		
	S20	—145.85	2.00		
L11	.		3.00	1.835	43.0
	S21	-31.12	0.00		
			0.20		

			ZOOM	DATA			
f/No.	EFL	FVD	Z 1	Z 2	Z 3	BFL	
2.9	28.6 mm	156.4 mm	.80 mm	15.3 mm	14.7 mm	43.6 mm	
3.1	40.0	161.3	10.4	10.4	10.3	48.5	
3.5	55.0	165.0	18.6	6.5	6.0	53.1	
3.9	87.0	171.7	29.2	1.0	0.8	58.9	

5.97

0.99

1.60

Axial Distance

Between Surfaces

(mm)

3.00

1.80

8.70

0.15

1.573

1.805

 N_d

1.805

1.700

 \mathbf{V}_d

25.5

47.8

42.6

25.5

51.53

-23.68

21.43

-993.13

Surface

Radius

(mm)

649.67

57.37

58.75

-237.36

TABLE II

52.8

59.3

0.8

1.8

		Т	ABLE I	[-continue	ed		
	S17	_	-40.93	0.66			
	S 18	_	-28.41	0.60	J		
Lio	S 19		40.69	13.30)	1.593	35.5
				2.84	L		
LII	S10	_	- 65.65	3.00)	1.583	46.5
271	S21	-	- 27.15				
	S22		50.97	0.20	,		
L12	S23	_	-23.28	7.25	5	1.517	52.2
	323			1.79	•		
L13	S24	-	20.86	1.60)	1.847	23.8
	S25	<u>-</u>	-56.24				
			ZOOM	DATA			
f/No.	EFL	FVD	Z 1	Z2	Z 3	BFL	
2.9	28.6	156.5	0.8 mm	15.1 mm	16.4 mm	42.5	mm
3.2	mm 40.0	mm 161.8	10.6	20.4	11.3	47.8	

166.7

173.3

55.0

87.0

4.0

19.0

29.8

		TAI	BLE III		
Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N _d	\mathbf{v}_d
	S1	367.16			<u></u>
L1	S2	53.15	3.00	1.805	25.5
	S3	54.36	1.80	4 = 20	488 0
L2	S4	- 220.65	8.90	1.700	47.8
т э	S5	46.30	0.15 4.00	1.834	37.3
L3	S6	83.28	Z1	1.05-	37.5
L4	S7	59.28	2.00	1.805	25.5
·	S 8	16.09	5.04		
L5	S9	 59.80	2.00	1.609	59.2
	S10	28.34	0.50		
L6	SII	23.44	8.00	1.699	30.1
L7	S12 S13	17.37 110.83	1.50	1.804	46.5
	aperture	110.03	Z 2		
	S14	63.48	1.30		
L8	S15	-659.47	2.00	1.834	37.3
	S16	32.68	Z3	1	ea ^
L9	S17	-42.95	4.79	1.661	57.0
Lio	S18	-29.12	0.60 12.32	1.593	35.5
LIV	\$ 19	43.26	3.27		2010
L11	S20	- 229.66	3.80	1.543	46.9
	S2 1	-29.26	0.20		
L12	S22	57.54	7.65	1.517	52.2
	S23	-24.09			

1.54

-21.66

S24

TABLE III-continued

L13			·- ·-	1.80	····	1.847	23.8
	S25	-	-68.41		· <u></u>		
		<u> </u>	ZOOM	DATA			
f/No.	EFL	FVD	Z 1	Z2	Z 3	BFL	
2.9	28.6 mm	156.3 mm	0.84 mm	13.30 mm	17.20 mm	42.3 1	mm
3.2	48.0	161.8	10.32	9.14	11.89	47.8	
3.5	55.0	167.0	18.36	5.95	7.03	53.0	
4.0	87.0	174.3	28.70	1.78	.86	60.3	

In the foregoing prescriptions, the front vertex distance (FVD) is calculated from a plane 6.5 mm in front of surfaces S1 when the lenses are focused to a magnification of 1:50.

The lenses set forth in Tables 1-III are so designed that the first and fourth groups move in the same direction for zooming. For simplicity of mechanical design of the zooming mechanism and to reduce the required size of the front group, the various lens groups move in fixed relation for focusing. Also the groups G1 and G4 move in fixed relation when zooming.

In the foregoing lens examples, the third group is in simplest form, a single element. In the given examples, the object side surface is convex, and on a much larger radius than the image side surface.

$$\left|\frac{R_1}{R_0}\right| > 8$$

where R_I is the radius of the image side surface and R_o is the radius of the object side surface.

FIGS. 2, 3, and 4 illustrate other embodiments of the invention where the third group at the aperture defining means is in the form of an air spaced doublet. FIG. 2 exemplifies the lens with the groups positioned toward its shorter EFL. The lens comprises elements L1-L6. Elements L1-L3 define a first positive group G1, elements L4-L8 define a second negative group G2. The aperture defining iris D is closely spaced to the third positive group G3 comprising elements L9 and L10. A fourth positive group is defined by elements L11-L16.

Group G1 has the same configuration as in examples I-III. Group G2 is again strongly negative, the forwardmost component is a doublet L4, L5 with the overall shape of a negative meniscus, followed by a biconcave element L6 and a positive doublet L7, L8. The third group G3 follows the aperture defining iris D and comprises a meniscus 19 air spaced from a biconvex element L10. Group G4 comprises a positive element L11, a doublet L12, L13, a biconvex doublet L14, L15, and a negative meniscus L16 concave to the object.

In the lens of FIG. 2, the third group G3 moves in fixed relation with the aperture defining iris D during variation in EFL. As the EFL is increased group G4 moves toward the object end, group G2 moves toward the image end, group G3 and the iris move in fixed relation toward the object, and group G1 moves toward the object.

The lens of FIG. 2 as scaled to an image frame of 24×36 mm for an EFL range of 25.5 mm to 124.0 mm is substantially described in Table IV.

		TAE	BLE IV		
Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	\mathbf{V}_d

		TABLE IV	'-continued							TABLE I	V-continu	ed		
F 1	S1	143.67				_		S23		29.36		<u>. </u>	· · · · · ·	<u>-</u>
L1	S2	45.42	3.00	1.805	25.5			S24		54.84	1.86	•		
	S3	45.12	0.03			5	L14	S25		19.80	2.05	;	1.835	63.0
L2	S4	-417.52	13.33	1,476	70.4		L15	S26		-20.07	11.48	}	1.465	65.8
	S5	43.91	0.10					S27			0.79			
L3	S 6	143.05	6.94	1.868	41.2	10	L16			-18.95	2.50		1.835	63.0
	S7		Z!					S28		-34.13 ZOOM	DATA		 '.	 :
L4		99.50	2.00	1.860	22.8		f/No.	EFL	FVD	Z1	Z2	Z 3	BFL	ı
L5	S 8	- 85.74	1.50	1.856	40.0	1.5	3.4		179.0	1.00 mm	17.58 mm	16.54 mm	39.0	mm
	S 9	12.47	5.26			15	4.1	mm 40.0	mm 179.6	9.53	11.05	13.26	51.0	
L6	S 10	-41.14	2.00	1.847	44.5		4.2 4.6	85.0 124.0	185.4 190.9	28.96 34.31	5.68 1.25	1.44 1.53	54.5 59.0	
	S11	36.97	0.20	1.047	 5				_		· · · · · · · · · · · · · · · · · · ·			
L7	S12	23.01			.	20	And FIG. 3	other : 3 and a	lens e compi	mbodying rises thirte	the inve	ntion is	show	vn in
	S 13	-13.81	6.81	1.711	26.7		group	s G1 -	G4 . C	Group G1	comprise	s elemen	its Li	1-L3
L8	S14	-91.05	2.00	1.836	31.1		in the	same	posit	tive config 4-L7 in	gurations.	Group	G2 (com-
	aperture		Z 2			25	config	uratio	n as F	IG. 1. Gr	oup G3 is	a positiv	neg: e do:	ative ublet
	S15	29.03	1.50				L8 and	1 Ly II	n fixed	l relation t	o an aperi	ture defii	iing i	ris I.
L9	S16	23.58	1.63	1.847	23.8		double	et L11	ompri ., L12	ses a position	ive eleme: gative me	nt L10, a niscus co	bico: oncav	nvex /e to
			3.32				the ob	ject. (Group	G4 is of	positive p	ower.		
L 10	S17	38.96	4.55	1.487	70.4	30	forth i	n Tab	ipies d les V	of the lens and VI. E	as snowr Both lense	s are sca	. 3 ar iled t	e set o an
	S18	40.98	Z 3				EFL r	ange	of 24.	5 to 124 n	nm for a 2	24×36 n	ım in	nage
LII	S 19	39.92	6.00	1.487	70.4		f/3.6 a	t the s	shorte	ses, the ref	F/4.7 at t	erture va he larger	ries i EFI	rom L. In
	\$ 10	109.09	0.50			35	both o	f Tabl	es V a	nd VI, gro G1 move	oup G3 an	d the iris	I rei	main
L12	S21	32.42		1 165	(£ 0		the El	ary. C FL is	roup incre	G1 move ased, grown	s toward	the obje	ct en	d as
L13	S22	- 173.96	3.48		65.8		image	end, a	nd gro	oup G4 mo	ves towa	rd the of	oject	end.
L13			2.00	1.600	38.4		Group	Gln	noves	for focusi	ng.			

TA	RI	F	\mathbf{V}

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
_	S1	169.45			
Li	S2	56.72	3.00	1.805	25.5
	S3	56.53	0.41		
L2	S4	-605.21	12.60	1.487	70.4
	S 5	54.35	0.10		
L3	S6	151.66	6.9	1.834	37.3
	S7	95.83	Zl		
L4	S8	14.79	1.50	1.834	37.3
	S9	-65.44	7.53		
L5			2.00	1.835	63.0
	S10	42.84	0.20		
L 6	S11	27.06	15.72	1.741	27.8
L 7	S12	26.96	1.53	1.773	49.6
	S 13	 508.18	Z 2		, -
	aperture	.			
_8	S14	33.47	1.50	1.847	23.8
	S15	25.18		11UT(0.0
			2.66		

1.620

60.3

-47.40

L13

S24

		TABLE V	'-continued	<u>. </u>	
	S16	32.36			
L9	C17	 58.18	4.55	1.487	70.4
	S17	36.16	Z 3		
T 10	S18	38.94	4.00	1.564	60.8
LlO	S19	1862.11	6.00	1.504	UU . 0
			10.93		
T 11	S20	94.60	2.00	1.850	32.2
L11	S21	22.04	2.00	1.050	J 2.2
L12			11.50	1.471	67.3
	S22	-25.15			
	S23	-21.83			(0.3

			ZOOM D	ATA			
f/No.	EFL	FVD	Zl	Z2	Z3	BFL	
3.6	25.5 mm	198.8 mm	1.000 mm	28.636 mm	27.353 mm	40.0 mm	
4.0	40.0	198.3	12.482	16.261	13.378	44.6	
4.6	85.0	214.1	37.390	5.983	2.061	67.1	
4.7	124.0	220.1	47.590	.874	.700	69.3	

2.00

T	A	BL	Æ	\mathbf{V}
	4 b		,	•

		<u>IA</u>	BLE VI		
Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	Nd	V_d
	Si	188.72			
L1			3.00	1.806	25.5
	S2	56.11	0.38		
	S3	56.11	0.50		
L2			12.20	1.487	70.4
	S4	- 608.85			
L3	S5	55.24	6.94	1.834	37.3
	S6	172.29			
	C	00.05	Zl		
L4	S7	99.95	1.50	1.834	37.3
1.7	S8	14.45	1.20		
			6.83		
1 6	S9	63.20	2.00	1.835	43.0
L5	S 10	42.33	2.00	1.055	45.0
			0.20		
1.6	S1 1	26.50	14.48	1.761	26.8
L6	S12	-28.98	17.70	1.701	20.0
L7			1.53	1.743	49.2
	S13	-699.54	71		
	aperture		Z 2		
			2.05		
T 0	S14	33.36	1.60	1.847	23.8
L8	S15	24.83	1.50	1.04/	23.6
			2.50		
	S16	31.37	A & #	1 763	26.9
L9	S17	56.74	4.55	1.762	20.9
	J. ,		Z 3		
	S18	38.07	<i>4</i> 00	1 570	40 t
L 10	S19	1365.55	6.00	1.570	60.1
	4. /	1505.50	11.47		
T 44	S20	88.72	3 00	1 0 4 0	22.2
L11	S21	21.05	2.00	1.850	32.2
L12		200 € + %(* ***	11.50	1.471	67.3
	S22	-25.14	1 4**		
	\$23	-21.79	1.47		
L13	42 0		2.00	1.591	63.0
	S24	-47.99	<u></u>		<u>-</u>
		_ZO	OM LENS		
f/No.	EFL	FVD Z1	Z2 Z3	В	FL

194.6 mm 0.800 mm 26.957 mm 27.515 mm 40.1 mm

25.5 mm

3.6

TABLE VI-continued

TITOLO VI CONTINUCU									
4.0	40.0	194.8	12.491	15.244	13.209	54.7			
4.6	85.0	212.2	38.085	5.614	1.817	67.4			
4.7	124.0	219.0	48.820	0.874	0.700	69.4			

FIG. 4 exemplifies another lens form comprising four groups G1-G4. Group G1 comprises elements L1-L3. Group G2 comprises a negative doublet L4, L5 in the overall shape of a meniscus, a biconcave element L6, 10 and a positive doublet L7, L8. Group G2 is of overall negative power. Group G3 comprises a positive doublet L9, L10 closely spaced behind aperture defining iris D. Group G4 comprises a biconvex element L11, a doublet L12, L13, and a triplet L14, L15, L16 of overall bicon- 15 vex shape. Group G4 is of positive power.

Two lenses as shown in FIG. 4 are described in Table VII and Table VIII as scaled to an EFL range of 24.5 to 124 mm for an image frame of 24×36 mm.

TABLE VII-continued

			ZOOM	DATA		
f/No	. EFL	FVD	Z 1	Z 2	Z 3	BFL
3.8	25.5	185.0	1.000	11.408	37.476	38.5
	mm	mm	mm	mm	mm	mm
4.3	40.0	185.0	9.669	6.664	23.055	49.0
4.5	85.0	185.0	29.817	3.579	5.742	49.2
4.0	124.0	185.0	35.019	0.150	0.401	52.8

TABLE VIII

Axial Distance

Between Surfaces

Surface

Radius

or a	•	rame of 24×36 n	nm.		30	Lens	s Surface		m)	(mm)	s N _d	V_d
	TA	ABLE VII	. 		_ 20 _		S1	142	69			
ce	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d		Ll	S2	46	.13	3.00 0.40	1.805	25.5
•	131.80	· · · · · · · · · · · · · · · · · · ·		- 4	_	12	S 3	46	.01		L 405	30
	45.99	3.00	1.805	25.5	25	L2	S4	-487	.79	13.33	1.487	70.4
		0.40					S 5	44	.75	0.10		
	45.95	13.33	1.487	70.4		L3				6.94	1.806	40.3
	-352.60		1. 107	70.4	•		S6	145	.88	Z 1		
	44.42	0.10			30	L4	S 7	106	.19		5.047	22.6
	145.11	6.94	1.806	40.7			S 8	—73	.61	2.00	1.847	23.8
		Zi				L5	S 9	12	.93	1.50	1.834	37.3
	138.87	2.00	1.847	23.8	25					5.26		
	 78.66				35	L6	S 10	– 49 .	.58	2.00	1.835	43.0
	13.60	1.50	1.834	37.3			SII	39.	.03			, , , ,
	53.44	5.26					S12	21.	.94	0.20		
		2.00	1.835	43.0	40	L7	S 13	— 13 .	0 2	14.07	1.717	29.5
	29.14	0.20			+0	L8				2.00	1.806	40.1
	20.88						S14	584.	.71	Z 2		
	- 12.94	10.12	1.717	29.5			Aperture	:				
	-475.25	2.00	1.806	40.7	45		S15	31.	39	2.05		
	- 475.23	Z 2			,,	L9	S16	23.	71	1.50	1.805	25.5
ire		1.50								1.58		
	32.75					L 10	S17	31.	06	4.55	1.487	70.4
	24.09	1.50	1.805	25.5	50		S 18	51 .	85 `		11107	, 0.1
	21 67	1.41					S 19	43.	25	Z 3		
	31.62	4.55	1.487	70.4		LII	S20	–70 .	0 <i>e</i>	6.00	1.487	70.4
	-44.76	773					320	— 70.	ده	0.20		
	42.56	Z 3			55	L12	S21	27	36	10.00	1.487	70.4
	-72.65	6.00	1.487	70.4			S22	43.	76			70.4
		0.20				L13	S23	23.4	42	2.00	1.541	47.2
	29.20	10.00	1.487	70.4						2.00		
	-42.37				60	L14	S24	45.1	83	2.05	1.786	43.9
	24.84	2.00	1.548	45.8		L15	S25	16.	77	11.00	1 5 1 1	40 E
	50.95	2.00					S26	— 18. .	30	11.00	1.511	60.5
		2.05	1.786	43.9		L16	S27	 52. (12	2.00	1.806	40.7
	18.30	11.00	1 511	60 S	65					M DATA	"	
	-18.72					f/No.	EFL	FVD	Z 1		Z 3	BFL
	50.49	2.00	1.806	40.7		3.8	25.5	179.1	1.00		70	38.5
		-18.72	11.00 -18.72 2.00	11.00 1.511 -18.72 2.00 1.806	11.00 1.511 60.5 -18.72 2.00 1.806 40.7	11.00 1.511 60.5 65 -18.72 2.00 1.806 40.7	11.00 1.511 60.5 65 -18.72 f/No. 2.00 1.806 40.7	11.00 1.511 60.5 65 -18.72 f/No. EFL 2.00 1.806 40.7	-18.72 11.00 1.511 60.5 65 -2.00 1.806 40.7 f/No. EFL FVD 3.8 25.5 179.1	-18.72 11.00 1.511 60.5 65 ZOO -18.72 2.00 1.806 40.7 50.49 2.00 1.806 40.7	-18.72 11.00 1.511 60.5 65 200M DATA -18.72 2.00 1.806 40.7 51.806 40.7 2.00 11.328	-18.72

TABLE VIII-continued

4.3	40.0	183.3	9 993	6.959	15.013	50.6			
4.5	85.0		30.520	3.333	3.717	56.6			
4.6	124.0	203.1	35.169	0.292	0.500	66.4			

The lens of Table VII has a relative aperture varying from f/3.8 at the shorter EFL to f/4.6 at the larger EFL. The front vertex distance (FVD) of this lens does not change during zooming. As the [FFL] EFL is increased from the lower value, group G2 moves toward the image end, group G3 and iris D move in fixed relation toward the image end and group G4 moves toward the object end.

The lens of Table VIII has a relative aperture varying from f/3.8 to f/4.6 at the larger EFL. Here all four groups move during zooming. As the EFL is increased, group G1 moves toward the object end, group G2 moves toward the image end, group G3 and iris D first move toward the image end and then reverse and move toward the object end, and group G4 moves toward the object.

In the prescriptions of Tables IV-VIII, the front vertex distance (FVD) is calculated from a plane 5.00 mm in front of surfaces 51. In tables IV and VI the lenses are focused for a magnification of 1:40 and in tables V, VII and VIII the lenses are focused at infinity.

The power of the groups G1-G4 of the various lenses are set forth in Table IX as K_1 - K_4 respectively together with the geometric mean of the powers K_G of the lens at the ERL extremities, and the zoom ratio Z_R .

TABLE IX

		1 77.1	/ L. J 1 / L	·			_
TABLE	Κl	K ₂	K3_	K4	\mathbf{K}_{G}	Z_R	_
I	.0121	0498	.0114	.0224	.020	3.04	
II	.0118	0512	.0129	.0220	.020	3.04	3
III	.0121	0556	.0145	.0223	.020	3.04	
IV	.0143	0726	.0182	.0149	.0178	4.86	
$\ddot{\mathbf{v}}$.0103	0521	.0156	.0110	.0178	4.86	
νī	.0137	0748	.0177	.0186	.0178	4.86	
VII	.0102	0528	.0159	.0115	.0178	4.86	
VIII	.0129	0763	.0171	.0189	.0178	4.86	4

$$K_G = \sqrt{K_L K_S}$$

where K_L is the power of the lens at its longest EFL and K_S is the power of the lens at its shortest EFL.

It will be noted from the foregoing examples that the power K_3 of group G3 is substantially equal to or greater than the power K_1 of the front group G1. Also K_3 is substantially equal to or less than the geometric mean power K_G of the lens at the extremes of its EFL range.

The power K₃ of group G3 as shown above bears certain relationships to other parameters of the lens:

$$1.2 > (K_3/K_G) > 0.4$$

 $0.006 > (K_3/Z_R) > 0.003$

 $0.25 > (K_3/K_GZ_R) > 0.15$

The third group G3 may be placed on either side of 60 the iris; however, in most cases to permit movement of the other groups to provide the smallest FVD, it will be very closely spaced to the image side of the iris.

While preferred embodiments of the invention have been described, alternate embodiments, as well as other 65 embodiments of the invention may occur to those skilled in the art. Accordingly, the appended claims are intended to encompass all modifications and embodi-

ments of the invention which do not depart from the spirit and scope of the invention.

What I claim is:

1. A lens of variable equivalent focal length extending from a dimension below the diagonal of the image frame of the lens to a dimension substantially above comprising from the object end a first positive group, a second negative group, an aperture defining means, a third positive group closely spaced in fixed relation to the aperture defining means, and a fourth positive group, said [second] first and fourth groups being movable in the same direction to vary the equivalent focal length of the lens, while said second group moves in the opposite direction, said third group and said aperture defining means remaining stationary during change in equivalent focal length, said second group being of strong negative optical power, and

$$5.0 > |K_2/K_G| > 2.0$$

where K_2 is the optical power of said second group and K_G is the geometric mean of the powers of said lens at the extremes of its equivalent focal lengths.

[2. The lens of claim 1 wherein said first group also moves to vary the equivalent focal length of said lens.]

3. The lens of claim [2] I wherein said first and fourth groups move in fixed relation.

4. The lens of claim 1 where all of said groups move in fixed relation to focus said lens.

5. The lens of claim 1 wherein said third group comprises a single element and

$$\left|\frac{R_1}{R_o}\right| > 8$$

where the image side surface of said element is defined on a radius R_I and the object side surface of said element is defined on a radius R_o .

6. The lens of claim 1 wherein said third group comprises two elements.

7. The lens of claim 6 wherein said third group comprises a negative meniscus and a biconvex element.

8. The lens of claim 1 wherein:

$$0.3 > K_3/K_GZ_R > 0.15$$

where

K₃ is the power of the third group

K_G is the geometric mean of the powers of the lens at the extremes of its focal length range, and

 Z_R is the zoom ratio of the lens.

9. The lens of claim 1 wherein:

$$1.3 > K_3/K_G > 0.4$$

where

55

K₃ is the power of the third group, and

 K_G is the geometric mean of the powers of the lens at the extremes of its focal length range.

L10. In a lens of variable focal length, of the type where a negative group on the object side of an aperture defining means and a positive group on the image side of the aperture defining means move axially with respect to the aperture defining means to vary the equivalent focal length of the lens, the improvement comprising, a positive lens component closely, positioned to said aperture defining means and in fixed relation

thereto; said aperture defining means and said positive lens component remaining stationary during variation of the equivalent focal length.

[11. The lens of claim 10 wherein:

 $0.3 > K_3/K_GZ_R > 0.15$

where

K₃ is the power of said positive lens component
K_G is the geometric means of the powers of the lens 10
at the extremes of its focal length range, and
Z_R is the zoom ratio of the lens.

[12. The lens of claim 10 wherein:

 $1.3 > K_3/K_G > 0.4.$

- 13. The lens of claim 1 where the power of said positive group in fixed relation to the aperture defining means is substantially equal to or greater than the power of said front group.
- 14. The lens of claim 1 where the power of said positive group in fixed relation to the aperture defining means is substantially equal to or less than the geometric mean power of said lens.
- 15. The lens of claim 1 where the power of said third 25 group is substantially equal to or greater than the power of said first group and substantially equal to or less [then] than the geometric mean of the powers of the lens at the extremes of its equivalent focal lengths.
- 16. A zoom lens having a range of equivalent focal 30 lengths from a dimension below the diagonal of the image frame of said lens to substantially above comprising means defining a variable aperture, a first positive and a second negative lens group on the object side of said aperture defining means, and a rear positive group on 35 the image side of said aperture defining means, said first, second and rear lens groups being axially movable with respect to said aperture defining means to vary the equivalent focal length of said lens and a third positive group closely positioned to said aperture defining 40 means and in fixed relation thereto, said third group being stationary as said other groups are moved to vary the equivalent focal length, all of said groups being movable in fixed relation to focus said lens.
- 17. The lens of claim 16 wherein said positive group 45 on the object side of said negative group and said positive group on the image side of said aperture defining means move in fixed relation with variation in equivalent focal length.
- 18. The lens of claim 16 where the group in fixed 50 relation to said aperture defining means has an optical power K_3 , the geometric mean power of said lens is K_G , and lens has a zoom ratio Z_R , and

 $0.25 > K_3/K_GZ_R > 0.15$

and where K_3 is the optical power of said third group, K_G is the geometric mean of the optical powers of said lens at the extremes of its equivalent focal length range and Z_R is the zoom ratio of said lens.

19. The lens of claim 16 where

 $0.006 > K_3/Z_R > 0.003$

where K_3 is the optical power of said lens expressed as the 65 reciprocal of its equivalent focal length in millimeters, and Z_R is the zoom ratio of said lens.

20. The lens of claim 16 where

 $1.2 > K_3/K_G > 0.4$

and where K_3 is the optical power of said third group, and K_G is the geometric mean of the optical powers of said lens at the extremes of its equivalent focal length range.

21. A lens according to claim 1 as scaled to an equivalent focal length of 28.5 to 87.0 mm for a 24×36 mm image frame defined substantially as follows:

	Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces	N.T.	* 7
		······································		(mm)	N_d	V_d
15	Li	S1 S2	878.67 53.00	3.00	1.805	25.5
- Z		S 3	54.94	1.80		
, 10	L2	S4	- 295.19	8.70	1.786	43.9
20 -	L3	S5	49.87	0.15	1 025	42.0
;	23	S6	100.18	4.30 Z 1	1.835	43.0
25	L4	S 7	83.91	2.00	1.850	32.2
•		S8	17.34	4.80		
;	L5	S9 S10	116.10 33.18	2.00	1.835	43.0
30		Si1	25.25	.20		
	L6	S12	-17.23	11.54	1.728	28.3
	L7	S13	-826.07	1.50 Z2	1.835	43.0
35		aperture		1.00		
	L8	S14	55.92	2.23	1.667	48.3
40		S15 S16	1165.66 28.44	Z 3		
	L9	S17	-41.5 9	4.79	1.613	58.6
	• • •	S18	—28.11	0.79		
45	L10	\$ 19	38.61	12.00	1.593	35.6
	L11	S20	-145.85	3.00	1.835	43.0
.		S21	-31.12	0.20	2.000	10.0
50	L12	S22	51.53	5.97	1.573	42.6
		S23 S24	-23.68 21.43	0.99		
55	L13	S25	-993.13	1.60	1.805	25.5
	-		7001		· · · · · · · · · · · · · · · · · · ·	

		ZOOM			
EFL	FVD	Z 1	Z 2	Z 3	BFL
28.6 mm	156.4 mm	.80 mm	15.3 mm	14.7 mm	43.6
40.0	161.3	10.4	10.4	10.3	48.5
55.0	165.0	18.6	6.5	6.0	53.1
87.0	171.7	29.2	1.0	0.8	58.9

where L1-L13 are lens elements from the object end; S1-S15 are the lens surfaces from the object end with positive radii struck from the right and negative [ratii] radii struck from the left; N_d is the index of refraction of the lens element; V_d is the Abbe number of the lens elements; Z1, Z2 and Z3 are variable during change in

equivalent focal length; EFL is the equivalent focal length; FVD is the front vertex distance; and BFL is the

back focal length. 22. A lens according to claim 1 as scaled to an equivalent focal length of 28.5 to 87.0 mm for a 24×36 mm 5 Axial Distance Surface image frame defined substantially as follows:

Ť	££		R	irface adius	Axial Dista Between Su (mm)		N_d	Vá	1
Lens	Surfa	ice		mm)	(11111)		1 a	a	ı
Ll	S1		04	19.67	3.00		1.805	25.5	
	S2		:	57.37	1.80				
	S 3			58.75	8.70		1.700	47.8	1
L2	S4		-2 :	37.36			1.700	71.0	
	S5		!	52.91	0.15				
L3	S 6		1	20.92	4.30		1.834	37.3	2
	S7			70.22	Z 1				2
L4					2.00		1.805	25.5	
	S8			17.07	5.10				
L5	S9			64.49	2.00		1.589	61.3	2
	S10		,	25.54	0.50				
L6	S11			22.97	7.17		1.699	30.1	
	S12		_	18.35			1.699	30.1	3
L7	S 13		1	58.15	7.17		1.077	30.1	•
	aperi	ture			Z 2				
	S14			61.35	1.30				
L8	S15			97.26	2.23		1.723	38.0	:
					Z 3				
L9	S16			31.91	4.79		1.658	57.3	
	S17		_	40.93	0.60				4
L10	S18		_	28.41	13.30		1.593	35.5	
	\$19			40.69	2.84				
L11	S 10		_	65.65	3.00		1.583	46.5	
D 11	S21		_	27.15	0.20				4
T 10	S22			50.97			1 617	53 3	
L12	S23		_	23.28	7.25		1.517	52.2	
	S24		_	20.86	1.79				
L13	S25			56.24	1.60		1.847	23.8	
-					I DATA		· · · · · ·		-
EFL		FVD		Zl	Z.2	Z 3	BFL		-
28.6 m 40.0	m	156.5 1 161.8 166.7	mm	0.8 mm 10.6 19.0	15.1 mm 20.4 6.7	16.4 mm 11.3 6.6	42.5 47.8 52.8		

		ZOOM DATA				
EFL	FVD	Zl	Z2	Z 3	BFL	_
28.6 mm	156.5 mm	0.8 mm	15.1 mm	16.4 mm	42.5 mm	5:
40.0	161.8	10.6	20.4	11.3	47.8	
55.0	166.7	19.0	6.7	6.6	52.8	
87.0	173.3	29.8	1.8	0.8	59.3	_

S1-S25 are the lens surfaces from the object end with positive radii struck from the right and negative radii struck from the left; N_d is the index of refraction of the lens elements; V_d is the Abbe number of the lens elements; Z1, Z2 and Z3 are variable during change in 65 equivalent focal length; EFL is the equivalent focal length; FVD is the front vertex distance; and BFL is the back focal length.

23. A lens according to claim 1 as scaled to an equivalent focal length of 28.5 to 87.0 mm for a 24×36 mm image frame defined substantially as follows:

Lens L1	Surfa	ice	{		The state of the s	$-\mathbf{V}_{\perp}$
Ll	-		(mm)	(mm)	N _d	V_d
	S1		367.16	3.00	1.805	25.5
	S2		53.15	1.80		
L2	S3		54.36	8.90	1.700	47.8
	S4	_	220.65	0.15		
L3	S5 S6		46.30 83.28	4.00	1.834	37.3
	S7		59.28	ZI		
L4	S8		16.09	2.00	1.805	25.5
	S9	-	- 59.80	5.04		
L5	S10		28.34	2.00	1.609	59.2
	S11		23.44	0.50		
L6	S 12	•	- 17.37	8.00	1.699	30.1
L7	S 13		110.83	1.50	1.804	46.5
	aper	ture		Z2		
L8	S14		63.48	2.00	1.834	37.3
Lō	S15	_	659.47	Z.3	1.034	نه اکن
L9	S16		32.68	4.79	1.661	57.0
	S17		-42.95	0.60		
L10	S18		-29.12	12.32	1.593	35.5
	S 19		43.26	3.27		
L11	S20		- 229.66	3.80	1.543	46.9
	S21		29.26 57.54	0.20		
L12	S22 S23		- 24.09	7.65	1.517	52.2
	S24		-24.66	1.54		
L13	S25		68.41	1.80	1.847	23.
			ZOO	M DATA		
EFL		FVD	Z 1	Z 2	Z3 BF	
28.6 mr	n	156.3 mm			17.20 mm 42.3	
48.0		161.8	10.32		11.89 47.8 7.03 53.0	
55.0		167.0	18.36 28.70	5.95 1.78		
87.0	<u></u>	174.3	28.70	1.78	.86 60.3	3

where L1-L13 are lens elements from the object end; S1-S25 are the lens surfaces from the object end with positive radii struck from the right and negative radii where L1-L13 are lens elements from the object end; 60 struck from the left; Nd is the index of refraction of the lens elements; V_d is the Abbe number of the lens elements; Z1, Z2, and Z3 are variable during change in equivalent focal length; EFL is the equivalent focal length; FVD is the front vertex distance; and BFL is the back focal length.

24. A lens according to claim 1 as scaled to an equivalent focal length of 25.5 to 124.0 mm for a 24×36 mm image frame defined substantially as follows:

LII

L12

L13

L14

L15

L16

EFL

40.0

85.0

124.0

25.5 mm

S19

S10

S21

S22

S23

S24

S25

S26

S27

S28

FVD

179.6

185.4

190.9

179.0 mm

6.00

0.50

8.48

2.00

1.86

2.05

11.48

0.79

2.50

Z3

13.26

1.44

1.53

1.487 70.4

1.465 65.8

1.600 38.4

1.835 63.0

1.465 65.8

1.835 63.0

BFL

51.0

54.5

59.0

16.54 mm 39.0 mm

-continued

39.92

32.42

29.36

54.84

19.80

-20.07

-18.95

-34.13

Z1

9.53

28.96

34.31

-109.09

-173.96

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	\mathbf{v}_d	
	S1	143.67	· · · · · · · · · · · · · · · · · · ·	···		- 5
Li	S2	45.42	3.00	1.805	25.5	
	S 3	45.12	0.03			
L2	S4	-417.52	13.33	1.476	70.4	10
	S5	43.91	0.10			
L3	S 6	143.05	6.94	1.868	41.2	
	S 7	99.50	Zl			15
L4	S 8	-85.74	2.00	1.860	22.8	1.5
L5	S 9	12.47	1.50	1.856	40.0	
	S10	-41.14	5.26			20
L6	S11	36.97	2.00	1.847	44.5	20
	S12	23.01	0.20			
L7	S 13	— 13.81	6.81	1.711	26.7	
L8	S14	-91.05	2.00	1.836	31.1	25
	aperture		Z 2			
	S15	29.03	1.50			
L9	\$16	23.58	1.63	1.847	23.8	30
	S17	38.96	3.32			
L10	S18	-40.98	4.55	1.487	70.4	
	210	- 10 .70	Z 3			35

where L1-L16 are lens elements from the object end; S1-S28 are the lens surfaces from the object end with positive radii struck from the right and negative radii struck from the left; N_d is the index of refraction of the lens elements; V_d is the Abbe number of the lens elements; Z1, Z2 and Z3 are variable during change in equivalent focal length; EFL is the equivalent focal length; FVD is the front vertex distance; and BFL is the back focal length.

ZOOM DATA

1.00 mm 17.58 mm

 Z_2

11.05

5.68

1.25

25. A lens according to claim 1 as scaled to an equivalent focal length of 25.5 to 124.0 mm for a 24×36 mm image frame defined substantially as follows:

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	\mathbf{v}_d
	SI	169.45			·
LI	S2	56.72	3.00	1.805	25.5
L2	S 3	56.53	0.41		
	S4	-605.21	12.60	1.487	70.4
7.3	S5	54.35	0.10		
L3	S6	151.66	6.9	1.834	37.3
	S 7	95.83	Z1		
L4	S8	14.79	1.50	1.834	37.3
	S 9	65.44	7.53		
L5	S 10	42.84	2.00	1.835	63.0
	S11	27.06	0.20		
L6	S12	-26.96	15.72	1.741	27.8
Ľ7	S 13	- 508.18	1.53	1.773	49.6
			Z2		
L8	aperture S14	33.47			
Lo	S15	25.18	1.50	1.847	23.8
T A	S16	32.36	2.66		
L9	S17	-58.18	4.55	1.487	70.4
			Z 3		

			<u> </u>			
	S18	38.94				
L10			6	5.00	1.564	60.8
	S 19	1862.11				
			10).93		
	S20	94.60				
LII			2	2.00	1.850	32.2
	S21	22.04				
Li2			11	.50	1.471	67.3
	S22	-25.15				
	\$23	-21.83				
L13			2	2.00	1.620	60.3
	S24	-47.40				
		ZC	OOM DATA	_		
EFL	FVD	ZI	Z2	Z 3	BFL	
25.5 m	ım 198.8 mm	1.000 mm	28.636 mm	27.353 mm	40.0	mm

-continued

40.0 85.0	198.3 214.1	12.482 37.390	16.261 5.983	13.378 2.061	44.6 67.1
124.0	220.1	47.590	.874	.700	69.3
1	T 4 T 43	11	manta franct	ha ahiaat an	d
			nents from t		
51-52	4 are the	iens surfaces	s from the o	bject end wit	th le

struck from the left; N_d is the index of refraction of the

lens element; V_d is the Abbe number of the lens ele-

ments; Z1, Z2 and Z3 are variable during change in

equivalent focal length; EFL is the equivalent focal length; FVD is the front vertex distance; and BFL is the back focal length.

26. A lens according to claim 1 as scaled to an equivalent focal length of 25.5 to 124.0 mm for a 24×36 mm image frame defined substantially as follows:

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	\mathbf{V}_d
	S1	188.72			
L1	63	S& 11	3.00	1.806	25.5
	S2	56.11	0.38		
	S 3	56.11	12.20	1 407	70.4
L2	S4	-608.85	12.20	1.487	70.4
	S5	55.24			
L3	64	172.29	6.94	1.834	37.3
	S6	172.27	Z 1		
	S7	99.95	1	1 0 3 4	777
L4	S8	14.45	1.50	1.834	37.3
			6.83		
Ĺ 5	S9	63.20	2.00	1.835	43.0
LJ	S 10	42.33			,,,,
	C11	26.50	0.20		
L6	S11	26.50	14.4	1.761	26.8
	S12	-28.98		1 7/2	40.2
L7	S13	-699.54	1.53	1.743	49.2
			Z2		
	aperture		2.05		
	S14	33.36		1 0 4 7	22.0
L8	S15	24.83	1.50	1.847	23.8
			2.50		
L9	S16	31.37	4.55	1.762	26.9
L,	S17	56.74	4.55	1., 02	20.7
	C10	38.07	Z 3		
L10	S18	36.07	6.00	1.570	60.1
	S19	1365.55	11 47		
	S20	88.72	11.47		
Lil			2.00	1.850	32.2
L12	S2 1	21.05	11.50	1.471	67.3
~	S22	-25.14		-	
	S23	21.79	1.47		
L13	323	41.17	2.00	1.591	63.0
	S24	-47.99			

-continued

		Z(OOM LENS	_	
EFL	FVD	ZI	Z 2	Z 3	BFL
25.5 mm	194.6 mm	0.800 mm	26.957 mm	27.515 mm	40.1 mm
40.0	194.8	12.491	15.244	13.209	54.7
85.0	212.2	38.085	5.614	1.817	67.4
124.0	219.0	48.820	0.874	0.700	69.4

wherein L1-L13 are lens elements from the object end; 10 S1-S24 are the lens surfaces from the object end with positive radii struck from the right and negative radii struck from the left; N_d is the index of refraction of the lens elements; V_d is the Abbe number of the lens elements; Z_1 , Z_2 , and Z_3 are variable during change in 15 equivalent focal length; EFL is the equivalent focal length; FVD is the front vertex distance; and BFL is the back focal length.

27. A lens according to claim 1 as scaled to an equivalent focal length of 25.5 to 124.0 mm for a 24×36 mm 20 image frame defined substantially as follows:

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	\mathbf{v}_d	_ 2
_	S1	131.80				-
Li			3.00	1.805	25.5	
	S2	45.99				
	63	44.04	0.40			
L2	S 3	45.95	12.22	1 405	70.4	3
Lí	S4	-352.60	13.33	1.487	70.4	
	•	332.00	0.10			
	S5	44.42				
L3			6.94	1.806	40.7	
	S6	145.11				4
	07	440.05	Zi			3
T 4	S7	138.87	2.00	1.047	21.0	

	L16	7 -	- 50.49	2.00	1.806	40.7
			Z 00	M DATA	37.5. "'	
	EFL	FVD	Z 1	Z 2	Z 3	BFL
	25.5 mm	185.0 mm	1.000 mm	11.408 mm	37.476 mm	38.5
	40.0	105.0	0.440	, , , ,		mm
	40.0	185.0	9.6 69	6.664	23.055	49.0
	85.0	185.0	29.817	3.579	5.742	49.2
	124.0	185.0	35.019	0.150	0.401	52.8
)						 .
,						

-continued

where L1-L16 are lens elements from the object end; S1-S27 are the lens surfaces from the object end with positive radii struck from the right and negative radii struck from the left; N_d is the index of refraction of the lens elements; V_d is the Abbe number of the lens elements; Z1, Z2, and Z3 are variable during change in equivalent focal length; EFL is the equivalent focal length; FVD is the front vertex distance; and BFL is the back focal length.

28. A lens according to claim 1 as scaled to an equivalent focal length of 25.5 to 124.0 mm for a 24×36 mm image frame defined substantially as follows:

	S 5	44.42	0.10				image frame defined substantially as follows:					
L3	S6 S7	145.11 138.87	6.94 Zi	1.806	40.7	35			Surface Radius	Axial Distance Between Surfaces	·- <u></u>	<u> </u>
L4			2.00	1.847	23.8		Lens	Surface	(mm)	(mm)	N_d	V_d
L5	S8	-78.66	1.50	1.834	37.3		Ll	Sl	142.69	3.00	1.805	25.5
	S9	13.60	6.37			40		S2	46.13			
L6	S 10	- 53.44	5.26	• 04=	43.6	40		S 3	46.01	0.40		
LU	S 11	29.14	2.00	1.835	43.0		L2	S4	- 487.79	13.33	1.487	70.4
			0.20					34		0.10		
L7	S12	20.88	10.13		20.0			S 5	44.75			
	S13	- 12.94	10.12	1.717	29.5	45	L3	S6	145.88	6.94	1.806	40.7
L8	S14	-475.25	2.00	1.806	40.7			C7	106.10	Z 1		
	J .	********	Z 2				L4	S7	106.19	2.00	1.847	23.8
	aperture							S 8	-73.61	2.00	1.047	25.0
	S 15	32.75	1.50			50	L5	50	12.02	1.50	1.834	37.3
L9		J 2 .73	1.50	1.805	25.5			S 9	12.93	5.26		
	S 16	24.09						S 10	-49.58	J. 2 0		
	S17	31.62	1.41				L6	C11	20.02	2.00	1.835'	43.0
L10			4.55	1.487	70.4			S11	39.03	0.20		
	S18	44.76	77.7			55	.	S12	21.94			
	S19	42.56	Z 3				L7	S13	-13.02	14.07	1.717	29.5
LII	020		6.00	1.487	70.4		L8		-13.02	2.00	1.806	40.1
	S20	 72.65	0.20					S14	584.71	~		
	S21	29.20	0.20			60		Aperture		Z 2		
L12	522	40.37	10.00	1.487	70.4			•		2.05		
L13	S22	-42.37	2.00	1.548	45.8		L9	S15	31.39	1.50	1 000	
	S23	24.84		1.540	ŦJ.U		L9	S16	23.71	1.50	1.805	25.5
	S24	50.95	2.00							1.58		
L14	324	30.93	2.05	1.786	43.9	65	L10	S17	31.06	4.55	1 407	70.4
* • •	S25	18.30					~.0	S18	-51.85	4.33	1.487	70.4
L15	S 26	18.72	11.00	1.511	60.5			S 19	43.25	Z 3		
		— -						317	73.23			

		-con	tinued		
L11			6.00	1.487	70.4
	S20	-70.85			
			0.20		
	S21	27.36			
L12			10.00	1.487	70.4
	S22	-43.76			
L13			2.00	1.541	47.2
	S23	23.42			
			2.00		
	S24	45.83		. =0.4	42.0
L14			2.05	1.786	43.9
	S25	16.77	11.00	1 211	(O.5
L15		10.20	11.00	1.511	60.5
	S26	-18.30	2.00	1 206	40.7
L16	C0=	23.03	2.00	1.806	40. 7
	S27	- 52.02			

ZOOM DATA						
EFL	FVD	ZI	Z 2	Z 3	BFL	
25.5 mm	179.1 mm	1.000 mm	11.328 mm	26.53 mm	38.5	
					mm	
40.0	183.3	9.993	6.959	15.013	50.6	
85.0	194.9	30.520	3.333	3.717	56.6	
124.0	203.1	35.169	0.292	0.500	66.4	

where L1-L16 are lens elements from the object end; S1-S27 are the lens surfaces from the object end with positive radii struck from the right and negative radii struck from the left; N_d is the index of refraction of the lens elements; V_d is the Abbe number of the lens elements; Z1, Z2 and Z3 are variable during change in equivalent focal length; EFL is the equivalent length; FVD is the front vertex distance; and BFL is the back focal length.

29. A lens of variable equivalent focal length consisting from the object end a first positive group, a second negative group, a third positive group, and a fourth positive group, an aperture defining means closely positioned to said third group and in fixed relation, said *first*, second and fourth groups being axially movable to vary the equivalent focal length of the lens, said third group

and said aperture defining means being stationary as the equivalent focal length of the lens is varied.

30. The lens of claim 29 where

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$$0.5 < K_1/K_G < 1.0$$

 $2.0 < |K_2/K_G| < 5.0$
 $0.4 < K_3/K_G < 1.2$
 $0.5 < K_4/K_G < 1.3$

where K_1 , K_2 , K_3 and K_4 are the powers of said first, second, third and fourth groups respectively, and K_G is the geometric mean of the powers of said lens at the extremes of its equivalent focal lengths.

31. A lens of variable equivalent focal length extending from a dimension below the diagonal of the image frame of the lens to a dimension substantially above for a camera having a 24×36 mm image frame comprising from the object end, a first positive group, a second negative group, a third positive group, and a fourth positive group, said first, second and fourth groups being movable simultaneously [in opposite directions] to vary the equivalent focal length of said lens, said first and fourth groups being movable in the same direction, said third lens group being stationary, an aperture defining means closely spaced to said third group and in fixed relation thereto, and

$$0.015 > K_1 > 0.010$$
 $0.080 > |K_2| > 0.040$
 $0.019 > K_3 > 0.010$
 $0.023 > K_4 > 0.010$

where K₁, K₂, K₃, and K₄, are the optical powers of said first, second, third, and fourth groups expressed as the reciprocal of the equivalent focal lengths in millimeters of said groups.

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