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Kreitzer

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[54] **ZOOM LENS**

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[73] Assignee: **Vivitar Corporation**, Chatsworth, Calif.

[21] Appl. No.: **659,334**

[22] Filed: **Oct. 10, 1984**

Related U.S. Patent Documents

Reissue of:

[64] Patent No.: **4,256,381**
Issued: **Mar. 17, 1981**
Appl. No.: **117,369**
Filed: **Jan. 31, 1980**

[51] **Int. Cl.**^{4} **G02B 15/14**

[52] **U.S. Cl.** **350/423**; 350/427; 350/450

[58] **Field of Search** 350/423, 427, 450

[56] **References Cited**

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3,501,224	3/1970	Takahashi	350/427
3,840,290	10/1974	Betensky et al.	350/427
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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

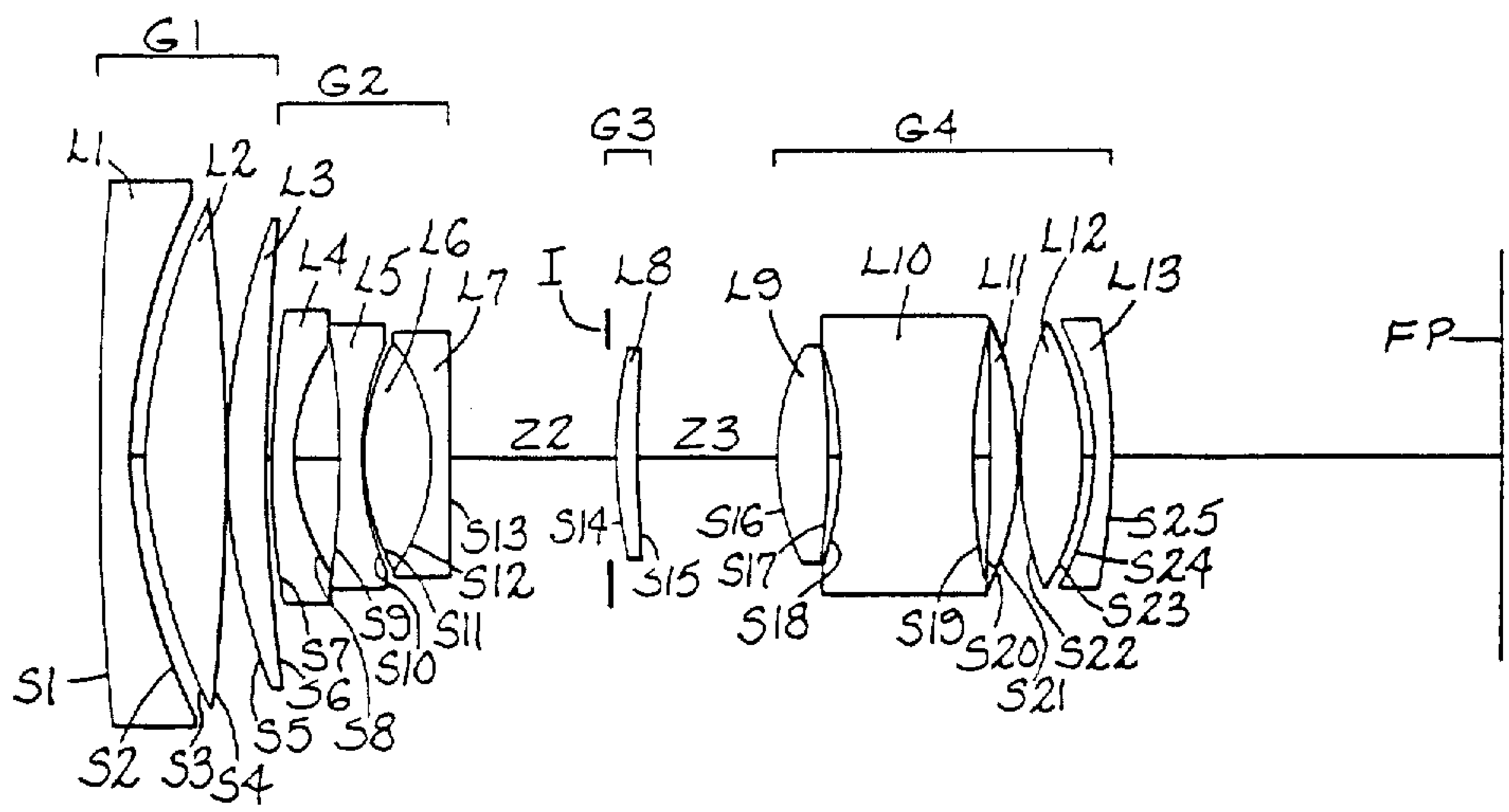
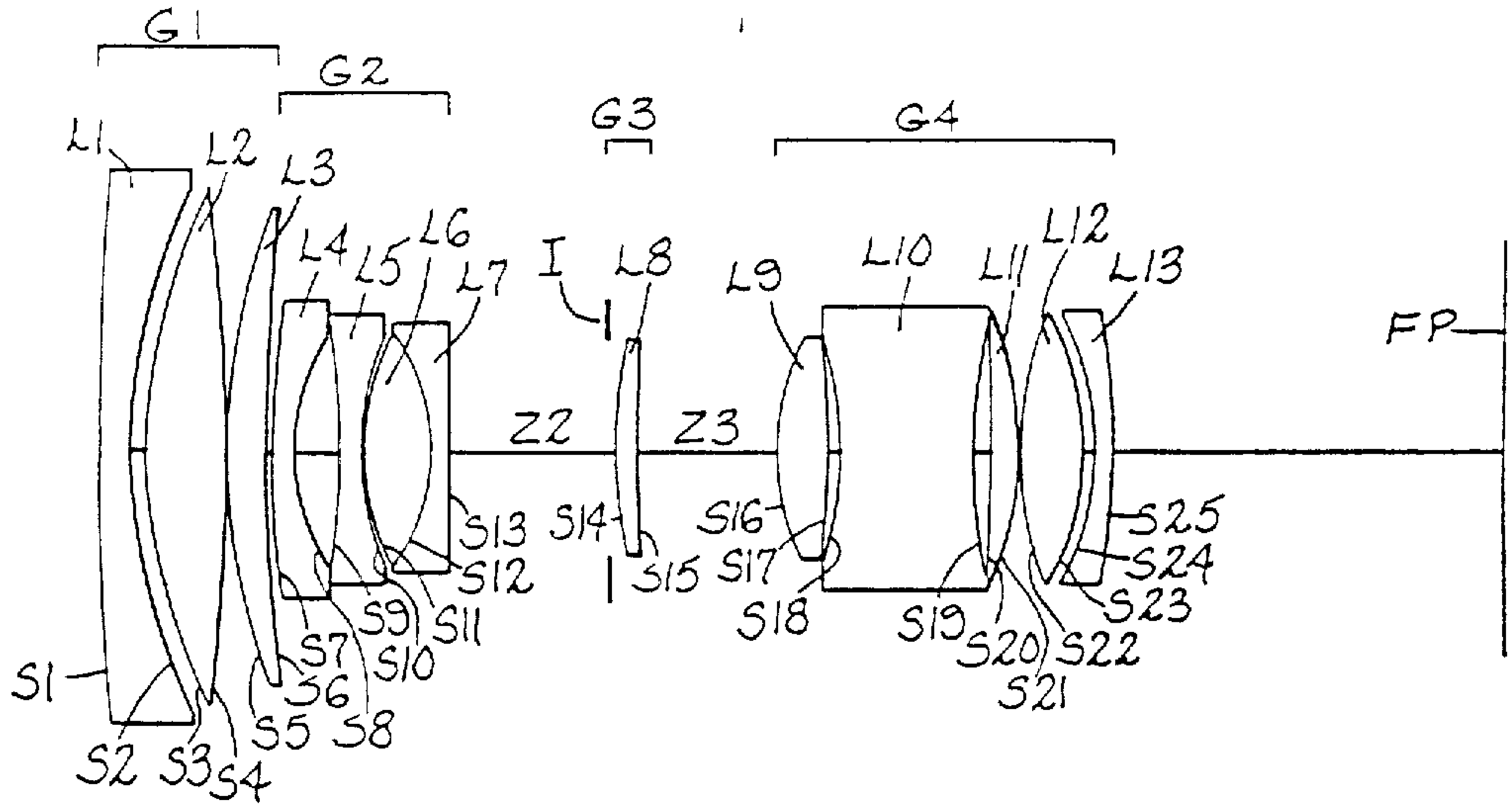


Fig-1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G4
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Fig-1a.

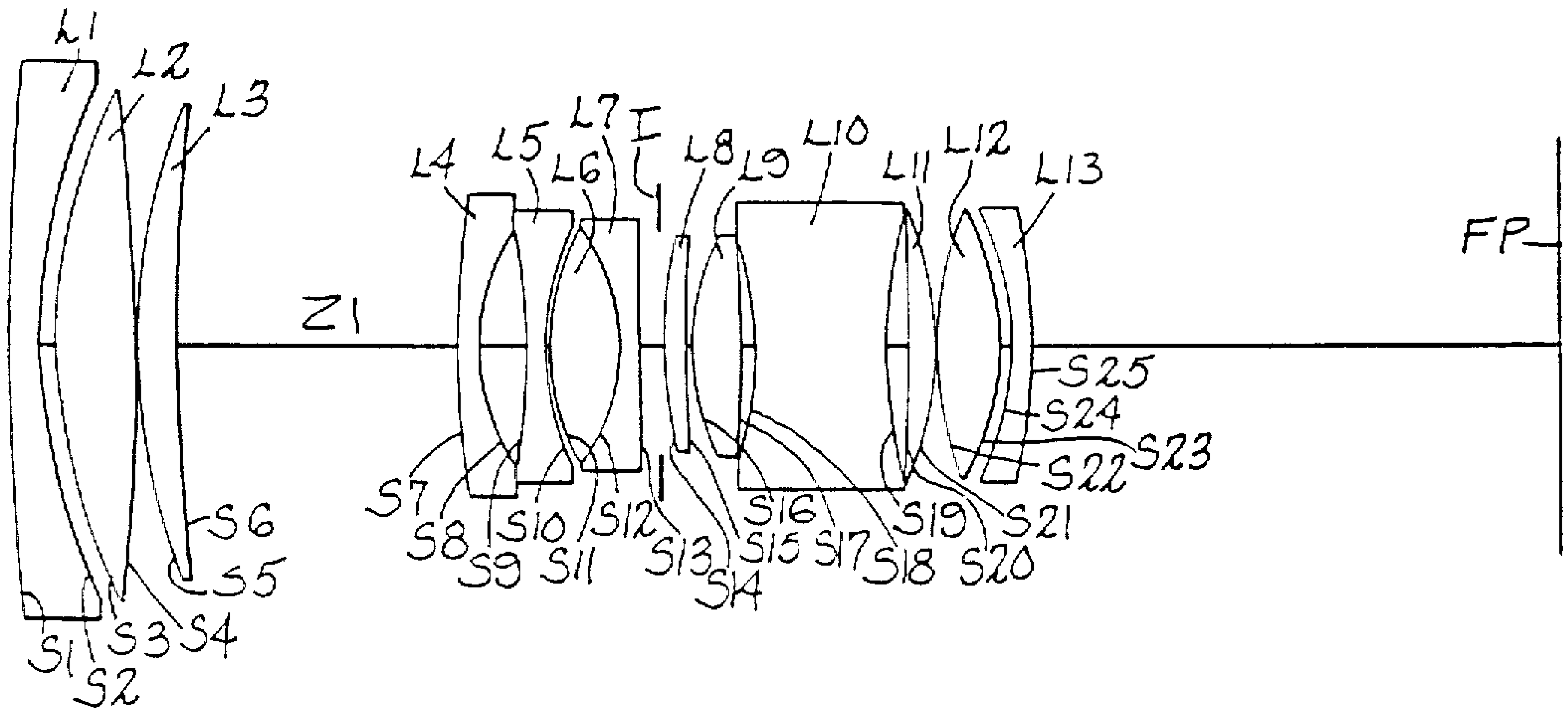
L1
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Fig. 2.

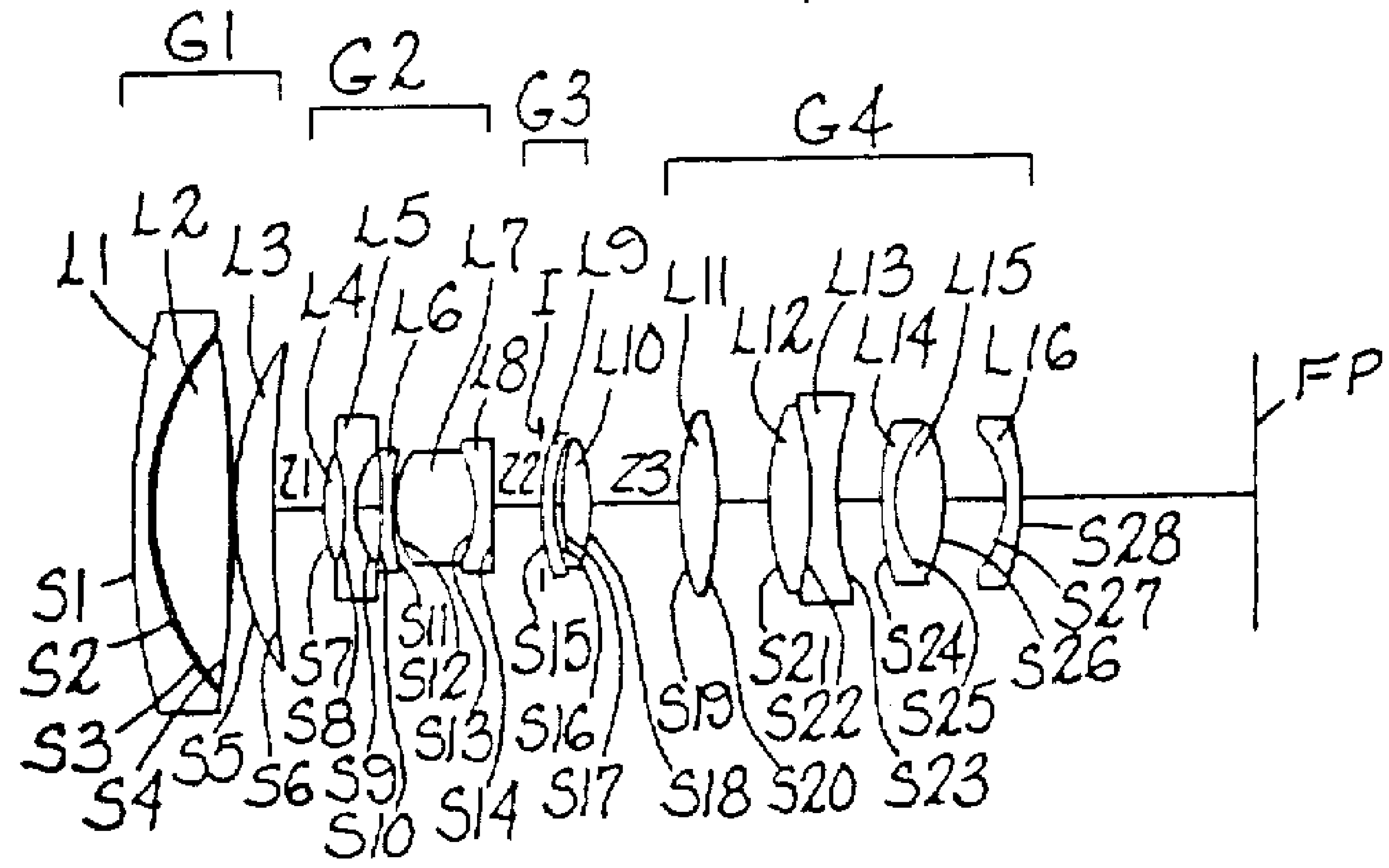


Fig. 3.

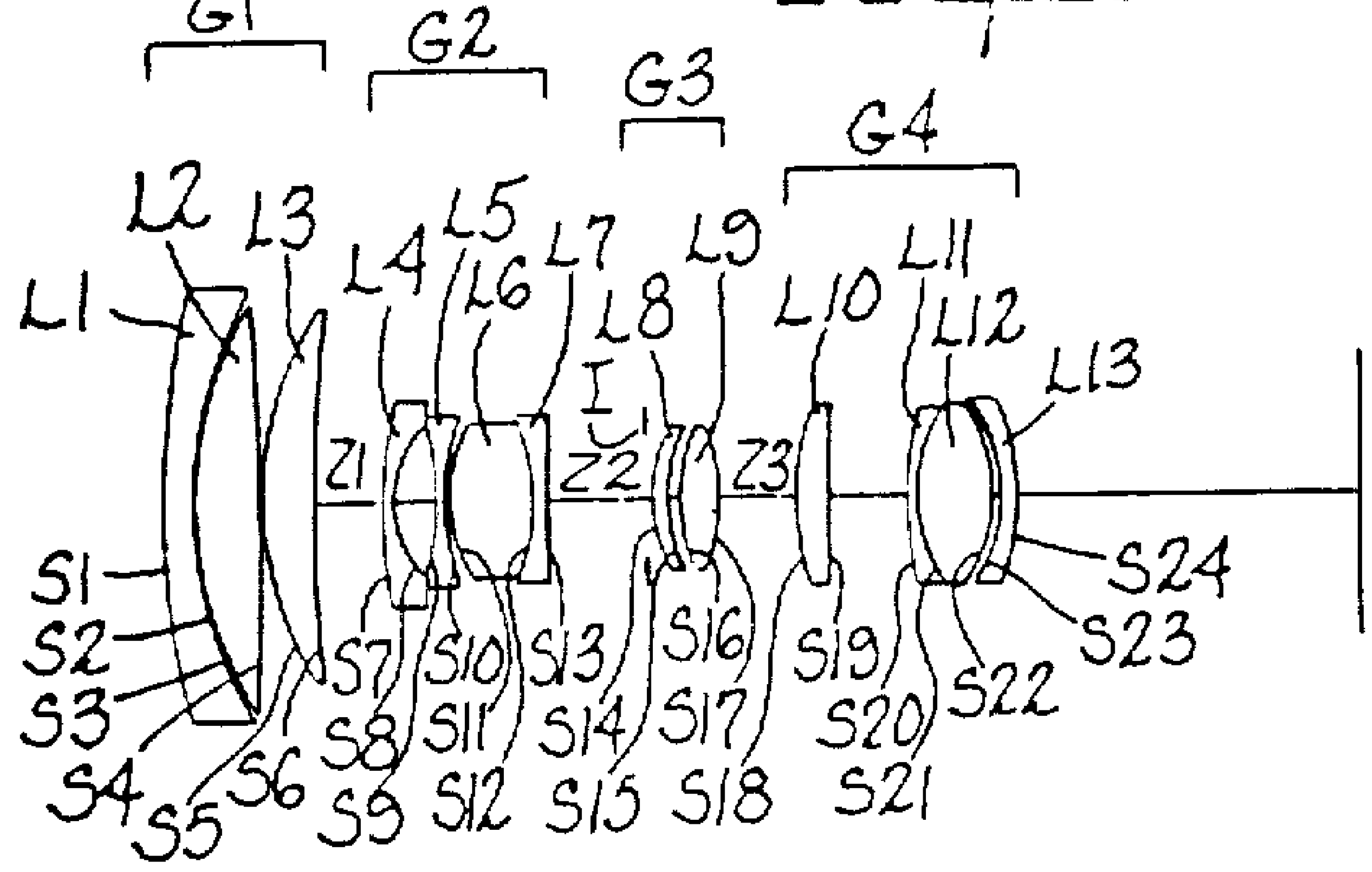
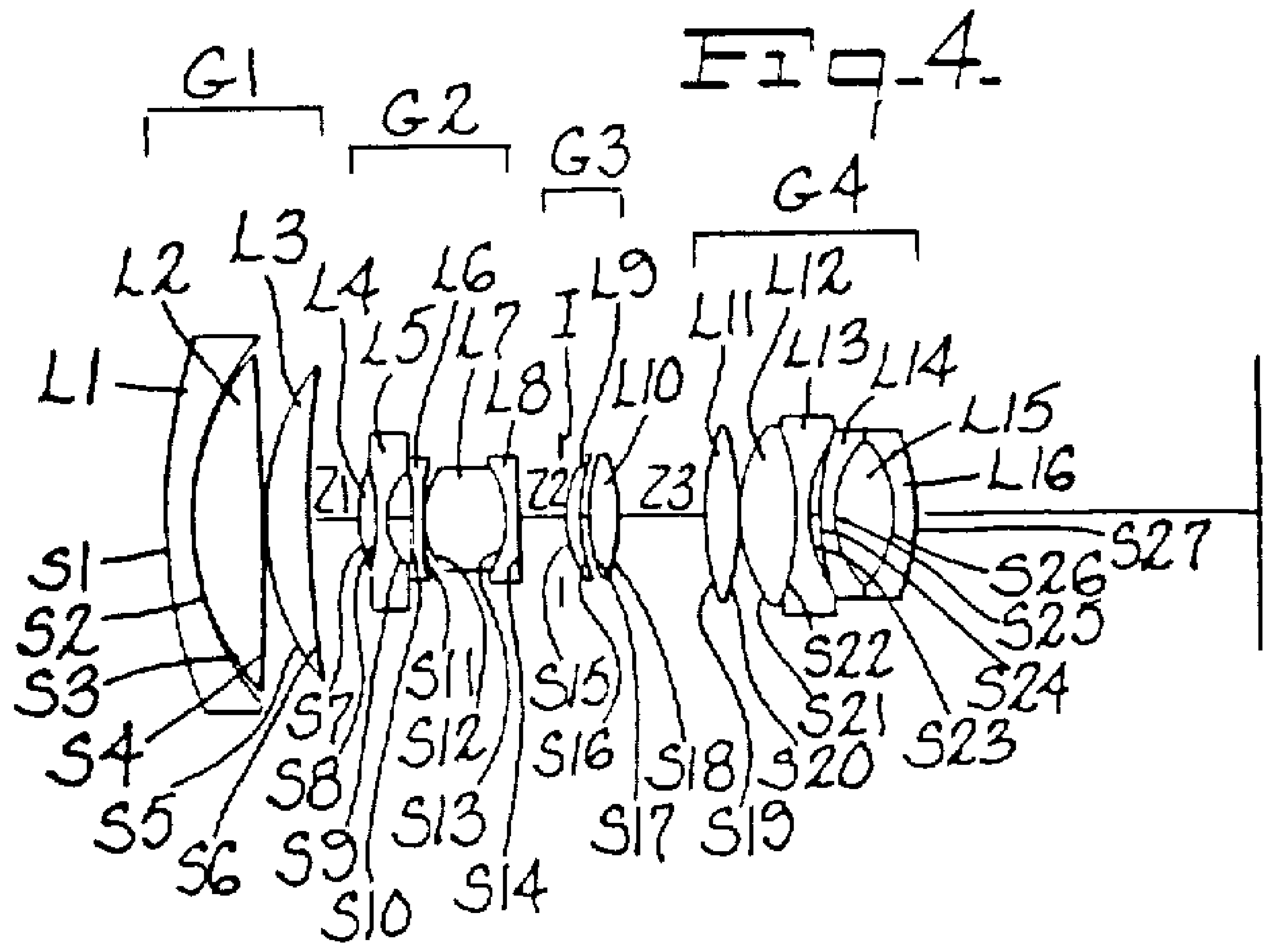


Fig. 4.



ZOOM LENS

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; 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 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 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 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 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 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 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 biconvex element L2, a positive meniscus L3, and is of 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.

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 bears a certain relationship to other parameters of the lens:

$$0.3<(K_3/K_G Z_R)<0.15$$

where

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 $K_G=\sqrt{K_L K_S}$

where

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 **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; 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 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 front vertex distance of the lens, and BFL is the back focal length of the lens. The relative aperture at the various EFL's is given under the heading f/No.

TABLE I

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S1	878.67			
L1			3.00	1.805	25.5
	S2	53.00			
			1.80		
	S3	54.94			
L2			8.70	1.786	43.9
	S4	−295.19			
			0.15		
	S5	49.87			
L3			4.30	1.835	43.0
	S6	100.18			
			Z1		
	S7	83.91			
L4			2.00	1.850	32.2
	S8	17.34			
			4.80		
	S9	−116.10			
L5			2.00	1.835	43.0
	S10	33.18			

TABLE I-continued

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
			.20		
	S11	25.25			
L6			11.54	1.728	28.3
	S12	−17.23			
L7			1.50	1.835	43.0
	S13	−826.07			
			Z2		
	aperture				
			1.00		
	S14	55.92			
L8			2.23	1.667	48.3
	S15	1165.66			
			Z3		
	S16	28.44			
L9			4.79	1.613	58.6
	S17	−41.59			
			0.79		
	S18	−28.11			
L10			12.00	1.593	35.6
	S19	38.61			
			2.68		
	S20	−145.85			
L11			3.00	1.835	43.0
	S21	−31.12			
			0.20		
	S22	51.53			
L12			5.97	1.573	42.6
	S23	−23.68			
			0.99		
	S24	21.43			
L13			1.60	1.805	25.5
	S25	−993.13			

ZOOM DATA

f/No.	EFL	FVD	Z1	Z2	Z3	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

TABLE II

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S1	649.67			
L1			3.00	1.805	25.5
	S2	57.37			
			1.80		
	S3	58.75			
L2			8.70	1.700	47.8
	S4	−237.36			
			0.15		
	S5	52.91			
L3			4.30	1.834	37.3
	S6	120.92			
			Z1		
	S7	70.22			
L4			2.00	1.805	25.5
	S8	17.07			
			5.10		
	S9	−64.49			
L5			2.00	1.589	61.3
	S10	25.54			
			0.50		
	S11	22.97			
L6			7.17	1.699	30.1
	S12	−18.35			
L7			7.17	1.699	30.1
	S13	158.15			
			Z2		
	aperture				
			1.30		
	S14	61.35			
L8			2.23	1.723	38.0
	S15	−697.26			
			Z3		
	S16	31.91			
L9			4.79	1.658	57.3

TABLE II-continued

	S17	−40.93			
			0.60		
	S18	−28.41			
L10			13.30	1.593	35.5
	S19	40.69			
			2.84		
	S10	−65.65			
L11			3.00	1.583	46.5
	S21	−27.15			
			0.20		
	S22	50.97			
L12			7.25	1.517	52.2
	S23	−23.28			
			1.79		
	S24	−20.86			
L13			1.60	1.847	23.8
	S25	−56.24			

ZOOM DATA

f/No.	EFL	FVD	Z1	Z2	Z3	BFL
2.9	28.6 mm	156.5 mm	0.8 mm	15.1 mm	16.4 mm	42.5 mm
3.2	40.0	161.8	10.6	20.4	11.3	47.8
3.5	55.0	166.7	19.0	6.7	6.6	52.8
4.0	87.0	173.3	29.8	1.8	0.8	59.3

TABLE III

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S1	367.16			
L1			3.00	1.805	25.5
	S2	53.15			
			1.80		
	S3	54.36			
L2			8.90	1.700	47.8
	S4	−220.65			
			0.15		
	S5	46.30			
L3			4.00	1.834	37.3
	S6	83.28			
			Z1		
	S7	59.28			
L4			2.00	1.805	25.5
	S8	16.09			
			5.04		
	S9	−59.80			
L5			2.00	1.609	59.2
	S10	28.34			
			0.50		
	S11	23.44			
L6			8.00	1.699	30.1
	S12	−17.37			
L7			1.50	1.804	46.5
	S13	110.83			
			Z2		
	aperture				
			1.30		
	S14	63.48			
L8			2.00	1.834	37.3
	S15	−659.47			
			Z3		
	S16	32.68			
L9			4.79	1.661	57.0
	S17	−42.95			
			0.60		
	S18	−29.12			
L10			12.32	1.593	35.5
	S19	43.26			
			3.27		
	S20	−229.66			
L11			3.80	1.543	46.9
	S21	−29.26			
			0.20		
	S22	57.54			
L12			7.65	1.517	52.2
	S23	−24.09			
			1.54		
	S24	−21.66			

TABLE III-continued

L13			1.80	1.847	23.8
	S25	−68.41			

ZOOM DATA

f/No.	EFL	FVD	Z1	Z2	Z3	BFL
2.9	28.6 mm	156.3 mm	0.84 mm	13.30 mm	17.20 mm	42.3 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.

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

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.

TABLE IV

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d

TABLE IV-continued

Lens	Surface	Radius	Axial Distance	N_d	V_d
	S1	143.67			
L1			3.00	1.805	25.5
	S2	45.42			
			0.03		
	S3	45.12			
L2			13.33	1,476	70.4
	S4	−417.52			
			0.10		
	S5	43.91			
L3			6.94	1.868	41.2
	S6	143.05			
			Z1		
	S7	99.50			
L4			2.00	1.860	22.8
	S8	−85.74			
L5			1.50	1.856	40.0
	S9	12.47			
			5.26		
	S10	−41.14			
L6			2.00	1.847	44.5
	S11	36.97			
			0.20		
	S12	23.01			
L7			6.81	1.711	26.7
	S13	−13.81			
L8			2.00	1.836	31.1
	S14	−91.05			
			Z2		
	aperture				
			1.50		
	S15	29.03			
L9			1.63	1.847	23.8
	S16	23.58			
			3.32		
	S17	38.96			
L10			4.55	1.487	70.4
	S18	−40.98			
			Z3		
	S19	39.92			
L11			6.00	1.487	70.4
	S10	−109.09			
			0.50		
	S21	32.42			
L12			8.48	1.465	65.8
	S22	−173.96			
L13			2.00	1.600	38.4
	S23	29.36			
			1.86		
	S24	54.84			
L14			2.05	1.835	63.0
	S25	19.80			
L15			11.48	1.465	65.8
	S26	−20.07			
			0.79		
	S27	−18.95			
L16			2.50	1.835	63.0
	S28	−34.13			

			ZOOM DATA			
f/No.	EFL	FVD	Z1	Z2	Z3	BFL
3.4	25.5 mm	179.0 mm	1.00 mm	17.58 mm	16.54 mm	39.0 mm
4.1	40.0	179.6	9.53	11.05	13.26	51.0
4.2	85.0	185.4	28.96	5.68	1.44	54.5
4.6	124.0	190.9	34.31	1.25	1.53	59.0

Another lens embodying the invention is shown in FIG. **3** and comprises thirteen elements **L1–L13** in four groups **G1–G4**. Group **G1** comprises elements **L1–L3** in the same positive configurations. Group **G2** comprises elements **L4–L7** in the same general negative configuration as FIG. **1**. Group **G3** is a positive doublet **L8** and **L9** in fixed relation to an aperture defining iris I. Group **G4** comprises a positive element **L10**, a biconvex doublet **L11**, **L12** and a negative meniscus concave to the object. Group **G4** is of positive power.

Two examples of the lens as shown in FIG. **3** are set forth in Tables V and VI. Both lenses are scaled to an EFL range of 24.5 to 124 mm for a 24×36 mm image frame. In both lenses, the relative aperture varies from f/3.6 at the shorter EFL to F/4.7 at the larger EFL. In both of Tables V and VI, group G3 and the iris I remain stationary. Group G1 moves toward the object end as the EFL is increased, group G2 moves toward the image end, and group G4 moves toward the object end. Group G1 moves for focusing.

TABLE V

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S1	169.45			
L1			3.00	1.805	25.5
	S2	56.72			
			0.41		
	S3	56.53			
L2			12.60	1.487	70.4
	S4	−605.21			
			0.10		
	S5	54.35			
L3			6.9	1.834	37.3
	S6	151.66			
			Z1		
	S7	95.83			
L4			1.50	1.834	37.3
	S8	14.79			
			7.53		
	S9	−65.44			
L5			2.00	1.835	63.0
	S10	42.84			
			0.20		
	S11	27.06			
L6			15.72	1.741	27.8
	S12	−26.96			
L7			1.53	1.773	49.6
	S13	−508.18			
			Z2		
	aperture				
	S14	33.47			
L8			1.50	1.847	23.8
	S15	25.18			
			2.66		

TABLE V-continued

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S16	32.36			
L9			4.55	1.487	70.4
	S17	−58.18			
			Z3		
	S18	38.94			
L10			6.00	1.564	60.8
	S19	1862.11			
			10.93		
	S20	94.60			
L11			2.00	1.850	32.2
	S21	22.04			
L12			11.50	1.471	67.3
	S22	−25.15			
	S23	−21.83			
L13			2.00	1.620	60.3
	S24	−47.40			

ZOOM DATA

f/No.	EFL	FVD	Z1	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

TABLE VI

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S1	188.72			
L1			3.00	1.806	25.5
	S2	56.11			
			0.38		
	S3	56.11			
L2			12.20	1.487	70.4
	S4	−608.85			
	S5	55.24			
L3			6.94	1.834	37.3
	S6	172.29			
			Z1		
	S7	99.95			
L4			1.50	1.834	37.3
	S8	14.45			
			6.83		
	S9	−63.20			
L5			2.00	1.835	43.0
	S10	42.33			
			0.20		
	S11	26.50			
L6			14.48	1.761	26.8
	S12	−28.98			
L7			1.53	1.743	49.2
	S13	−699.54			
			Z2		
	aperture				
			2.05		
	S14	33.36			
L8			1.50	1.847	23.8
	S15	24.83			
			2.50		
	S16	31.37			
L9			4.55	1.762	26.9
	S17	−56.74			
			Z3		
	S18	38.07			
L10			6.00	1.570	60.1
	S19	1365.55			
			11.47		
	S20	88.72			
L11			2.00	1.850	32.2
	S21	21.05			
L12			11.50	1.471	67.3
	S22	−25.14			
			1.47		
	S23	−21.79			
L13			2.00	1.591	63.0
	S24	−47.99			

ZOOM LENS

f/No.	EFL	FVD	Z1	Z2	Z3	BFL
3.6	25.5 mm	194.6 mm	0.800 mm	26.957 mm	27.515 mm	40.1 mm

TABLE VI-continued

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**, 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 biconvex 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

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S1	131.80			
L1			3.00	1.805	25.5
	S2	45.99			
			0.40		
	S3	45.95			
L2			13.33	1.487	70.4
	S4	−352.60			
			0.10		
	S5	44.42			
L3			6.94	1.806	40.7
	S6	145.11			
			Z1		
	S7	138.87			
L4			2.00	1.847	23.8
	S8	−78.66			
L5			1.50	1.834	37.3
	S9	13.60			
			5.26		
	S10	−53.44			
L6			2.00	1.835	43.0
	S11	29.14			
			0.20		
	S12	20.88			
L7			10.12	1.717	29.5
	S13	−12.94			
L8			2.00	1.806	40.7
	S14	−475.25			
			Z2		
	aperture				
			1.50		
	S15	32.75			
L9			1.50	1.805	25.5
	S16	24.09			
			1.41		
	S17	31.62			
L10			4.55	1.487	70.4
	S18	−44.76			
			Z3		
	S19	42.56			
L11			6.00	1.487	70.4
	S20	−72.65			
			0.20		
	S21	29.20			
L12			10.00	1.487	70.4
	S22	−42.37			
L13			2.00	1.548	45.8
	S23	24.84			
			2.00		
	S24	50.95			
L14			2.05	1.786	43.9
	S25	18.30			
L15			11.00	1.511	60.5
	S26	−18.72			
L16			2.00	1.806	40.7
	S27	−50.49			

TABLE VII-continued

			ZOOM DATA			
f/No.	EFL	FVD	Z1	Z2	Z3	BFL
3.8	25.5 mm	185.0 mm	1.000 mm	11.408 mm	37.476 mm	38.5 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

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S1	142.69			
L1			3.00	1.805	25.5
	S2	46.13			
			0.40		
	S3	46.01			
L2			13.33	1.487	70.4
	S4	−487.79			
			0.10		
	S5	44.75			
L3			6.94	1.806	40.7
	S6	145.88			
			Z1		
	S7	106.19			
L4			2.00	1.847	23.8
	S8	−73.61			
L5			1.50	1.834	37.3
	S9	12.93			
			5.26		
	S10	−49.58			
L6			2.00	1.835	43.0
	S11	39.03			
			0.20		
	S12	21.94			
L7			14.07	1.717	29.5
	S13	−13.02			
L8			2.00	1.806	40.1
	S14	584.71			
			Z2		
	Aperture				
			2.05		
	S15	31.39			
L9			1.50	1.805	25.5
	S16	23.71			
			1.58		
	S17	31.06			
L10			4.55	1.487	70.4
	S18	−51.85			
			Z3		
	S19	43.25			
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			
L14			2.05	1.786	43.9
	S25	16.77			
L15			11.00	1.511	60.5
	S26	−18.30			
L16			2.00	1.806	40.7
	S27	−52.02			

			ZOOM DATA			
f/No.	EFL	FVD	Z1	Z2	Z3	BFL
3.8	25.5 mm	179.1 mm	1.00 mm	11.328 mm	26.532 mm	38.5 mm

TABLE VIII-continued

4.3	40.0	183.3	9 993	6.959	15.013	50.6
4.5	85.0	194.9	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

TABLE	K_1	K_2	K_3	K_4	K_G	Z_R
I	.0121	−.0498	.0114	.0224	.020	3.04
II	.0118	−.0512	.0129	.0220	.020	3.04
III	.0121	−.0556	.0145	.0223	.020	3.04
IV	.0143	−.0726	.0182	.0149	.0178	4.86
V	.0103	−.0521	.0156	.0110	.0178	4.86
VI	.0137	−.0748	.0177	.0186	.0178	4.86
VII	.0102	−.0528	.0159	.0115	.0178	4.86
VIII	.0129	−.0763	.0171	.0189	.0178	4.86

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

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 K_3 of group G3 as shown above bears certain relationships to other parameters of the lens:

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

$$0.006 > (K_3/Z_R) > 0.003$$

$$0.25 > (K_3/K_G Z_R) > 0.15$$

The third group G3 may be placed on either side of 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 embodiments of the invention may occur to those skilled in the art. Accordingly, the appended claims are intended to encompass all modifications and embodiments 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**] *1* 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:

$$0.3 > K_3/K_G Z_R > 0.15$$

where
- K_3 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
- K_3 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.

[**10.** 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:

$0.3 > K_3/K_G Z_R > 0.15$

where

K_3 is the power of said positive lens component

K_G is the geometric means of the powers of the lens 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 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 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 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 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 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 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

$0.25 > K_3/K_G Z_R > 0.15$

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 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 (mm)	N_d	V_d
	S1	878.67			
L1			3.00	1.805	25.5
	S2	53.00			
			1.80		
	S3	54.94			
L2			8.70	1.786	43.9
	S4	−295.19			
			0.15		
	S5	49.87			
L3			4.30	1.835	43.0
	S6	100.18			
			Z1		
	S7	83.91			
L4			2.00	1.850	32.2
	S8	17.34			
			4.80		
	S9	−116.10			
L5			2.00	1.835	43.0
	S10	33.18			
			.20		
	S11	25.25			
L6			11.54	1.728	28.3
	S12	−17.23			
L7			1.50	1.835	43.0
	S13	−826.07			
			Z2		
	aperture				
			1.00		
	S14	55.92			
L8			2.23	1.667	48.3
	S15	1165.66			
			Z3		
	S16	28.44			
L9			4.79	1.613	58.6
	S17	−41.59			
			0.79		
	S18	−28.11			
L10			12.00	1.593	35.6
	S19	38.61			
			2.68		
	S20	−145.85			
L11			3.00	1.835	43.0
	S21	−31.12			
			0.20		
	S22	51.53			
L12			5.97	1.573	42.6
	S23	−23.68			
			0.99		
	S24	21.43			
L13			1.60	1.805	25.5
	S25	−993.13			

ZOOM DATA

EFL	FVD	Z1	Z2	Z3	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 image frame defined substantially as follows:

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S1	649.67			
L1			3.00	1.805	25.5
	S2	57.37			
			1.80		
	S3	58.75			
L2			8.70	1.700	47.8
	S4	−237.36			
			0.15		
	S5	52.91			
L3			4.30	1.834	37.3
	S6	120.92			
			Z1		
	S7	70.22			
L4			2.00	1.805	25.5
	S8	17.07			
			5.10		
	S9	−64.49			
L5			2.00	1.589	61.3
	S10	25.54			
			0.50		
	S11	22.97			
L6			7.17	1.699	30.1
	S12	−18.35			
L7			7.17	1.699	30.1
	S13	158.15			
			Z2		
	aperture				
			1.30		
	S14	61.35			
L8			2.23	1.723	38.0
	S15	−697.26			
			Z3		
	S16	31.91			
L9			4.79	1.658	57.3
	S17	−40.93			
			0.60		
	S18	−28.41			
L10			13.30	1.593	35.5
	S19	40.69			
			2.84		
	S10	−65.65			
L11			3.00	1.583	46.5
	S21	−27.15			
			0.20		
	S22	50.97			
L12			7.25	1.517	52.2
	S23	−23.28			
			1.79		
	S24	−20.86			
L13			1.60	1.847	23.8
	S25	−56.24			

ZOOM DATA

EFL	FVD	Z1	Z2	Z3	BFL
28.6 mm	156.5 mm	0.8 mm	15.1 mm	16.4 mm	42.5 mm
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

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 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.

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	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S1	367.16			
L1			3.00	1.805	25.5
	S2	53.15			
			1.80		
	S3	54.36			
L2			8.90	1.700	47.8
	S4	−220.65			
			0.15		
	S5	46.30			
L3			4.00	1.834	37.3
	S6	83.28			
			Z1		
	S7	59.28			
L4			2.00	1.805	25.5
	S8	16.09			
			5.04		
	S9	−59.80			
L5			2.00	1.609	59.2
	S10	28.34			
			0.50		
	S11	23.44			
L6			8.00	1.699	30.1
	S12	−17.37			
L7			1.50	1.804	46.5
	S13	110.83			
			Z2		
	aperture				
			1.30		
	S14	63.48			
L8			2.00	1.834	37.3
	S15	−659.47			
			Z3		
	S16	32.68			
L9			4.79	1.661	57.0
	S17	−42.95			
			0.60		
	S18	−29.12			
L10			12.32	1.593	35.5
	S19	43.26			
			3.27		
	S20	−229.66			
L11			3.80	1.543	46.9
	S21	−29.26			
			0.20		
	S22	57.54			
L12			7.65	1.517	52.2
	S23	−24.09			
			1.54		
	S24	−21.66			
L13			1.80	1.847	23.8
	S25	−68.41			

ZOOM DATA

EFL	FVD	Z1	Z2	Z3	BFL
28.6 mm	156.3 mm	0.84 mm	13.30 mm	17.20 mm	42.3 mm
48.0	161.8	10.32	9.14	11.89	47.8
55.0	167.0	18.36	5.95	7.03	53.0
87.0	174.3	28.70	1.78	.86	60.3

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 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.

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:

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S1	143.67			
L1			3.00	1.805	25.5
	S2	45.42			
			0.03		
	S3	45.12			
L2			13.33	1.476	70.4
	S4	−417.52			
			0.10		
	S5	43.91			
L3			6.94	1.868	41.2
	S6	143.05			
			Z1		
	S7	99.50			
L4			2.00	1.860	22.8
	S8	−85.74			
L5			1.50	1.856	40.0
	S9	12.47			
			5.26		
	S10	−41.14			
L6			2.00	1.847	44.5
	S11	36.97			
			0.20		
	S12	23.01			
L7			6.81	1.711	26.7
	S13	−13.81			
L8			2.00	1.836	31.1
	S14	−91.05			
			Z2		
	aperture				
			1.50		
	S15	29.03			
L9			1.63	1.847	23.8
	S16	23.58			
			3.32		
	S17	38.96			
L10			4.55	1.487	70.4
	S18	−40.98			
			Z3		

-continued

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S19	39.92			
L11			6.00	1.487	70.4
	S10	−109.09			
			0.50		
	S21	32.42			
L12			8.48	1.465	65.8
	S22	−173.96			
L13			2.00	1.600	38.4
	S23	29.36			
			1.86		
	S24	54.84			
L14			2.05	1.835	63.0
	S25	19.80			
L15			11.48	1.465	65.8
	S26	−20.07			
			0.79		
	S27	−18.95			
L16			2.50	1.835	63.0
	S28	−34.13			

		ZOOM DATA			
EFL	FVD	Z1	Z2	Z3	BFL
25.5 mm	179.0 mm	1.00 mm	17.58 mm	16.54 mm	39.0 mm
40.0	179.6	9.53	11.05	13.26	51.0
85.0	185.4	28.96	5.68	1.44	54.5
124.0	190.9	34.31	1.25	1.53	59.0

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.

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	V_d
	S1	169.45			
L1			3.00	1.805	25.5
	S2	56.72			
			0.41		
	S3	56.53			
L2			12.60	1.487	70.4
	S4	−605.21			
			0.10		
	S5	54.35			
L3			6.9	1.834	37.3
	S6	151.66			
			Z1		
	S7	95.83			
L4			1.50	1.834	37.3
	S8	14.79			
			7.53		
	S9	−65.44			
L5			2.00	1.835	63.0
	S10	42.84			
			0.20		
	S11	27.06			
L6			15.72	1.741	27.8
	S12	−26.96			
L7			1.53	1.773	49.6
	S13	−508.18			
			Z2		
	aperture				
	S14	33.47			
L8			1.50	1.847	23.8
	S15	25.18			
			2.66		
	S16	32.36			
L9			4.55	1.487	70.4
	S17	−58.18			
			Z3		

-continued

	S18	38.94			
L10			6.00	1.564	60.8
	S19	1862.11			
			10.93		
	S20	94.60			
L11			2.00	1.850	32.2
	S21	22.04			
L12			11.50	1.471	67.3
	S22	−25.15			
	S23	−21.83			
L13			2.00	1.620	60.3
	S24	−47.40			

ZOOM DATA

EFL	FVD	Z1	Z2	Z3	BFL
25.5 mm	198.8 mm	1.000 mm	28.636 mm	27.353 mm	40.0 mm
40.0	198.3	12.482	16.261	13.378	44.6
85.0	214.1	37.390	5.983	2.061	67.1
124.0	220.1	47.590	.874	.700	69.3

where **L1-L13** are lens elements from the object end; **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 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.

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	V_d
	S1	188.72			
L1			3.00	1.806	25.5
	S2	56.11			
			0.38		
	S3	56.11			
L2			12.20	1.487	70.4
	S4	−608.85			
	S5	55.24			
L3			6.94	1.834	37.3
	S6	172.29			
			Z1		
	S7	99.95			
L4			1.50	1.834	37.3
	S8	14.45			
			6.83		
	S9	−63.20			
L5			2.00	1.835	43.0
	S10	42.33			
			0.20		
	S11	26.50			
L6			14.4	1.761	26.8
	S12	−28.98			
L7			1.53	1.743	49.2
	S13	−699.54			
			Z2		
	aperture				
			2.05		
	S14	33.36			
L8			1.50	1.847	23.8
	S15	24.83			
			2.50		
	S16	31.37			
L9			4.55	1.762	26.9
	S17	−56.74			
			Z3		
	S18	38.07			
L10			6.00	1.570	60.1
	S19	1365.55			
			11.47		
	S20	88.72			
L11			2.00	1.850	32.2
	S21	21.05			
L12			11.50	1.471	67.3
	S22	−25.14			
			1.47		
	S23	21.79			
L13			2.00	1.591	63.0
	S24	−47.99			

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			ZOOM LENS		
EFL	FVD	Z1	Z2	Z3	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; **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; **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.

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 image frame defined substantially as follows:

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S1	131.80			
L1			3.00	1.805	25.5
	S2	45.99			
			0.40		
	S3	45.95			
L2			13.33	1.487	70.4
	S4	−352.60			
			0.10		
	S5	44.42			
L3			6.94	1.806	40.7
	S6	145.11			
			Z1		
	S7	138.87			
L4			2.00	1.847	23.8
	S8	−78.66			
L5			1.50	1.834	37.3
	S9	13.60			
			5.26		
	S10	−53.44			
L6			2.00	1.835	43.0
	S11	29.14			
			0.20		
	S12	20.88			
L7			10.12	1.717	29.5
	S13	−12.94			
L8			2.00	1.806	40.7
	S14	−475.25			
			Z2		
	aperture				
			1.50		
	S15	32.75			
L9			1.50	1.805	25.5
	S16	24.09			
			1.41		
	S17	31.62			
L10			4.55	1.487	70.4
	S18	−44.76			
			Z3		
	S19	42.56			
L11			6.00	1.487	70.4
	S20	−72.65			
			0.20		
	S21	29.20			
L12			10.00	1.487	70.4
	S22	−42.37			
L13			2.00	1.548	45.8
	S23	24.84			
			2.00		
	S24	50.95			
L14			2.05	1.786	43.9
	S25	18.30			
L15			11.00	1.511	60.5
	S26	−18.72			

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L16			2.00	1.806	40.7
	S27	−50.49			

			ZOOM DATA		
EFL	FVD	Z1	Z2	Z3	BFL
25.5 mm	185.0 mm	1.000 mm	11.408 mm	37.476 mm	38.5 mm
40.0	185.0	9.669	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

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:

Lens	Surface	Surface Radius (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
	S1	142.69			
L1			3.00	1.805	25.5
	S2	46.13			
			0.40		
	S3	46.01			
L2			13.33	1.487	70.4
	S4	−487.79			
			0.10		
	S5	44.75			
L3			6.94	1.806	40.7
	S6	145.88			
			Z1		
	S7	106.19			
L4			2.00	1.847	23.8
	S8	−73.61			
L5			1.50	1.834	37.3
	S9	12.93			
			5.26		
	S10	−49.58			
L6			2.00	1.835'	43.0
	S11	39.03			
			0.20		
	S12	21.94			
L7			14.07	1.717	29.5
	S13	−13.02			
L8			2.00	1.806	40.1
	S14	584.71			
			Z2		
	Aperture				
			2.05		
	S15	31.39			
L9			1.50	1.805	25.5
	S16	23.71			
			1.58		
	S17	31.06			
L10			4.55	1.487	70.4
	S18	−51.85			
			Z3		
	S19	43.25			

-continued

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			
L14			2.05	1.786	43.9
	S25	16.77			
L15			11.00	1.511	60.5
	S26	−18.30			
L16			2.00	1.806	40.7
	S27	−52.02			

ZOOM DATA

EFL	FVD	Z1	Z2	Z3	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

$$0.5<K_1/K_G<1.0$$

$$2.0<|K_2/K_G|<5.0$$

$$0.4<K_3/K_G<1.2$$

$$0.5<K_4/K_G<1.3$$

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 K_1, K_2, K_3, and K_4, 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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