

SPECIFICATION

Improvements in zoom lenses

5 This invention relates to zoom lens. 5

In most zoom lenses, the first group of lens elements may be moved along the optical axis to achieve focusing from infinity to moderately close distances, typically having a magnification of 1/10 or less. To enable these lenses to focus still closer, in a macro or close focusing mode, the lens is adjusted by suitable repositioning of the zooming groups, or by other lens group repositioning.

10 An example of such optics is disclosed in U.S. Patent No 3,817,600, where the zooming elements are moved in a different relationship to achieve close focusing below two meters up to a magnification of 1:2.2 as close as eighteen inches from the front element. 10

A lens of this type has proven to be an optic and has been marketed as a Vivitar Series I Lens of 70-210mm equivalent focal length (EFL). In the close focusing mode, it is possible to achieve magnifications in the range 15 of 1:2.2 to 1:5. However, this lens does require repositioning of the zooming groups for different movement for close focusing. 15

Attempted competitive lenses of lesser quality generally exhibit poor off-axis image quality caused by large amounts of astigmatism in the close focusing mode. In some cases, spherical aberration causing poor contrast is also introduced.

20 Conventional zoom lenses are characterized by a weak power (long focal length) first group which had been believed to be the best way to minimize aberration change due to focusing. Zoom lens objectives generally do have an optically strong front group. 20

The present invention consists in a zoom lens having a first group movable axially for focusing, a plurality of following groups movable axially of the lens to vary the equivalent focal length of the lens, said front 25 focusing group comprising a positive doublet followed by a positive singlet 25

$$0 < \frac{\theta_s}{\theta_D} < 2.0$$

and

$$.543 > \frac{F_1}{F_L} > .468$$

where θ_s is the optical power of the singlet,

θ_D is the optical power of the doublet,

35 F_1 is the equivalent focal length of the first group, and 35

F_L is the maximum equivalent focal length of the lens.

One lens embodying the present invention is a mechanically compensated zoom lens having the capability of focusing continuously from infinity down to the macro or close focusing mode at the longer equivalent focal length (EFL) by small movement of a front focusing group, i.e. without switching the zooming groups 40 into a close focusing mode. For purposes of definition, "macro" refers to close-up photography with image magnifications, typically in the range of 1:2 magnification. 40

In the present embodiment the close focusing capability to a magnification of 1:2 is achieved by the appropriate design of the front focusing group in relation to the overall lens. This design overcomes the usual design shortcomings by having stability of spherical aberration with conjugate change, strong power, 45 and simple construction. These generally are considered to be conflicting parameters. It is well known that the front group is required to be quite stable with respect to variation of spherical aberration over the focusing range. However, it is also desirable that the front group have strong power to provide a compact system and to reduce as much as possible the required focusing motion. In addition, it is mechanically 50 convenient that the front group be of simple construction, so that the weight of the lens is reduced. This is particularly important for maintaining balance of a lens with a large focusing range, normally resulting in a long lens travel to achieve close focusing. It is also desirable to achieve the above-mentioned effects in an optical system having a relatively fast aperture. 50

It has been determined that by appropriate selection of the power of the front focusing group in relationship to the powers of the overall lens that close focusing as close as 20" to 24" from the front lens 55 element can be achieved with a magnification of about 1:2. 55

This is achieved in a zoom lens in which the front focusing group has a given relationship to the overall power of the lens and where the elements of the focusing group have a given relationship as hereinafter described.

The invention will now be described, by way of example, with reference to the accompanying drawings, in 60 which:- 60

Figures 1-4 are diagrammatic side views of lens embodying the invention.

A lens embodying the invention includes a strongly positive first group G1, which is adjustable axially for focusing of the optical system. A second component is a variator or negative component group variable along the optical axis for varying the equivalent focal length of the objective lens. This group G2 is movable 65 along with, and relative to a third component group G3 which acts as a compensator to maintain a fixed 65

(14)

image plane as the focal length of the optical system is varied. Although this lens is capable of focusing to extremely close distances, the zoom components G2 and G3 are not required to be independently adjustable to assist in the focusing of the optical system when in a macro or close focusing range. Group G4 is a fixed objective lens for relaying the image to the image or focal plane of the system.

- 5 In the optical design typifying the embodiments, the first positive group G1 comprises two positive components, a doublet L1, L2, followed by a positive element L3.

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The elements of group G1 satisfy the conditions:

$$0 < \theta_s / \theta_D < 2.0$$

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where θ_D designates the power of the doublet group within the front group G1 and θ_s designates the power of the singlet lens within the front group. Also,

$$.543 > \frac{F_1}{F_L} > .468$$

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where F_1 is the focal length of the first group, and F_L is the long extreme equivalent focal length of the lens.

- 20 The parameters set forth are necessary for suitably balancing the aberrations of the lens system when the lens is focused across the intended broad range. Together, the conditions prevent or significantly reduce aggravation of spherical aberrations and astigmatism which may occur as the angles of the incident light rays change due to focusing of the lens on distant, and extremely close objects. Satisfaction of these parameters ensures a compact lens with a relatively short focusing motion. As set forth hereinafter, the dimensions, relationships, and parameters of the lenses are such as to satisfy the conditions as set forth above.

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- 25 More specifically, the first parameter

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$$0 < \theta_s / \theta_D < 2.0$$

- 30 is required in order to yield the distribution of power necessary for stability of spherical aberration with respect to conjugate change.

30

The second parameter

$$.543 > \frac{F_1}{F_L} > .468$$

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is required because of the relationship between the power θ_1 of the focusing group and the necessary focusing travel FT for a given object distance FD, namely

$$FD = \frac{F_1^2}{F_T} \text{ (mm)}$$

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- 45 where FD is the focusing distance, F_1 is the EFL of the front focusing group and F_T is the focusing travel of the front group from infinity to the closest focusing distance. As the power of group G1 increases, the F_1 correspondingly decreases, the focusing distance FD decreases.

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Moreover, if the power of the front group becomes too strong, it is impossible to satisfactorily correct the spherical aberration and astigmatism over a range of conjugates.

- 50 Particularly, the first lens group G1, as shown in Figure 1, includes a positive doublet subtending a negative element L1 and a biconcave element L2 formed as a cemented doublet of strong positive power, followed by a positive meniscus element L3 convex to the object. These elements are in fixed relation, adapted to be shifted axially as a group for focusing images of subjects at distances as close as 20 inches from the front element L1, regardless of the equivalent focal length of the lens. This selection of the relatively strong power in group G1 reduces the focusing travel as will be apparent from the foregoing equation.

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- 55 The variator or second lens group G2 is negative and is air-spaced from the first component by a variable amount. This variator group G2 includes a negative element L4 which is separated from a negative biconcave doublet L5, L6.

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The compensator or third lens group G3 is of biconvex and of positive power and includes a negative meniscus L7 and a biconvex element L8. Group G3 is movable axially relative to the variator group G2 and the forward component of a fixed relay group G3.

- 60 The relay group G4 is divided into two separate widely spaced subgroups or components. The forward component has positive power and is fixed relative to the rear component of that group. The forward component includes a positive element L9 spaced from a doublet formed of positive element L10 and a negative element L11 forming a cemented doublet. The rear component, a negative component L12, is closely spaced to a positive component L13.

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- 65 The foregoing preferred embodiment includes 13 elements arranged in the four component groups.

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In the following tables, various embodiments of the invention are set forth for various EFL ranges, with the parameters of the invention. In the following prescription tables, the reference L followed by an arabic numeral indicates lens elements, the lens elements progressively from the object end to the image end of the lens. The reference surface numbers R are the progressive lens surfaces. N_d is the index of refraction of the lens elements. V_d is the dispersion of the lens elements as measured by the Abbe number. The spaces Z are spaces between lens groups which vary with change in equivalent focal length (EFL). Positive surface radii are struck from the right at the optical axis. Negative radii are struck from the left at the optical axis.

5 A lens as shown in Figure 1 scaled to an image frame of 24×36 mm and EFL's of 101mm to 195mm is substantially described in Table I.

TABLE I

Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
L1	S1 = 69.077	3.0	1.7847	26.06
L2	S2 = 44.817	10.0	1.5101	63.43
	S3 = -213.552	0.3		
L3	S4 = 92.077	3.5	1.5101	63.43
	S5 = 142.825	Z1		
L4	S6 = 600.754	2.0	1.6583	57.26
	S7 = 69.943	3.5		
L5	S8 = -71.613	2.0	1.6910	54.70
L6	S9 = 32.133	4.76	1.8467	23.83
	S10 = 76.984	Z2		
L7	S11 = 74.163	2.0	1.7847	26.06
L8	S12 = 39.674	6.29	1.5638	60.83
	S13 = -96.905	Z3		
L9	S14 = 78.588	3.0	1.5101	63.43
	S15 = 693.028	0.3		
L10	S16 = 26.460	5.826	1.5101	63.43
L11	S17 = 427.148	2.0	1.8061	40.74
	S18 = 45.219	4.81		
	Aperture Stop	40.26		
L12	S19 = -18.927	2.0	1.7725	49.62
	S20 = -53.001	0.3		
L13	S21 = 412.053	3.42	1.6727	32.17
	S22 = -53.841			
EFL	Z1	Z2	Z3	
101mm	2.81mm	31.68mm	3.72mm	
152	18.84	14.89	4.50	
195	25.51	1.33	11.37	

A lens as shown in Figure 2 scaled to an image frame of $24 \times 36\text{mm}$ and EFL's of 76.0mm to 200.1mm is substantially described in Table II.

TABLE II

5	Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d	5
10	L1	S1 = 100.120	3.0	1.785	26.1	10
	L2	S2 = 58.560	7.34	1.510	63.4	
		S3 = plano	0.3			
15	L3	S4 = 97.870	5.15	1.510	63.4	15
		S5 = -539.860	Z1			
20	L4	S6 = 205.760	1.5	1.720	50.3	20
		S7 = 70.027	3.74			
	L5	S8 = -84.552	1.5	1.720	50.3	
25	L6	S9 = 27.698	4.51	1.785	25.7	25
		S10 = 126.250	Z2			
30	L7	S11 = 104.624	6.08	1.487	70.4	30
	L8	S12 = -32.924	1.2	1.785	26.1	
		S13 = -51.566	Z3			
35	L9	S14 = 32.652	6.24	1.573	57.5	35
	L10	S15 = -85.340	2.0	1.806	40.7	
40		S16 = 175.960	4.81			40
		Aperture Stop	42.660			
	L11	S17 = -19.451	2.0	1.804	46.5	
45		S18 = -37.265	0.3			45
	L12	S19 = 101.789	2.27	1.673	3.22	
		S20 = -300.147				
50	EFL	Z1	Z2	Z3		50
	76.00mm	1.73mm	37.58mm	12.09mm		
	125.00	26.25	23.15	2.00		
55	200.1	39.92	1.48	10.00		55

Another embodiment of an optical system according to this invention is given in Table III. In this embodiment, group G1 is substantially the same as described with respect to Figure 2, S3 is plano and S5 is negative. Group G2 includes a first positive element L4 which forms a doublet with negative element L5. In this group G2 component, a negative element L6 is spaced slightly from the doublet and is spaced variably by a larger distance from group G3.

In group G3, the doublet is reversed with respect to Figure 2 in that L11 is a meniscus and L12 is a biconvex element. Group G4 has the same elemental configuration as Figure 2.

A lens as shown in Figure 2 scaled to an image frame of 24×36 mm and EFL's of 72mm to 150 mm is substantially described in Table III.

TABLE III

5	Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d	5
10	L1	S1 = 62.296	3.0	1.7847	26.06	10
	L2	S2 = 41.370	12.806	1.4875	70.44	
		S3 = -266.277	0.3			
15	L3	S4 = 86.478	4.095	1.4875	70.44	15
		S5 = 2731.894	Z1			
20	L4	S6 = -259.053	2.0	1.6910	54.70	20
		S7 = 65.984	2.805			
	L5	S8 = -71.603	2.0	1.7433	49.22	
25	L6	S9 = 24.730	4.755	1.8467	23.83	25
		S10 = 72.248	Z2			
30	L7	S11 = 49.336	2.0	1.8467	23.83	30
	L8	S12 = 25.951	6.287	1.6667	48.30	
		S13 = -133.121	Z3			
35	L9	S14 = 22.123	5.381	1.4875	70.44	35
		S15 = -684.989	2.0	1.8042	46.50	
	L10	S16 = 66.251	29.67			40
40		S17 = -14.503	2.0	1.5310	58.20	
	L11	S18 = -31.216	0.3			
45		S19 = 120.523	2.350	1.8040	46.50	45
	L12	S20 = -189.269				
50	EFL	Z1	Z2	Z3		50
	72.0mm	1.6	27.051	0.3		
	111.0	14.289	13.162	1.5		
	150.0	19.843	0.3	8.809		

55 Another twelve element form of the invention is generally similar to Figure 2. This lens differs from Figure 2 in that S3 is very weakly negative instead of plano, and S12 is positive, thus reversing the doublet forming group G3. 55

As scaled to a 24 × 36mm image frame and EFL's of 72mm to 203mm, this lens is substantially described in Table IV.

TABLE IV

Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N _d	V _d
L1	S1 = 87.504	3.000	1.7847	26.06
	S2 = 57.456			
L2	S3 = -576.167	12.806	1.4875	70.44
	S4 = 110.904			
L3	S5 = -1960.632	3.500	1.4875	70.44
	S6 = -829.307			
L4	S7 = 84.246	2.000	1.6910	54.70
	S8 = -91.582			
L5	S9 = 29.357	2.000	1.7433	49.22
	S10 = 80.962			
L6	S11 = 76.817	4.755	1.8467	23.83
	S12 = 36.571			
L7	S13 = -118.534	6.287	1.6667	48.30
	S14 = 25.919			
L8	S15 = -154.920	7.000	1.4875	70.44
	S16 = 92.608			
L9	S17 = -17.481	2.000	1.8042	46.50
	S18 = -37.440			
L10	S19 = 251.831	2.029	1.7495	35.04
	S20 = -69.558			
L11		2.452		
L12				
EFL	Z1	Z2	Z3	
72.0mm	1.5mm	49.045mm	0.3mm	
150.0	30.760	18.585	1.5	
203.0	36.664	0.3	13.881	

Another embodiment of the invention as shown in Figure 3, scaled to an image frame of 24 × 36mm and EFL's of 101mm to 194mm, is substantially described in Table V.

TABLE V

Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N _d	V _d
L1	S1 = 70.981	3.0	1.7847	26.06
	S2 = 45.725			
L2	S3 = -190.826	10.0	1.5101	63.43
	S4 = 77.534			
L3	S5 = 115.121	3.5	1.5101	63.43
	S6 = -366.358			
L4	S7 = -49.175	3.829	1.8467	23.83
	S8 = 61.777			
L5	S9 = -53.090	2.0	1.6910	54.70
	S10 = 255.263			
L6	S11 = 93.727	3.961	1.6583	57.26
	S12 = -35.861			
L7	S13 = -71.255	6.429	1.5638	60.83
	S14 = 74.385			
L8	S15 = 259.362	2.0	1.7847	26.06
	S16 = 26.413			
L9	S17 = 366.100	2.629	1.5101	63.43
	S18 = 43.497			
L10	S19 = 112.212	5.653	1.5101	63.43
	S20 = -77.326			
L11	S21 = -24.455	2.0	1.8061	40.74
	S22 = -97.188			
L12		27.063	1.6727	32.17
L13		2.615	1.6727	32.17
L14		6.977	1.7725	49.62
L15		2.0	1.7725	49.62
L16		0.3		
L17		2.0		
L18		3.961		
L19		3.829		
L20		10.0		
L21		3.0		
L22		0.3		
L23		3.5		
L24		3.0		
L25		3.0		
L26		3.0		
L27		3.0		
L28		3.0		
L29		3.0		
L30		3.0		
L31		3.0		
L32		3.0		
L33		3.0		
L34		3.0		
L35		3.0		
L36		3.0		
L37		3.0		
L38		3.0		
L39		3.0		
L40		3.0		
L41		3.0		
L42		3.0		
L43		3.0		
L44		3.0		
L45		3.0		
L46		3.0		
L47		3.0		
L48		3.0		
L49		3.0		
L50		3.0		
L51		3.0		
L52		3.0		
L53		3.0		
L54		3.0		
L55		3.0		
L56		3.0		
L57		3.0		
L58		3.0		
L59		3.0		
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L61		3.0		
L62		3.0		
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L64		3.0		
L65		3.0		
L66		3.0		
L67		3.0		
L68		3.0		
L69		3.0		
L70		3.0		
L71		3.0		
L72		3.0		
L73		3.0		
L74		3.0		
L75		3.0		
L76		3.0		
L77		3.0		
L78		3.0		
L79		3.0		
L80		3.0		
L81		3.0		
L82		3.0		
L83		3.0		
L84		3.0		
L85		3.0		
L86		3.0		
L87		3.0		
L88		3.0		
L89		3.0		
L90		3.0		
L91		3.0		
L92		3.0		
L93		3.0		
L94		3.0		
L95		3.0		
L96		3.0		
L97		3.0		
L98		3.0		
L99		3.0		
L100		3.0		
EFL	Z1	Z2	Z3	
101.0mm	2.812mm	29.314mm	3.744mm	
152.0	18.190	13.176	4.503	
194.0	24.580	0.3	10.990	

Another embodiment of the invention is substantially as shown in Figure 3 differing in elemental configuration only that in negative group G3 the elements L7 and L8 are reversed. Such lens as scaled to an image frame of $24 \times 36\text{mm}$ and EFL of 71.5mm to 146.5mm is substantially described in Table VI.

TABLE VI				
Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d
L1	S1 = 55.041	2.50	1.785	26.1
L2	S2 = 36.225	8.50	1.510	63.4
L3	S3 = -246.043	0.2		
L3	S4 = 86.032	3.0	1.510	63.4
L4	S5 = 380.808	Z1		
L4	S6 = -192.163	1.5	1.658	57.3
L5	S7 = 51.582	2.56		
L5	S8 = -63.000	1.5	1.691	54.7
L6	S9 = 21.990	3.6	1.785	26.1
L6	S10 = 67.930	Z2		
L7	S11 = 54.447	1.5	1.785	26.1
L8	S12 = 27.783	5.5	1.540	59.7
L9	S13 = -85.292	Z3		
L9	S14 = 74.074	2.5	1.510	63.4
L9	S15 = -300.882	0.2		
L10	S16 = 18.412	5.0	1.510	63.4
L11	S17 = 153.957	1.5	1.806	40.7
L11	S18 = 31.629	2.25		
L12	Aperture	26.614		
L12	S19 = -13.655	1.5	1.773	49.6
L13	S20 = -23.408	0.2		
L13	S21 = 93.578	3.5	1.673	3.22
L13	S22 = -193.289			
EFL	Z1	Z2	Z3	
71.5mm	1.50mm	22.89mm	3.49mm	
110.0	14.45	11.83	1.60	
146.5	20.58	1.00	6.30	

The invention may be embodied in various lens forms. Figure 4 shows a zoom lens having thirteen elements in three moving groups, G1, G2 and G3. The first two groups G1 and G2 comprise elements L1-L6 in configurations previously described. The third group G3 comprises a positive meniscus L7, a doublet L8, L9, a biconvex element L10, a negative meniscus L11 and a closely spaced biconvex element L12 and a

negative meniscus concave to the object. This lens has only two internal variable spaces Z1 and Z2; however, the front group G1 moves forward as the EFL increases, thus increasing the front vertex distance (FVD).

Another embodiment of the invention according to Figure 4, scaled to an image frame of 24 × 36mm and 5 having EFL's of 51.6mm to 145.3mm is substantially described in Table VII.

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TABLE VII

Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N _d	V _d
L1	S1 = 154.274	2.000	1.805	25.5
	S2 = 60.625			
L2	S3 = -166.752	7.482	1.603	60.7
	S4 = 49.425			
L3	S5 = 976.009	0.200	1.487	70.4
	S6 = -111.965			
L4	S7 = 29.937	4.711	1.834	37.3
	S8 = -40.282			
L5	S9 = 34.267	1.500	1.487	70.4
	S10 = -661.409			
L6	S11 = 58.780	4.190	1.847	23.8
	S12 = 588.325			
L7	S13 = 40.593	0.200	1.785	25.7
	S14 = -38.790			
L8	S15 = 60.207	6.062	1.518	59.0
	S16 = 29.884			
L9	S17 = 47.488	1.500	1.805	25.5
	S18 = 17.934			
L10	S19 = 18.509	0.200	1.603	60.7
	S20 = -62.404			
L11	S21 = -19.946	4.661	1.834	37.3
	S22 = -58.480			
L12	Aperture	15.024	1.632	34.8
	S17 = 47.488			
L13	S18 = 17.934	0.309	1.632	34.8
	S19 = 18.509			
L14	S20 = -62.404	5.462	1.632	34.8
	S21 = -19.946			
L15	S22 = -58.480	6.297	1.632	34.8
L16		1.500	1.834	37.3
EFL	Z1	Z2	BFL	
51.6mm	2.00mm	36.18mm	38.66mm	
65.0	5.63	29.28	42.82	
80.1	9.14	21.50	46.04	
145.3	16.17	1.00	59.53	

As previously pointed out, there are certain parameters which must be satisfied to achieve the close focusing capability with minimum focusing travel. Table VIII sets forth the important parameters of each lens.

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TABLE VIII

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Table	K_1	F_1	K_L	F_L	F_1/F_L	θ_S/θ_D
I	.0096	104.17	.0051	195	.534	0.26
10 II	.0092	109.13	.0050	201	.543	0.31
10 III	.0124	80.65	.0066	150	.538	0.75
IV	.0091	109.89	.0049	203	.541	1.00
V	.0100	100.0	.0052	194	.515	0.33
VI	.0131	76.1	.0068	146.5	.519	1.91
15 VII	.0147	67.9	.0069	145.3	.468	0.57

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Table IX sets forth the powers of the various groups as the reciprocal of the EFL and the geometric means power KM (sub M) of lens I-VIII.

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TABLE IX

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Table	K_1	K_2	K_3	K_4	KM
I	.0096	-.0251	.0107	.0053	.0071
25 II	.0092	-.0197	.0108	.0066	.0081
25 III	.0124	-.0326	.0151	.0061	.0096
30 IV	.0091	-.0251	.0116	.0042	.0083
V	.0100	-.0261	.0107	.0061	.0071
35 VI	.0131	-.0361	.0118	.0116	.0098

35

where K_1 to K_4 are the powers of groups G1 to G4 and KM is the geometric mean of the power of each lens at the extremes of equivalent focal lengths.

From the powers given in Table IX one obtains the following values for the ratios K_1/KM , K_2/KM , K_3/KM and K_4/KM :-

40

TABLE X

40

Table	K_1/KM	K_2/KM	K_3/KM	K_4/KM
45 I	1.35	3.53	1.51	.746
II	1.36	2.43	1.33	.815
50 III	1.29	3.40	1.57	.635
50 IV	1.10	3.02	1.40	.506
V	1.41	3.68	1.51	.859
55 VI	1.34	3.06	1.20	1.18

55



CLAIMS

1. A zoom lens having a first group movable axially for focusing, a plurality of following groups movable axially of the lens to vary the equivalent focal length of the lens, said front focusing group comprising a positive doublet followed by a positive singlet

$$0 < \frac{\phi_s}{\phi_d} < 2.0$$

and

$$.543 \geq \frac{F_1}{F_L} \geq .468$$

where

- 20 ϕ_s is the optical power of the singlet,
 ϕ_d is the optical power of the doublet,
 F_1 is the equivalent focal length of the first group, and
 F_L is the maximum equivalent focal length of the lens.
- 25 2. The lens of claim 1, wherein said front group is followed by a second negative group, a third group, said second and third groups being movable axially of said lens for varying the equivalent focal length, and a fourth positive group.
3. The lens of claim 2, wherein

$$\begin{aligned} 1.41 &> K_1/K_M > 1.10 \\ 3.68 &> K_2/K_M > 2.43 \\ 1.57 &> K_3/K_M > 1.20 \\ 1.2 &> K_4/K_M > .50 \end{aligned}$$

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

4. The lens of claim 2, where said third group is a biconvex doublet.

5. The lens of Claim 1 where

$$2.5K_4 > K_1 > 1.0K_4$$

where K_1 is the power of the first group and K_4 is the power of the fourth group.

6. A lens according to Claim 1 wherein said second group consists of a negative singlet followed by a negative doublet.

7. A lens according to Claim 1 wherein said second group consists of a negative doublet followed by a negative singlet.

8. A lens according to Claim 2, wherein said third group consists of a biconvex doublet.

9. A lens according to Claim 1 where said fourth group comprises a positive subgroup followed by a negative subgroup with a large separating air-space.

10. A lens according to Claim 9 wherein said first subgroup consists of a positive doublet.

11. A lens according to Claim 9 wherein said second subgroup consists of a positive lens followed by a negative lens.

12. A lens according to Claim 9 wherein said second subgroup consists of a negative lens followed by a positive lens.

13. A zoom lens according to Claim 1, wherein said second lens group is of negative power, said second group being a variator group consisting of a negative singlet and a negative doublet; a third lens group of positive power, said third group consisting of a positive doublet, and a positive fourth group fixed in relation to the focal plane.

14. A lens according to claim 1 scaled to an equivalent focal length of 101mm to 195mm substantially as described.



25

Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d	
5 L1	S1 = 69.077	3.0	1.7847	26.06	5
	S2 = 44.817				
	S3 = -213.552				
10 L2	S4 = 92.077	10.0	1.5101	63.43	10
	S5 = 142.825				
	S6 = 600.754				
15 L3	S7 = 69.943	2.0	1.6583	57.26	15
	S8 = -71.613				
	S9 = 32.133				
20 L4	S10 = 76.984	4.76	1.8467	23.83	20
	S11 = 74.163				
	S12 = 39.674				
25 L5	S13 = -96.905	6.29	1.5638	60.83	25
	S14 = 78.588				
	S15 = 693.028				
30 L6	S16 = 26.460	3.0	1.5101	63.43	30
	S17 = 427.148				
	S18 = 45.219				
35 L7	S19 = -18.927	4.81	1.7725	49.62	35
	S20 = -53.001				
	S21 = 412.053				
40 L8	S22 = -53.841	3.42	1.6727	32.17	40
45 L9		40.26	1.7725	49.62	45
50 L10		0.3	1.7725	49.62	50
55 L11		40.26	1.7725	49.62	55
50 EFL		0.3	1.7725	49.62	50
101mm		3.42	1.6727	32.17	101mm
152		40.26	1.7725	49.62	152
195		0.3	1.7725	49.62	195
55		40.26	1.7725	49.62	55

where the lens comprises elements L1-L13 having surfaces S1-S22, the index of refraction is given by N_d , the dispersion is measured by the Abbe number as given by V_d , and Z1, Z2 and Z3 are the variable air-spacings at the indicated equivalent focal length (EFL).

80



15. A lens according to claim 1 scaled to an equivalent focal length of 76.0mm to 200.1mm substantially as described.

5 Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N _d	V _d	5
L1	S1 = 100.120	3.0	1.785	26.1	
10 L2	S2 = 58.560	7.34	1.510	63.4	10
	S3 = plano	0.3			
L3	S4 = 97.870	5.15	1.510	63.4	
15	S5 = -539.860	Z1			15
L4	S6 = 205.760	1.5	1.720	50.3	
	S7 = 70.027	3.74			
20	S8 = -84.552	1.5	1.720	50.3	20
L5	S9 = 27.698	4.51	1.785	25.7	
L6	S10 = 126.250	Z2			
25	S11 = 104.624	6.08	1.487	70.4	25
L7	S12 = -32.924	1.2	1.785	26.1	
30 L8	S13 = -51.566	Z3			30
	S14 = 32.652	6.24	1.573	57.5	
L9	S15 = -85.340	2.0	1.806	40.7	
35 L10	S16 = 175.960	4.81			35
	Aperture Stop	42.660			
40	S17 = -19.451	2.0	1.804	46.5	40
L11	S18 = -37.265	0.3			
45	S19 = 101.789	2.27	1.673	3.22	45
L12	S20 = -300.147				
EFL	Z1	Z2	Z3		
50					50
76.00mm	1.73mm	37.58mm	12.09mm		
125.00	26.25	23.15	2.00		
20.0	39.92	1.48	10.00		



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where the lens comprises elements L1-L12 having surfaces S1-S20, the index of refraction is given by N_d , the dispersion is measured by the Abbe number as given by V_d , and Z1, Z2 and Z3 are the variable air-spacings at the indicated equivalent focal length (EFL).

16. A lens according to claim 1 scaled to an equivalent focal length of 72mm to 150mm substantially as described.

5

Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d	
10	S1 = 62.296				10
L1		3.0	1.7847	26.06	
	S2 = 41.370				
L2		12.806	1.4875	70.44	
	S3 = -266.277				
15		0.3			15
	S4 = 86.478				
L3		4.095	1.4875	70.44	
	S5 = 2731.894				
		Z1			
20	S6 = -259.053				20
L4		2.0	1.6910	54.70	
	S7 = 65.984				
		2.805			
	S8 = -71.603				
25	L5	2.0	1.7433	49.22	25
	S9 = 24.730				
L6		4.755	1.8467	23.83	
	S10 = 72.248				
		Z2			
30	S11 = 49.336				30
L7		2.0	1.8467	23.83	
	S12 = 25.951				
L8		6.287	1.6667	48.30	
	S13 = -133.121				
35		Z3			35
	S14 = 22.123				
L9		5.381	1.4875	70.44	
	S15 = -684.989				
L10		2.0	1.8042	46.50	
40	S16 = 66.251				40
		29.67			
	S17 = -14.503				
L11		2.0	1.5310	58.20	
	S18 = -31.216				
45		0.3			45
	S19 = 120.523				
L12		2.350	1.8040	46.50	
	S20 = -189.269				
50	EFL	Z1	Z2	Z3	50
	72.0mm	1.6	27.051	0.3	
	111.0	14.289	13.162	1.5	
	150.0	19.843	0.3	8.809	
55					55

where the lens comprises elements L1-L12 having surfaces S1-S20, the index of refraction is given by N_d , the dispersion is measured by the Abbe number as given by V_d , and Z1, Z2 and Z3 are the variable air-spacings at the indicated equivalent focal length (EFL).

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17. A lens according to claim 1 scaled to an equivalent focal length of 72mm to 203mm substantially as described.

5 Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d	5
L1	S1 = 87.504	3.000	1.7847	26.06	
	S2 = 57.456				
10 L2	S3 = -576.167	12.806	1.4875	70.44	10
	S4 = 110.904				
L3	S5 = -1960.632	3.500	1.4875	70.44	15
	S6 = -829.307				
L4	S7 = 84.246	2.000	1.6910	54.70	
	S8 = -91.582				
20 L5	S9 = 29.357	2.000	1.7433	49.22	20
	S10 = 80.962				
L6	S11 = 76.817	4.755	1.8467	23.83	25
	S12 = 36.571				
30 L8	S13 = -118.534	6.287	1.6667	48.30	30
	S14 = 25.919				
L9	S15 = -154.920	7.000	1.4875	70.44	35
	S16 = 92.608				
35 L10	S17 = -17.481	2.000	1.8042	46.50	
	S18 = -37.440				
40 L11	S19 = 251.831	2.029	1.8042	46.50	40
	S20 = -69.558				
45 L12	S20 = -69.558	2.452	1.7495	35.04	45
EFL	Z1	Z2	Z3		
72.0mm	1.5mm	49.045mm	0.3mm		
150.0	30.760	18.585	1.5		50
203.0	36.664	0.3	13.881		

where the lens comprises elements L1-L12 having surfaces S1-S20, the index of refraction is given by N_d , the dispersion is measured by the Abbe number as given by V_d , and Z1, Z2 and Z3 are the variable air-spacings at the indicated equivalent focal length (EFL).



18. A lens according to claim 1 scaled to an equivalent focal length of 101mm to 194mm substantially as described.

5 Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d	5
L1	S1 = 70.981	3.0	1.7847	26.06	
10 L2	S2 = 45.725	10.0	1.5101	63.43	10
	S3 = -190.826	0.3			
L3	S4 = 77.534	3.5	1.5101	63.43	
15	S5 = 115.121	Z1			15
	S6 = -366.358	3.829	1.8467	23.83	
L4	S7 = -49.175	2.0	1.6910	54.70	
20 L5	S8 = 61.777	3.961			20
	S9 = -53.090	20	1.6583	57.26	
L6	S10 = 255.263	Z2			25
25	S11 = 93.727	6.429	1.5638	60.83	
	S12 = -35.861	2.0	1.7847	26.06	
L7	S13 = -71.255	Z3			30
30 L8	S14 = 74.385	2.629	1.5101	63.43	
	S15 = 259.362	0.3			35
L9	S16 = 26.413	5.653	1.5101	63.43	
35	S17 = 366.100	2.0	1.8061	40.74	
	S18 = 43.497	27.063			40
L10	S19 = 112.212	2.615	1.6727	32.17	
40 L11	S20 = -77.326	6.977			45
	S21 = -24.455	2.0	1.7725	49.62	
L12	S22 = -97.188				50
45		Z1	Z2		
L13			Z3		
50					
EFL					
101.0mm	2.812mm	29.314mm	3.744mm		
152.0	18.190	13.176	4.503		
55 194.0	24.580	0.3	10.990		55

where the lens comprises elements L1-L13 having surfaces S1-S22, the index of refraction is given by N_d , the dispersion is measured by the Abbe number as given by V_d , and Z1, Z2 and Z3 are the variable air-spacings at the indicated equivalent focal length (EFL).



19. A lens according to claim 1 scaled to an equivalent focal length of 76mm to 201mm substantially as described.

5	Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N_d	V_d	5
	L1	S1 = 55.041	2.50	1.785	26.1	
10	L2	S2 = 36.225	8.50	1.510	63.4	10
		S3 = -246.043	0.2			
	L3	S4 = 86.032	3.0	1.510	63.4	
15		S5 = 380.808	Z1			15
	L4	S6 = -192.163	1.5	1.658	57.3	
		S7 = 51.582	2.56			
20		S8 = -63.000	1.5	1.691	54.7	20
	L5	S9 = 21.990	3.6	1.785	26.1	
	L6	S10 = 67.930	Z2			
25		S11 = 54.447	1.5	1.785	26.1	25
	L7	S12 = 27.783	5.5	1.540	59.7	
30	L8	S13 = -85.292	2.5	1.510	63.4	30
		S14 = 74.074	0.2			
	L9	S15 = -300.882	5.0	1.510	63.4	
35		S16 = 18.412	1.5	1.806	40.7	35
	L10	S17 = 153.957	2.25			
		S18 = 31.629	26.614			
40	L11	S19 = -13.655	1.5	1.773	49.6	40
		S20 = -323.408	0.2			
	L12	S21 = 93.578	3.5	1.673	3.22	
45		S22 = -193.289				45
	L13					
	EFL	Z1	Z2	Z3		
55	71.5mm	1.50mm	22.89mm	3.49mm		55
	110.0	14.45	11.83	1.60		
	146.5	20.58	1.00	6.30		

where the lens comprises elements L1-L13 having surfaces S1-S22, the index of refraction is given by N_d , the dispersion is measured by the Abbe number as given by V_d , and Z1, Z2 and Z3 are the variable air-spacings at the indicated equivalent focal length (EFL).



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20. A lens according to claim 1 scaled to an equivalent focal length of 51.6mm to 145.3mm substantially as described.

5	Element	Surface Radii (mm)	Axial Distance Between Surfaces (mm)	N _d	V _d	5
	L1	S1 = 154.274	2.000	1.805	25.5	
10	L2	S2 = 60.625	7.482	1.603	60.7	10
		S3 = -166.752	0.200			
	L3	S4 = 49.425	4.711	1.487	70.4	
15		S5 = 976.009	Z1			15
	L4	S6 = -111.965	1.500	1.834	37.3	
		S7 = 29.937	4.683			
20		S8 = -40.282	1.500	1.487	70.4	20
	L5	S9 = 34.267	4.190	1.847	23.8	
	L6	S10 = -661.409	Z2			
25		S11 = 58.780	3.370	1.785	25.7	25
	L7	S12 = 588.325	0.200			
30		S13 = 40.593	6.062	1.518	59.0	30
	L8	S14 = -38.790	1.500	1.805	25.5	
	L9	S15 = 60.207	0.200			
35		S16 = 29.884	4.661	1.603	60.7	35
	L10	Aperture	15.024			
40		S17 = 47.488	1.500	1.834	37.3	40
	L11	S18 = 17.934	0.309			
45		S19 = 18.509	5.462	1.632	34.8	45
	L12	S20 = -62.404	6.297			
		S21 = -19.946	1.500	1.834	37.3	
50	L13	S22 = -58.480				50
	EFL	Z1	Z2	BFL		
55	51.6mm	2.00mm	36.18mm	38.66mm		55
	65.0	5.63	29.28	42.82		
	80.1	9.14	21.50	46.04		
	145.3	16.17	1.00	59.53		



where the lens comprises elements L1-L13 having surfaces S1-S22, the index of refraction is given by N_d , the dispersion is measured by the Abbe number as given by V_d , and Z1 and Z2 are the variable air-spacings at the indicated equivalent focal length (EFL).

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