

FOUR COMPONENT COMPACT ZOOM LENS

This invention relates to compact zoom lenses including four lens groups all of which are axially movable.

It is an object of the present invention to provide an objective zoom lens for a viewfinder camera, which is sufficiently compact that the front end of the zoom lens does not intrude into the field of view of the viewfinder when the viewfinder is positioned desirably close to the taking lens for avoiding viewfinder parallax. Obviously, both diameter of the front end of the zoom lens and the distance of the front end of the zoom lens from the film plane are factors in this problem. The lens may also be light in weight and easily stored.

In accordance with the present invention there is provided a zoom lens comprising four components each movable axially to vary the focal length through a range of at least 2.5:1, including a front negative component, a positive component, a positive cemented doublet component and a rear negative negative component comprising three elements, and a diaphragm mounted with the first-mentioned positive component, the total length from the vertex of the front surface of the front lens element to the focal plane being less than $1.8 F_s$ at the short focal length setting and less than F_L at the long focal length setting, wherein F_s is the short focal length and F_L is the long focal length.

For the purposes of the present specification, the term "component" means a part of the zoom lens that includes one or more lens elements, wherein those lens elements forming the component are located in close proximity with one another and are capable of moving together as a group.

An alternative zoom lens is described and claimed in our copending divisional application GB-A-2 238 401.

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

Fig. 1 schematically represents a first embodiment of the present invention;

10 Figs. 2 and 3 are tables of constructional data for the first embodiment, illustrated in Fig. 1;

Fig. 4 schematically represents a second embodiment of the present invention;

15 Figs. 5 and 6 are tables of constructional data for the second embodiment, illustrated in Fig. 4;

Fig. 7 schematically represents a third embodiment of the present invention; and

20 Figs. 8 and 9 are tables of constructional data for the third embodiment, illustrated in Fig. 7.

A first embodiment of the present invention, represented in Fig. 1, is a zoom lens 21 intended to be the taking objective lens of a viewfinder camera. The lens 21 has an image plane 23 in which the film is disposed in the camera. The lens has an object plane 25. In the ensuing description, the front of the lens or of a component or element is nearer or towards the object plane 25.

25 The lens 21 includes four components, all of which are axially movable. There are: a front, first component 27; a second component 29; a third component 31 and a fourth, rear component 33.

30 Front component 27 is a negative meniscus lens element A having front and rear surfaces R_1 and R_2 and a thickness t_1 . The values of the radii of the surfaces R_1 , R_2 and the value of t_1 are given in the table in Fig. 2. The front component 27 is utilized to adjust the image to

focus at the image plane 23. The object plane 25 is spaced by a variable distance S_1 from the element A.

5 Spaced from front component 27 by a variable air gap S_2 is the second component 29, which is positive and includes a diaphragm DM and a double convex lens element B having a front surface R_3 , which is aspheric, and a rear surface R_4 .
10 The thickness t_3 of the lens element B is given in the table in Fig. 2.

 The aspheric surface R_3 conforms to the formula:

15
$$X = \frac{CY^2}{1 + \sqrt{1 - (K+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10}$$

 wherein $C = 0.02557865$

$K = 12.0445$

$D = -0.37847 \times 10^{-4}$

20 $E = -0.26615 \times 10^{-6}$

$F = 0.26087 \times 10^{-8}$

$G = -0.33251 \times 10^{-10}$

 X is the longitudinal coordinate of a point on the surface which is a distance Y from the X axis.
25

 The position of the diaphragm DM is determined by the variable space S_2 from the element A and by fixed distance FS_1 from element B. The diaphragm DM has a clear aperture of
30 17.20mm, and is movable with the lens element B.

 Spaced from the second component 29 by a variable air gap S_3 is the third component 31 which is a positive cemented doublet including a meniscus lens element C and a double convex lens element D. The lens element C has a front surface R_5 , a rear surface R_6 and a thickness t_4 . The double convex lens element D has front and rear surfaces R_6 and R_7 , respectively, and a thickness t_5 .
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Spaced from the third component 31 by a variable air gap S_4 is the fourth component 33 which is a two units, both units being negative, three element component and is herein termed a negative negative component. The fourth, negative negative component includes a front meniscus lens element E having front and rear surfaces R_8 and R_9 , respectively, and thickness t_7 , a middle meniscus lens element F having front and rear surfaces R_{10} and R_{11} and thickness t_9 , and a double concave lens element G having front and rear surfaces R_{12} and R_{13} , and thickness t_{11} . The lens elements E and F are spaced by a fixed distance FS_2 at the vertices of their surfaces R_9 and R_{10} . The lens elements F and G are spaced by a fixed distance FS_3 at the vertices of their surfaces R_{11} and R_{12} .

As each of the four moving components increases (or decreases) its distance from its adjacent component, the change in focal length with respect to increasing (or decreasing) incremental space is of the same sign for each component. Thus, every component has a constructive contribution to the decrease (or increase) of the focal length. This contributes to the large zoom ratio and short front vertex to image plane distance exhibited.

The variation in space S_4 between components 31 and 33 contributes to the focal length change four or five times more than equal increments of variation in space S_3 and two to three times more than equal increments of variation in space S_2 . The actual magnitude of the ratios depends on whether the lens is in wide angle or telephoto configuration.

Besides changing focal length, the increments of change of spaces S_2 , S_3 and S_4 also partially compensate for aberrations,

especially the spherical aberration in the telephoto configuration. The negative spherical aberration that results as spaces S_2 and S_4 are varied is
5 compensated for by the positive spherical aberration that results as space S_3 is varied. This contributes to the stability of the aberration over the large zoom ratio.

It has been found that with four movable
10 components aberrations are controlled to acceptable levels and a relatively large back focus is maintained.

In the third component 31, if the ratio VR_{CD} of the Abbé numbers of the elements C and D
15 is computed so that VR_{CD} is greater than unity (i.e., of the two possible ratios $a:b$ and $b:a$, that one is selected which gives a value greater than unity) then $3 > VR_{CD} > 1.8$. With such parameters axial color is corrected.

In the fourth component 33 the choice of
20 glasses is such that the ratio VR_{EF} of the Abbé numbers of the elements E and F is computed so that VR_{EF} is greater than unity (i.e., of the two possible ratios $a:b$ and $b:a$, that one is selected
25 which gives a value greater than unity) then $3 > VR_{EF} > 1.3$. If these parameters are not observed axial and lateral color correction will not be achievable.

In order to control higher order distortion
30 in the wide angle mode and balance the distortion and lateral color over the full zoom range, the following relationship exists:

$$0.4 > |N_C - N_D| > 0.1$$

wherein N_C is the refractive index of
35 element C; and

N_D is the refractive index of
element D.

The focal lengths of each of the four components, as well as the ratio L of those lengths to the minimum effective focal length F_s are given in the ensuing table:

Component	Focal Length F	$L = F/F_s$
27	-49.27 mm	-1.41
29	27.73 mm	0.79
31	55.29 mm	1.58
33	-25.12 mm	-0.72

The lens 21 is a positive-negative zoom lens in that the first three components 27, 29 and 31 together have a positive net power, and the rear component 33 has a negative power. The positive-negative arrangement tends to make the lens telephoto in the longer focal length modes. The table in Fig. 3 gives the back focal length; lens length; length from front vertex of the front element to the image plane (i.e., the sum of lens length and back focal length); and the telephoto ratio (i.e., length from front vertex of the front element to the image plane divided by the focal length), for each of four focal lengths including the two extreme focal lengths. As elsewhere in this specification, all linear dimensions are in mm. It will be seen that at the longest focal length, the lens has a telephoto ratio of 0.93 which is an indication of compactness. In the wide angle mode, the lens has a length, 50.68 mm, which, together with the back focal length of 8.25 mm, renders the lens comparable in its forward protrusion to a normal taking lens of a 35mm camera which typically extends 58 mm in front of the film plane. In that the camera for which the lens is intended is a camera with a separate viewfinder, it is important

that the forward protrusion of the lens not be such as to obscure a portion of the field of view of the viewfinder.

5 The ratio of the extreme focal lengths of this embodiment is 104.56:35.06; i.e. 2.98:1 which would normally be termed a 3:1 zoom lens.

 From Fig. 3 it will be seen that at a focal length of 35.06 mm, being F_s , the shortest focal
10 length, the length from the vertex of the front surface R_1 of the front element A to the film plane 23 is 58.93 mm, and the telephoto ratio, i.e., the ratio of that length to the focal length, F_s , is 1.68 which is less than 1.8. Also, at the long
15 focal length, F_L , of 104.56 mm, the length from the front surface R_1 of the front element A to the film plane 23 is 97.15 mm, which is less than the focal length F_L .

 The clear aperture of lens A is 15.91 mm
20 which, together with the shortness of the distance between the vertex of the front surface R_1 of the front lens A and the film plane 23, ensures that a separate viewfinder can be placed close to the zoom lens without intruding on the field of view of the
25 viewfinder, thus minimizing viewfinder parallax.

 Fig. 4 illustrates a second embodiment of the present invention which is generally similar in construction to the first embodiment described above. Figs. 5 and 6 are tables giving the values
30 for the various parameters. In Figs. 4 and 5, the four components are given the same reference numerals but with a prime (') suffix. Similarly, the lens elements are given the same reference letters but with a prime (') suffix. Likewise, the
35 variable spacings are given the same references but with a prime (') suffix.

 In this second embodiment, the diaphragm DM' is placed behind the element B' at a fixed

distance FS_{22} and a baffle BF is included in front of element B' at a fixed distance FS_{21} . The variable spacing S_2' is between the element A' and the baffle BF. The variable spacing S_3' is between the diaphragm DM' and the component 31'.

Again, in this second embodiment, the third component 31' is a cemented doublet. However, in this embodiment, in the fourth component 33', which again is a triplet, the lens elements E' and F' are cemented.

In this second embodiment, the aspheric surface R_{23} of the second lens element B', has the formula:

$$X = \frac{CY^2}{1 + \sqrt{1 - C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10}$$

wherein $C = 0.03467647$

$$D = -0.42786 \times 10^{-4}$$

$$E = -0.11867 \times 10^{-6}$$

$$F = 0.98374 \times 10^{-8}$$

$$G = -0.75315 \times 10^{-10}$$

and its vertex radius is 28.838 mm.

The focal lengths of each of the four components, as well as the ratio L of those lengths to the minimum effective focal length, F_s , are given in the ensuing table:

Component	Focal Length F	$L = F/F_s$
27'	-54.75 mm	-1.56
29'	27.01 mm	0.77
31'	45.32 mm	1.29
33'	-19.38 mm	-0.55

The ratio of the extreme focal lengths of the second embodiment is 104.79:35.02, i.e., 2.99:1.

From Fig. 6 it will be seen that at a focal length of 35.02 mm, being F_s , the shortest focal

length, the length from the vertex of the front surface R_{21} of the front element A' to the film plane 23' is 57.56 mm and the telephoto ratio, i.e.,
5 the ratio of that length, 57.56 mm, to the focal length, F_s , is 1.64 which is less than 1.8. Also, at the long focal length, F_L , of 104.79 mm, the length from the front surface R_{21} of the first element A' to the film plane 23' is 93.01 mm which
10 is less than the focal length F_L .

The clear aperture of the lens A' is 21.70 mm which, together with the shortness of the distance between the vertex of the front surface R_{21} of the front lens A' and the focal plane 23',
15 ensures that a separate viewfinder can be placed close to the zoom lens without intruding on the field of view of the viewfinder, thus minimizing viewfinder parallax.

Fig. 7 illustrates a third embodiment of the present invention and Figs. 8 and 9 are tables
20 giving the values of various parameters. In Figs. 7 and 8, the components are given the same reference numerals as their counterparts in the first embodiment described above and illustrated in Fig. 1, but with the addition of a double prime ("")
25 suffix. Similarly, the lens elements are given the same reference letter (with an exception described below), but with the addition of a double prime ("") suffix. Likewise, the variable spacings are given the same reference but with a double prime suffix
30 added.

Again, in this third embodiment, the third component 31" is a cemented doublet and, as in the case of the second embodiment, the lens elements E"
35 and F" in the fourth component 33" are a cemented doublet.

In this third embodiment, the second component 29" is a doublet instead of a singlet. In

the first and second embodiments, the lens elements B and B' are both glass with one aspheric surface, namely R_3 on lens element B, and R_{23} on lens element B'. In order to avoid forming an aspheric surface on a glass element, the third embodiment places the aspheric surface R_{43} on a plastic lens element B_a " and has a glass lens element B_b " with two spherical surfaces R_{45} and R_{46} . Aspheric surfaces are relatively easily formed on plastics material elements. Plastic lenses are relatively susceptible to temperature changes. When subjected to a temperature change, their focal lengths change greater than is the case with glass. In order to avoid such disadvantageous effect, the plastic lens element B_a " has no power. The glass element B_b " has power but glass is markedly less susceptible to power change with temperature change than is the case with plastics material.

In this third embodiment, the diaphragm DM" is placed at the rear of the second component 29" and there is no baffle in front of the second component. The variable spacing S_2 " is between the element A" and the element B_a ". The fixed spacing FS_{32} is between the element B_b " and the diaphragm DM". The variable spacing S_3 " is between the diaphragm DM" and the third component 31.

The aspheric surface R_{43} again has the formula:

$$X = \frac{CY^2}{1 + \sqrt{1 - (K+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10}$$

wherein $C = 0.0307541$
 $D = -0.6111104 \times 10^{-4}$
 $E = -0.2224872 \times 10^{-6}$
 $F = 0.7541840 \times 10^{-9}$
 $G = -0.1842949 \times 10^{-10}$
 $K = 7.0508870$

The focal lengths of each of the four components, as well as the ratio R of those lengths to the minimum effective focal length, F_s , are given in the ensuing table:

5

Component	Focal Length F	$L + F/F_s$
27"	-59.28 mm	-1.69
29"	27.81 mm	0.79
10 31"	47.86 mm	1.37
33"	-19.87 mm	-0.57

The ratio of the extreme focal lengths of the third embodiment is 104.88:35.01, i.e., 3.00:1

15 From Fig. 9 it will be seen that at the shortest focal length, F_s , namely 35.01 mm, the length from the vertex of the front surface R_{41} of the front element A" to the film plane 23", is 58.94 mm and the telephoto ratio, i.e. the ratio of that
20 length, 58.94 mm, to the focal length, F_s , is 1.68 which is less than 1.8. Also, at the long focal length F_L , of 104.88 mm, the length from the front surface R_4 of the front element A" to the film plane 23" is 93.80 mm which is less than the focal
25 length F_L .

The clear aperture of the lens A" is 22.75 mm which, together with the shortness of the distance between the vertex of the front surface R_{41} of the front lens A" and the film plane 23",
30 ensures that a separate viewfinder can be placed close to the lens without intruding on the field of view of the viewfinder, thus minimizing viewfinder parallax.

The values of $L = F/F_s$ were given above
35 for each of the components of each of the three embodiments and they were:

COMPONENT	Embodiment 1			Embodiment 2			Embodiment 3		
	L	+10%	-10%	L	10%	-10%	L	+10%	-10%
27	-1.41	-1.55	-1.27	-1.56	-1.72	-1.40	-1.69	-1.86	-1.52
29	0.79	0.87	0.71	0.77	0.85	0.69	0.79	0.87	0.71
31	1.58	1.74	1.42	1.29	1.42	1.16	1.37	1.51	1.23
33	-0.72	-0.79	-0.71	-0.55	-0.61	-0.50	-0.57	-0.63	-0.51

In the table immediately above $\pm 10\%$ values are given for each of the L values. It will be seen that the largest and smallest L values in the table for each of the components are:

5	Component	Largest	Smallest
		L	L
	27	-1.86	-1.27
	29	0.87	0.69
10	31	1.74	1.16
	33	-0.79	-0.50

Embodiments of the present invention may be successfully constructed with the following ranges:

15 $-1.86F_s < F_1 < -1.27F_s$
 $0.87F_s > F_2 > 0.69F_s$
 $1.74F_s > F_3 > 1.16F_s$
 $-0.79F_s < F_4 < -0.50F_s$

wherein F_1 , F_2 , F_3 and F_4 are the focal
20 lengths of the components 27, 29, 31 and 33,
respectively.

While in the above-described three
embodiments the zoom ratios are 2.98:1; 2.99:1; and
3.00:1, respectively, it is believed that the
25 invention may be embodied successfully in zoom
lenses having a ratio close to 2.5:1.

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CLAIMS:

1. A zoom lens comprising four components each movable axially to vary the focal length through a range of at least 2.5:1, including a front
5 negative component, a positive component, a positive cemented doublet component and a rear negative negative component comprising three elements, and a diaphragm mounted with the first-mentioned positive component, the total length from the vertex of the
10 front surface of the front lens element to the focal plane being less than $1.8 F_s$ at the short focal length setting and less than F_L at the long focal length setting, wherein F_s is the short focal length and F_L is the long focal length.
- 15 2. A zoom lens as claimed in claim 1, wherein with the ratio VR of the Abbé V numbers of the elements of said positive cemented doublet greater than unity $3 > VR > 1.8$.
- 20 3. A zoom lens as claimed in claim 1 or 2, wherein said negative negative component comprises front, second, and rear elements and with the ratio VR_{12} of the Abbé V numbers of the front and second element greater than unity $3 > VR_{12} > 1.3$.
- 25 4. A zoom lens as claimed in claim 1, 2 or 3 wherein the positive cemented doublet component includes a front element having a refractive index N_C and a rear element having a refractive index N_D and wherein $0.4 > |N_C - N_D| > 0.1$.
- 30 5. A zoom lens assembly substantially as shown in Figure 1 and having the specifications set out in Figure 2 of the accompanying drawings.
6. A zoom lens assembly substantially as shown in Figure 4 and having the specifications set out in Figure 5 of the accompanying drawings.
- 35 7. A zoom lens assembly substantially as shown in Figure 7 and having the specifications set out in Figure 8 of the accompanying drawings.