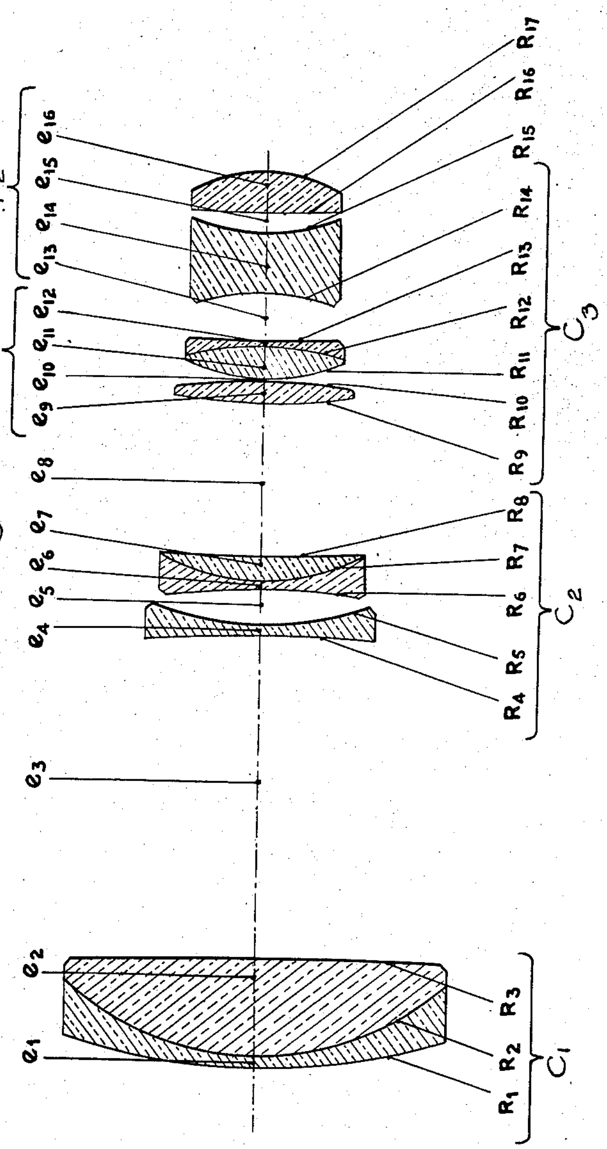
Aug. 19, 1958 P. ANGENIEUX 2,847,907

VARIABLE FOCAL-LENGTH OBJECTIVES

Filed Jan. 10, 1956 2 Sheets-Sheet 1

Fig. 1



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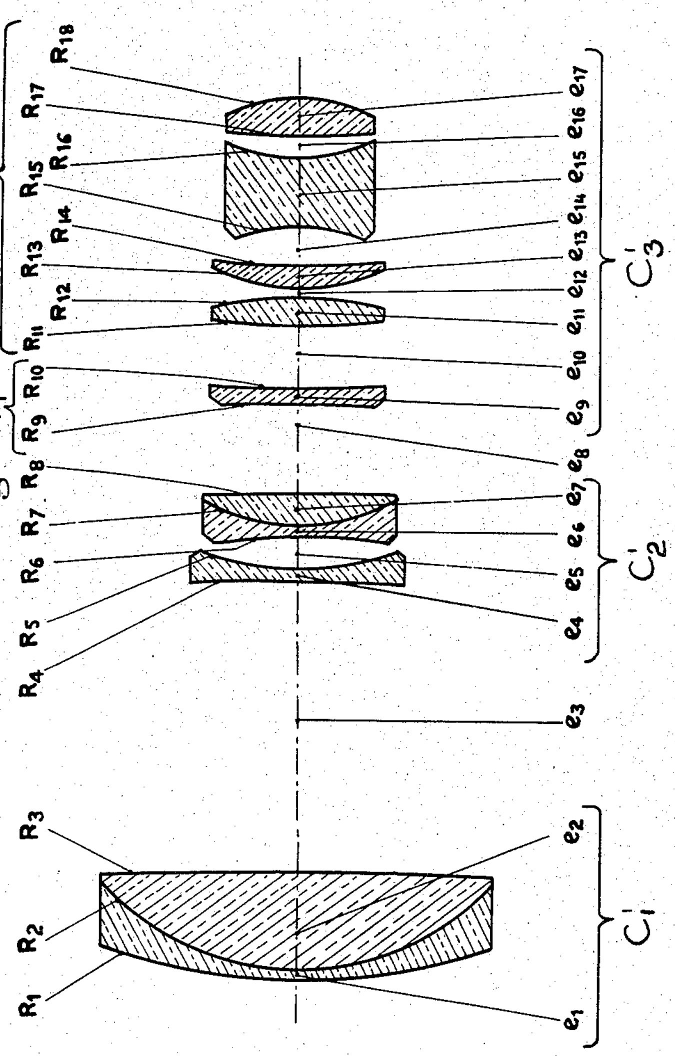

Fig. 2

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VARIABLE FOCAL-LENGTH OBJECTIVES

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10 Claims. (Cl. 88—57)

This invention relates in general to variable focal-length objectives and particularly to a variable focal-length objective of the type wherein the variations in magnification result essentially from the axial displacements of a divergent component disposed between two convergent components, the image produced by the complete system being maintained in a fixed position with the assistance of another axial movement of either one of said convergent components or simply one part of the said components.

It is the essential object of this invention to define certain characteristics of the movable divergent component because it is well known that in devices of this type it is mainly by improving the nature and shape of this component that an image of adequate quality can be obtained irrespective of the position of said movable component.

It is another object of this invention to define certain characteristics of the front convergent component and of the rear convergent component, an axial movement being applicable to the whole or part of these components and adapted to be combined with the aforesaid axial movement of the movable divergent component in order to maintain the focal plane of the assembly in a fixed position with respect to the fixed components of the system.

As a rule, it is the axial displacement of the internal divergent component which has the greatest amplitude. As a result, the oblique rays contributing in the formation of the image points positioned outside the central zone of the field impinge on this component at widely differing locations according to the position of this component. In other words, the pupils relevant to the component are movable within very wide limits. Therefore, the study of this component is all-important in that it constitutes the essential problem if it is desired to obtain an image of constantly good quality.

Consequently, a device of the type indicated herein above may be developed by disregarding in a first study the possibility of maintaining the fixedness of the final image and by limiting the first approach to this problem to the formation, in the first place, of an optical system consisting of two fixed convergent components between which a divergent component is axially movable to simply provide a continuous variation in the magnification of the image resulting from the complete assembly.

According to this invention and to the calculations effected in this connection I have found that very satisfactory results could be achieved provided that the following requirements were complied with:

The two convergent components being separated by a distance representing from 30% to 100% of the focal length of the front convergent component, and the divergent component having a focal length ranging from 15% to 45% of the same focal length of the front convergent component, the movable divergent component must consist of at least three lens elements arranged as two members separated by an air space, the front member having a front concave surface the radius of curvature of which is numerically greater than 200% of the focal length of said divergent component and smaller than infinity, and a rear concave surface the radius of curvature of which is numerically greater than 70% and smaller than 300% of said focal length. The rear member of the said divergent component has a concave front surface the radius of curvature of which is numerically greater than the focal length of said divergent component and smaller than infinity, the other lens of said pair of separate lenses, which is positioned behind the former, having a concave front surface with a radius of curvature numerically greater than the focal length of said divergent component.

On the other hand, the divergent component must be achromatic; therefore, at least one of the lenses constituting this component will consist of a convergent lens cemented on a divergent lens, the convergent lens having a dispersion ratio or Abbe number ν_1 lower than that ν_2 of the divergent lens, the difference $\nu_2-\nu_1$ ranging preferably from 15 to 38.

According to this invention, it is also convenient to employ as a front convergent component a doublet consisting of a divergent meniscus lens having its convex surface positioned at the front, and of a convergent lens positioned behind this meniscus. These two lenses may be cemented together but this is not an essential requirement. Regarding the convex surface located at the front of the meniscus, it is advantageous to select a radius of curvature ranging from 40% to 100% of the focal length of the convergent component in question, the radius of curvature of the rear surface of said divergent meniscus ranging preferably from 20% to 50% of this focal length.

When the divergent component is moved in the axial direction for the purpose of altering the focal length of the assembly, the back focal length of this assembly varies if the other two components remain stationary. However, the front convergent component may also be moved along its axis according to the law governing the positions of these two components with respect to the fixed convergent component in view of maintaining the back focal length of the assembly at a constant value.

Obviously, the same result may be obtained by maintaining the front convergent component in a fixed position and utilizing the rear convergent component as a second movable component; but it is advantageous to select a rear convergent component constituted by two parts of which one is utilized as a second movable component. In this case, the diaphragm will be positioned between these two parts. Three cases may occur: both parts are convergent; the front part is convergent while the rear part is divergent; the front part is divergent while the rear part is convergent.

If the front part is convergent, it is interesting to constitute it by two separate convergent lenses, either simple or made of cemented lenses, of which the former, at the front, is biconvex and has on both surfaces a radius of curvature numerically greater than 150% of, and smaller than five times, the focal length of said front part, while the other lens, located at the rear of the same part, has a convex front surface having a radius of curvature greater than 60% of, and smaller than three times, the focal length of said part. In case that the front part is divergent, it can be constituted by a simple biconcave lens.

Figs. 1 and 2 of the attached drawing illustrate diagrammatically in axial section two practical forms of embodiment of a variable focal-length objective made in accordance with the teachings of this invention. In Fig. 1, C_1, C_2 and C_3 designate, from the front to the rear, the three components of the objective, while P_1 and P_2 designate the two parts of component C_3, said two parts in this case being convergent; $e_1, e_2 \ldots e_{16}$ designate the thicknesses and axial distances between the components, parts or lenses, while $R_1, R_2 \ldots R_{17}$ designate the radiuses of curvature of each lens surface. The characteristics of this first form of embodiment are given in the Table I below, the reference symbols $R_1, R_2, R_3 \ldots R_{17}$ representing as in the drawing the radiuses of curvature of each lens surface from the front to the rear, the sign + indicating that the surface is convex towards the front and the sign — that it is concave towards the front, whilst $e_1, e_2, e_3 \ldots e_{16}$, as in the drawing designate the axial distances measured between two adjacent lens surfaces, e_3 representing the axial distance measured between the front convergent component C_1 and the divergent component C_2, e_8 representing on the other hand the axial distance separating the divergent component C_2 from the front part P_1 of the rear component C_3, and e_{13} being the axial distance measured between the two parts P_1, P_2 of the rear component C_3.

The focal length of the front convergent component C_1 is 100.34 millimeters. The focal length of the divergent component C_2 is 30.33 millimeters. The focal length of the front part P_1 of the rear component C_3 is 21.35 millimeters.

In this example, when the movable divergent component C_2 is moved axially, the front convergent component C_1 may be moved axially in accordance with the law governing the positions of these two components in view of obtaining a constant back focal length in the complete system however, it is preferable to leave the front component C_1 in a fixed position and to cause the front part P_1 of the rear component C_3 to move axially, this last-mentioned part P_1 being located between the air gaps e_8 and e_{13}.

Under these conditions, the distances e_3, e_8 and e_{13} are governed by the relations:

$$e_3+e_8+e_{13}=51.26 \text{ mm.}$$

$$\frac{21.35^2+(e_{13}+3.164)^2}{e_{13}+3.164}-\frac{30.331^2+(62.193-e_3)^2}{62.193-e_3}=6.433$$

TABLE I

Example of a practical embodiment of a variable focal length objective

[Relative aperture: 1/2.5.]

Radiuses, mm.	Thicknesses and distances, mm.	Glass characteristics	
		n_D	v
R_1 =+ 61.47	e_1 =1.22	1.6669	33.2
R_2 =+ 28.32	e_2 =9.71	1.6088	56.6
R_3 =−504.28	e_3 =from 4.46 to 46.96	air	
R_4 =−161.60	e_4 =1.22	1.6204	60.2
R_5 =+ 32.63	e_5 =3.31	air	
R_6 =− 70.61	e_6 =0.91	1.6567	57
R_7 =+ 21.57	e_7 =2.51	1.6992	30.2
R_8 =+370.97	e_8 =from 43.80 to 1.41	air	
R_9 =+ 52.78	e_9 =2.36	1.6588	51.1
R_{10}=− 57.68	e_{10}=0.15	air	
R_{11}=+ 21.96	e_{11}=2.90	1.6211	57
R_{12}=− 33.14	e_{12}=0.83	1.6751	32.3
R_{13}=+191.20	e_{13}=from 2.82 to 4.5	air	
R_{14}=− 27.62	e_{14}=6	1.6500	33.8
R_{15}=+ 19.41	e_{15}=2	air	
R_{16}=+125.25	e_{16}=4	1.6567	57
R_{17}=− 17.38			

The focal distance varies from 21.7 mm. to 80 mm.

In the second form of embodiment according to Fig. 2, the two parts of the rear component C_3 are respectively divergent and convergent. In said figure, C'_1, C'_2 and C'_3 designate the three components of the objective, while P'_1 and P'_2 designate the two parts of component C'_3, part P'_1 being divergent while part P'_2 is convergent; $e_1, e_2 \ldots e_{17}$ designate the thicknesses and axial distances between the components, parts or lenses, while $R_1, R_2, \ldots R_{18}$ designate the radiuses of curvature of each lens surface. The characteristics of this second form of embodiment are given in the Table II below, in which, as in the drawing, the reference symbols $R_1, R_2 \ldots R_{18}$ represent the radiuses of curvature of each lens surface from the front to the rear, the sign + indicating that the surface is convex towards the front, and the sign — that it is concave towards the front, whilst $e_1, e_2, e_3 \ldots e_{17}$ designate the axial distances measured between two adjacent lens surfaces, e_3 representing the axial distance measured between the front convergent component C'_1 and the divergent component C'_2, e_8 representing the axial distance separating the divergent component C'_2 from the front part P'_2 of the rear component C'_3, e_{10} being the axial distance measured between the two parts P'_1 and P'_2 of the rear component C'_3.

The focal length of the fixed front convergent component C'_1 is 100.34 millimeters. The focal length of the divergent component C'_2 is 30.33 millimeters. The focal length of the front part P'_1 of the rear component C'_3 is 100 millimeters.

As in the preceding example, when the movable divergent component C'_2 is moved axially, the front convergent component C'_1 may be moved axially in accordance with the law governing the positions of these two components in view of obtaining a constant back focal length in the complete system; however, according to the invention, it is preferable to leave the front component C'_1 in a fixed position and to cause the front part P'_1 of the rear component C_3 to move axially, this last-mentioned part P'_1 being located between the air gaps e_8 and e_{10}.

Under these conditions, the distances e_3, e_8 and e_{10} are governed by the relations:

$$e_3+e_8+e_{10}=48.93 \text{ mm.}$$

$$\frac{100^2+(50.169+e_{10})^2}{50.169+e_{10}}-\frac{30.331^2+(62.193-e_3)^2}{62.193-e_3}=171.98$$

TABLE II

Example of a practical embodiment of a variable focal length objective

[Relative aperture: 1/2.5.]

Radiuses, mm.	Thicknesses and distances, mm.	Glass characteristics	
		n_D	v
R_1=+ 61.47	e_1=1.22	1.6658	32.2
R_2=+ 28.32	e_2=9.71	1.6088	56.6
R_3=−504.28	e_3=from 5.36 to 47.36	air	
R_4=−161.60	e_4=1.22	1.6208	60
R_5=+ 32.63	e_5=3.31	air	
R_6=− 70.61	e_6=0.91	1.6566	57.4
R_7=+ 21.57	e_7=2.51	1.6986	30.3
R_8=+370.97	e_8=from 41.99 to 1.35	air	
R_9=−160.42	e_9=1.20	1.6605	36.2
R_{10}=+112.61	e_{10} variable	air	
R_{11}=+ 64.50	e_{11}=2.80	1.6913	53.8
R_{12}=− 41.95	e_{12}=0.15	air	
R_{13}=+ 20	e_{13}=2.50	1.6913	53.8
R_{14}=+ 85.50	e_{14}=4	air	
R_{15}=− 31.70	e_{15}=7.70	1.6992	30.2
R_{16}=+ 20.50	e_{16}=1.65	air	
R_{17}=+ 75	e_{17}=4	1.6913	53.8
R_{18}=− 20.40			

The focal distance varies from 22.80 mm. to 85.08 mm.

What I claim is:

1. A variable focal-length objective comprising a convergent component positioned at the front, a convergent component positioned at the rear, and a divergent component positioned between said two convergent components, said divergent component consisting of at least three lens elements arranged as two members separated by an air space, the front member having a front concave surface the radius of curvature of which is numerically greater than 200% of the focal length of said divergent component and smaller than infinity, and a rear concave surface the radius of curvature of which is numerically greater than 70% and smaller than 300% of the said focal length, the said divergent component being axially movable in order to obtain a continuous variation of the focal length of the complete system.

2. A variable focal-length objective comprising a convergent component positioned at the front, a convergent component positioned at the rear, and a divergent component positioned between said two convergent components, said divergent component consisting of at least three lens elements arranged as two members separated by an air space, the front member having a front concave surface the radius of curvature of which is numerically greater than 200% of the focal length of said divergent component and smaller than infinity, and a rear concave surface the radius of curvature of which is numerically greater than 70% and smaller than 300% of the said focal length, the rear member of the said divergent component having a concave front surface the radius of curvature of which is numerically greater than the focal length of said divergent component and smaller than infinity, the said divergent component being axially movable in order to obtain a continuous variation of the focal length of the complete system.

3. A variable focal-length objective comprising a convergent component positioned at the front, a convergent component positioned at the rear, and a divergent component positioned between said two convergent components, said divergent component consisting of at least three lens elements arranged as two members separated by an air space, the front member having a front concave surface the radius of curvature of which is numerically greater than 200% of the focal length of said divergent component and smaller than infinity, and a rear concave surface the radius of curvature of which is numerically greater than 70% and smaller than 300% of the said focal length, and the said convergent component positioned at the rear consisting of two parts, one fixed rear part and one movable front part, said movable front part and said divergent component being axially and simultaneously movable in order to obtain a continuous variation of the focal length of the complete system and ensuring to the complete system a constant back focal length.

4. A variable focal-length objective comprising a convergent component positioned at the front, a convergent component positioned at the rear, and a divergent component positioned between said two convergent components, said divergent component consisting of at least three lens elements arranged as two members separated by an air space, the front member having a front concave surface the radius of curvature of which is numerically greater than 200% of the focal length of said divergent component and smaller than infinity, and a rear concave surface the radius of curvature of which is numerically greater than 70% and smaller than 300% of the said focal length, the rear member of the said divergent component having a concave front surface the radius of curvature of which is numerically greater than the focal length of said divergent component and smaller than infinity and the said convergent component positioned at the rear consisting of two parts, one fixed rear part and one movable front part, said movable front part and said divergent component being axially and simultaneously movable in order to obtain a continuous variation of the focal length of the complete system and ensuring to the complete system a constant back focal length.

5. A variable focal-length objective comprising a convergent component positioned at the front, a convergent component positioned at the rear, and a divergent component positioned between said two convergent components, said divergent component consisting of at least three lens elements arranged as two members separated by an air space, the front member having a front concave surface the radius of curvature of which is numerically greater than 200% of the focal length of said divergent component and smaller than infinity, and a rear concave surface the radius of curvature of which is numerically greater than 70% and smaller than 300% of the said focal length, the said divergent component being axially movable in order to obtain a continuous variation of the focal length of the complete system, and means for displacing also along its axis said front convergent component in accordance with the positions of these two components with respect to the fixed convergent component located at the rear, in view of obtaining a constant back focal length in the complete assembly.

6. A variable focal-length objective comprising a convergent component positioned at the front, a convergent component positioned at the rear, and a divergent component positioned between said two convergent components, said divergent component consisting of at least three lens elements arranged as two members separated by an air space, the front member having a front concave surface the radius of curvature of which is numerically greater than 200% of the focal length of said divergent component and smaller than infinity, and a rear concave surface the radius of curvature of which is numerically greater than 70% and smaller than 300% of the said focal length, one of said two members constituting the divergent component consisting of a convergent lens cemented on a divergent lens, said convergent lens having a dispersion ratio or Abbe number lower than that of said divergent lens, the said divergent component being axially movable in order to obtain a continuous variation of the focal length of the complete assembly.

7. A variable focal-length objective comprising a convergent component positioned at the front, a convergent component positioned at the rear, and a divergent component positioned between said two convergent components, said divergent component consisting of at least three lens elements arranged as two members separated by an air space, the front member having a front concave surface the radius of curvature of which is numerically greater than 200% of the focal length of said divergent component and smaller than infinity, and a rear concave surface the radius of curvature of which is numerically greater than 70% and smaller than 300% of the said focal length, the said divergent component being axially movable in order to obtain a continuous variation of the focal length of the complete system, the convergent component positioned at the front of the system consisting of two lenses, the front lens of which being a divergent meniscus, the convex surface of which is located at the front, said convex surface having a radius of curvature greater than 40% and smaller than 100% of the focal length of said front convergent component, whilst the rear surface of said divergent meniscus has a radius of curvature greater than 20% and smaller than 50% of the focal length of said front convergent component.

8. A variable focal-length objective comprising a convergent component positioned at the front, a convergent component positioned at the rear, and a divergent component positioned between said two convergent components, said divergent component consisting of at least three lens elements arranged as two members separated by an air space, the front member having a front concave surface the radius of curvature of which is numerically

greater than 200% of the focal length of said divergent component and smaller than infinity, and a rear concave surface the radius of curvature of which is numerically greater than 70% and smaller than 300% of the said focal length, and the said convergent component positioned at the rear consisting of two parts, one fixed rear part and one movable front part, the said movable front part of said rear convergent component consisting of a pair of separate lenses both of convergent character, the first lens at the front of said pair being biconvex, its two surfaces having a radius of curvature numerically greater than 150% and smaller than 500% of the focal length of said front part, the second or rear lens of the pair having a convex front surface of which the radius of curvature is greater than 60% and smaller than 300% of the focal length of said movable front part, the said movable front part and said divergent component being axially and simultaneously movable in order to obtain a continuous variation of the focal length of the complete system and ensuring to said complete system a constant back focal length.

9. A variable focal-length objective comprising a convergent component positioned at the front, a convergent component positioned at the rear, and a divergent component positioned between said two convergent components, said divergent component consisting of at least three lens elements arranged as two members separated by an air space, the front member having a front concave surface the radius of curvature of which is numerically greater than 200% of the focal length of said divergent component and smaller than infinity, and a rear concave surface the radius of curvature of which is numerically greater than 70% and smaller than 300% of the said focal length, and the said convergent component positioned at the rear consisting of two parts, one fixed rear part and one movable front part, the said movable front part of said rear convergent component consisting of a pair of separate lenses both of convergent character, the first lens at the front of said pair being biconvex, its two surfaces having a radius of curvature numerically greater than 150% and smaller than 500% of the focal length of said front part, the second or rear lens of the pair having a convex front surface of which the radius of curvature is greater than 60% and smaller than 300% of the focal length of said movable front part, the said movable front part and said divergent component being axially and simultaneously movable in order to obtain a continuous variation of the focal length of the complete system and ensuring to said complete system a constant back focal length, one lens of said pair of separate lenses constituting said movable front part of said rear convergent component consisting of a convergent lens cemented on a divergent lens, said convergent lens having a dispersion ratio or Abbe number greater than that of said divergent lens.

10. A variable focal-length objective comprising a convergent component positioned at the front, a convergent component positioned at the rear, and a divergent component positioned between said two convergent components, said divergent component consisting of at least three lens elements arranged as two members separated by an air space, the front member having a front concave surface the radius of curvature of which is numerically greater than 200% of the focal length of said divergent component and smaller than infinity, and a rear concave surface the radius of curvature of which is numerically greater than 70% and smaller than 300% of the said focal length, and the said convergent component positioned at the rear consisting of two parts, one fixed rear part and one movable front part consisting of a divergent lens, the said movable front part and said divergent component being axially and simultaneously movable in order to obtain a continuous variation of the focal length of the complete system and ensuring to the said complete system a constant back focal length.

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