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COMPLETE SPECIFICATION

DRAWINGS ATTACHED

Variable Focal Length Lens System

I, PIERRE ANGENIEUX, a citizen of the French Republic, of 27, Rue du Cherche-Midi, Paris (Seine)-France do hereby declare the invention for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to variable focal length lens systems of the type comprising at the front a convergent member which is fixed for focusing on an object at any given distance, and therebehind an axially movable divergent member followed by a third member in the form of an axially movable convergent member, these three members being aligned on a common optical axis.

A fixed correcting or compensating member aligned on the same optical axis is located behind this assembly and the aperture stop or diaphragm is disposed preferably between the third member and this correcting member. It is known that in a device of this character the movable members are moved simultaneously according to the law giving a fixed position to the final image of an object at a given distance in relation to the fixed members of the system, the dimension of this image varying according to the relative position of the movable members.

It is known that each optical member of an assembly gives, of a first image situated optically in front of it, a second image situated optically behind it, and that the magnification produced by such a member is the ratio between the linear transverse dimension of the second image and that of the first image.

If it is now assumed that g_2 is the magnification given by the second member and g_3 the magnification given by the third member the focal length of the partial system comprising the three members (while disregarding the correcting member) is: $F = f_1 \times g_2 \times g_3$, wherein f_1 is the focal length of the first fixed convergent member.

If the correcting member introduces a magnification g_4. the focal length of the device is:

$$\Phi = g_4 \times F$$

or $$\Phi = (g_4 \times f_1) \times (g_2 \times g_3)$$

This last expression comprises two variable values g_2 and g_3. Under these conditions the range of focal lengths available in the system depends on the magnitude of the variations of g_2 and g_3, that is, on the amplitude of the movements of the movable members.

With variable focal length lens assemblies of the above-mentioned type good-quality lens systems have already been constructed, but when it is desired to increase the range of available focal lengths a limit is set up by the possibilities of correcting the various aberrations affecting such assemblies. In fact, it was observed that it is easier to obtain these corrections by using the second divergent movable member as a main element for varying the focal lengths, as its displacement is of substantial amplitude so that g_2 varies between relatively wide limits, while the moveable convergent member had to be used mainly as a compensator member adapted to keep the final image in a fixed position, its displacement being of moderate amplitude whereby g_3 varies within relatively narrow limits. Under these conditions it is clear that the extreme values of Φ depend mainly on the extreme values of g_2 and that the moderate amplitude of movement of the movable convergent member g_3 limits the possibility of extending the range of focal lengths, as g_3 exerts only a very moderate influence.

This invention aims at providing a lens

system whereby a satisfactory correction of the different aberrations can be obtained while using a movable convergent member having end positions relatively remote from each other, thus influencing favourably the extent of the range of focal lengths of the complete device.

According to the present invention there is provided a variable focal length lens system comprising a first frontal convergent member which is fixed for focusing on an object at any given distance, a second axially movable divergent member, and a third axially movable convergent member, all these members being aligned on the same optical axis in front of a fixed correcting member also aligned on the same optical axis, characterised in that said second member produces a magnification lower than .5 (and preferably greater than .15) when it has completed its forward stroke while simultaneously the third member, which has then completed its backward stroke, produces a magnification also lower than .5 (and preferably greater than .15), said third member consisting of at least three lens elements among which are a divergent lens element having a concave rear face and a convergent lens element located behind the rear face of said divergent lens element at a distance which at minimum is zero and at a maximum is 5% of the focal length of the third member, the front face of said convergent lens element being convex and having a radius of curvature at least equal to that of the rear face of said divergent lens element this last named radius being greater than half the focal length of said third member (and preferably less than twice this focal length).

Preferably, the ratio of the focal length of said third member to that of said second member ranges from 1 to 1.6.

According to a simple embodiment of the invention, said third member consists of a first frontal divergent lens element having a concave rear face, of a second biconvex lens element disposed at a distance which at minimum is zero and at maximum is 5% of the focal length of the third member behind said first lens element, and of a third convergent lens element.

In a modified embodiment, said third member consists of a front convergent doublet and of a rear convergent lens element, said doublet comprising a frontal divergent lens element having a concave rear face and a biconvex lens element cemented to said devergent frontal lens element, said divergent lens element having a higher index of refraction than said biconvex lens element.

According to a preferred embodiment of this invention said first frontal convergent member, which is fixed for focusing on an object at any given distance, and said movable second divergent member consist each of at least three lens elements including two lens elements disposed in the manner described hereinabove in connection with said third movable convergent member, that is a divergent lens element having a concave rear face located very close to and in front of another convergent lens element having a convex front face.

However, it should be emphasized that if in the said frontal convergent member, as in the case of the movable convergent member, the combined effect resulting from the two refracting surfaces consisting of the rear face of said divergent lens element and the front face of said convergent lens element must be divergent, the same does not apply to the movable divergent member wherein this effect must be convergent. As a result, when in this divergent member the above-defined pair of lens elements are cemented to each other, the index of refraction for the spectrum line D of the divergent lens element should be lower than that of the convergent lens element.

The axially movable divergent second member is constituted by two components. In a preferred form, the said second member comprises three lens elements divided into two components, the front component being constituted by a divergent meniscus-shaped lens having a convex front face with a radius of curvature greater than twice the focal length of said second member, the rear component comprising a cemented surface having its convexity facing forward and providing a convergent optical effect.

Preferably, this rear component of said second member consists only of two cemented lens elements, one of these, the front one, being biconcave and having an index of refraction for the spectrum line D which is inferior (as already stated hereinabove) to that of the lens cemented thereto which is convergent.

The fixed correcting member disposed at the rear has a two-fold function. Firstly, it acts as an amplifying or reducing member for. according to the magnification effected thereby it permits of modifying the zone in which the focal lengths of the complete device vary. Furthermore, it permits of correcting the aberrations remaining in the image formed by the partial device comprising the first three members. It may be constructed in various manners. However, in a preferred form, this correcting element comprises at the front a biconcave lens element having its rear surface cemented to the next lens element behind, the cemented surface having a convergent effect and said cemented surface having preferably a radius of curvature ranging from 50% to 150% of the focal length of said biconcave lens.

The corrector member may be convergent

or divergent, according to the value of the smallest focal length of the system. In the case of the first example given hereinafter, this corrector member is convergent and permits of having the smallest focal length of the system equal to 12.92 mm. If it was desired to have the smallest focal length of the system equal for example to 24 mm. whilst retaining unchanged the members C_1, C_2 and C_3, this corrector member would then become divergent, that being obtained, for example, by the addition, to the rear of the zoom lens, of a divergent "attachment" which would permit, according to whether it was used or not, of having two ranges of focal length of 24 to 196.70 mm. or 12.92 to 105.9 mm.

Regarding the correction of chromatic aberrations, and more particularly those concerning the dimensional chromatism, the Abbe number selected for the biconcave lens element is greater than that of the lens element cemented thereto. In practice the Abbe number of the biconcave lens element will range from 40 to 70.

In the attached drawings, Figs. 1, 2 and 3 illustrate diagrammatically three practical embodiments of lens systems constructed according to the teachings of this invention.

In each figure C1, C2 and C3 designate the fixed convergent member, the movable divergent member and the movable convergent member, respectively, and C4 designates the correcting member; the reference numberals 1, 2, 3 . . designate the different lens elements, s_1, s_2, s_3 . . . designate the air spaces provided between two adjacent lens elements and t_1, t_2, t_3 . . . are the axial thicknesses of these lens elements; finally, R_1, R_2, R_3 . . . designate the radii of curvature of the lens surfaces.

The numerical characteristics are given in the following tables, wherein Table I corresponds to Fig. 1, Table II to Fig. 2, and Table III to Fig. 3.

TABLE I

(N = Refractive indices and V = dispersive indices)

Lens element	N	V	Radii in mm.	Thicknesses in mm.
1	1.6979	30.2	R_1 = + 1876	t_1 = 1.35
			R_2 = + 65.37	s_1 = 0.54
2	1.6201	60.2	R_3 = + 71.92	t_2 = 7.36
			R_4 = − 251.80	s_2 = 0.09
3	1.6201	60.2	R_5 = + 54.00	t_3 = 4.98
			R_6 = + 335.35	s_3 from 0.781 to 43.60
4	1.6903	54.0	R_7 = + 194.29	t_4 = 0.68
			R_8 = + 20.95	s_4 = 6.16
5	1.5743	57.4	R_9 = − 39.63	t_5 = 0.51
6	1.6979	30.2	R_{10} = + 20.44	t_6 = 5.28
			R_{11} = + 310.15	s_5 from 52.375 to 0.492
7	1.6979	30.2	R_{12} = + 160	t_7 = 0.44
			R_{13} = + 23.07	s_6 = 0.11
8	1.6574	57.2	R_{14} = + 23.57	t_8 = 6.16
			R_{15} = − 33.30	s_7 = 0.05
9	1.6903	54.0	R_{16} = + 26.70	t_9 = 2.20
			R_{17} = + 77.367	s_8 from 4.716 to 13.781
			R_{18} = − 20.28	
10	1.5162	64.0	R_{19} = + 10.57	t_{10} = 0.53
11	1.6253	46.9	R_{20} = + 71.04	t_{11} = 3.52
			R_{21} = + 87.98	s_9 = 5.35
12	1.6979	30.2	R_{22} = + 16.75	t_{12} = 0.88
			R_{23} = + 28.65	s_{10} = 0.53
13	1.6903	54.0	R_{24} = − 11.73	t_{13} = 3.52
14	1.7304	28.4	R_{25} = − 18.95	t_{14} = 0.88

The focal length varies from 12.76 to 74.86, and the relative aperture is 1/2.2 over the whole range of focusing.

TABLE II

Lens element	N	V	Radii in mm.	Thicknesses in mm.
1	1.6973	30.2	R_1 = + 1658.44 R_2 = + 64.60	t_1 = 1.42 s_1 = 0.48
2	1.6201	60.2	R_3 = + 69.55 R_4 = − 292.60	t_2 = 7.73 s_2 = 0.09
3	1.6201	60.2	R_5 = + 59.55 R_6 = + 555.99	t_3 = 5.23 s_3 from 0.915 to 47.476
4	1.6903	54.0	R_7 = + 194.29 R_8 = + 20.95	t_4 = 0.68 s_4 = 6.16
5 6	1.5894 1.6973	61.5 30.2	R_9 = − 39.63 R_{10} = + 19.90 R_{11} = + 464.80	t_5 = 0.51 t_6 = 6.10 s_5 from 66.680 to 0.116
7 8	1.6973 1.6566	30.2 57.2	R_{12} = + 105.67 R_{13} = + 21.72 R_{14} = − 44	t_7 = 0.55 t_8 = 7.85 s_6 = 0.06
9	1.6213	60.2	R_{15} = + 41.72 R_{16} = + 422.706	t_9 = 3.20 s_7 from 3.986 to 23.990
10 11	1.5154 1.6273	54.5 36.3	R_{17} = − 23.94 R_{18} = + 12.58 R_{19} = + 104.56	t_{10} = 0.62 t_{11} = 4.16 s_8 = 7.40
12	1.6973	30.2	R_{20} = + 54.76 R_{21} = + 19.81	t_{12} = 1.04 s_9 = 0.62
13 14	1.6903 1.7304	54.0 28.4	R_{22} = + 46.96 R_{23} = − 12.32 R_{24} = − 22.98	t_{13} = 4.16 t_{14} = 1.04

The focal length varies from 12.92 to 105.89, and the relative aperture is $\frac{1}{2}$.2 over the whole range of focusing.

TABLE III

Lens element	N	V	Radii in mm.	Thicknesses in mm.
1	1.6973	30.2	R_1 = + 1703.565 R_2 = + 69.49	t_1 = 1.53 s_1 = 0.53
2	1.6201	60.2	R_3 = + 74.97 R_4 = − 315.38	t_2 = 8.33 s_2 = 0.10
3	1.6201	60.2	R_5 = + 64.19 R_6 = + 599.28	t_3 = 5.64 s_3 from 0.916 to 54.030
4	1.6903	54.0	R_7 = + 194.29 R_8 = + 20.95	t_4 = 0.68 s_4 = 6.16
5 6	1.5894 1.6973	61.5 30.2	R_9 = − 39.63 R_{10} = + 19.90 R_{11} = + 464.80	t_5 = 0.51 t_6 = 6.10 s_5 from 73.303 to 0.219
7	1.6973	30.2	R_{12} = + 101.80 R_{13} = − 200	t_7 = 3 s_6 = 0.50
8 9	1.6973 1.6566	30.2 57.2	R_{14} = − 300 R_{15} = + 21.72 R_{16} = − 47.31	t_8 = 1 t_9 = 7.85 s_7 = 0.06
10	1.6213	60.2	R_{17} = + 39.20 R_{18} = + 287.263	t_{10} = 3.20 s_8 from 2.078 to 22.048
11 12	1.5154 1.6273	54.5 36.3	R_{19} = − 23.94 R_{20} = + 12.58 R_{21} = + 104.56	t_{11} = 0.62 t_{12} = 4.16 s_9 = 7.40
13	1.6973	30.2	R_{22} = + 54.76 R_{23} = + 19.81	t_{13} = 1.04 s_{10} = 0.62
14 15	1.6903 1.7304	54.0 28.4	R_{24} = + 46.96 R_{25} = − 12.32 R_{26} = − 22.98	t_{14} = 4.16 t_{15} = 1.04

The focal length varies from 11.46 to 105.98, and the relative aperture is $\frac{1}{2}$.2 over the whole range of focusing.

In these tables as in the drawings the lens elements are designated in the front to rear order in the first column; the indices of refraction N for the spectrum line D and the conventional dispersive indices or Abbe number V are given in the second and third columns; the radii of curvature R of the lens surfaces, the thicknesses t of the lens elements and the air spaces s are given in the fourth and fifth columns.

In each table the value of s_3 for the space between the first and second members correspond to the focusing of the lens system for an object located at infinity, but member C1 is independently displaceable axially forward to permit the focusing on nearby objects.

In the example illustrated in Fig. 1 the focal length of member C1 is 93.58 mm., that of member C2 is 23.71 mm., and that of member C3 is 25. 60 mm. The lens system is adjusted to its minimum focal length $\Phi=12.76$ mm., when $s_3=0.781$, $s_5=52.375$ and $s_8 = 4.716$, and when the movable members are so arranged the image magnification given by member C2 is $g_2 = 0.3674$, the image magnification given by member C3 is $g_3 = 0.3638$, and the image magnification given by the corrector member is $g_4 = 1.020$. When member C2 is moved in the front to rear direction the member C3 is moved in the opposite direction to a position such that $s_8 = 13.980$ and simultaneously $s_3 = 41.607$. Then, as member C2 continues its movement in the same direction, member C3 changes its direction of movement to a position such that $s_8 = 13.781$ while $s_3 = 43.60$. The focal length of the lens system is then 74.86 mm. When the movable members are so disposed, the image magnification given by the member C2 is $g_2 = 1.092$, and the image magnification given by the member C3 is $g_3 = 0.718$.

In the example illustrated in Fig. 2 the focal length of member C1 is 98.30 mm., that of member C2 is 23.57 mm., that of member C3 is 30.81 mm., and that of the convergent corrector member is 105.48 mm. The lens system is adjusted to its smallest focal length $\Phi = 12.92$ when $s_3 = 0.915$, $s_5 = 66.680$ and $s_7 = 3.986$, and when the movable members are so disposed the image magnification given by member C2 is $g_2 = 0.3405$, the image magnification given by member C3 is $g_3 = 0.3859$, and the image magnification given by the corrector member is $g_4 = 1.000$.

When member C2 is moved in the front to rear direction, member C3 moves simultaneously in the opposite direction to its endmost position wherein $s_7 = 23.99$, while $s_3 = 47.476$. The focal length of the lens system is then 105.89 mm. When the movable members are so disposed, the image magnification given by the member C2 is $g_2 = 1.040$, and the image magnification given by the member C3 is $g_3 = 1.036$.

In the example illustrated in Fig. 3 the focal length of member C1 is 105.95 mm., that of member C2 is 23.57 mm., that of member C3 is 30.81 mm., and that of the corrector member is 105.48 mm. The lens system is adjusted to its smallest focal length $\Phi = 11.46$ when $s_3 = 0.916$, $s_5 = 73.303$, and $s_8 = 2.078$, and when the movable members are so disposed the magnification of the image given by member C2 = 0.3074, the image magnification given by member C3 is $g_3 = 0.3518$ and the image magnification given by the corrector member is $g_4 = 1.000$.

When member C2 is moved in the front to rear direction member C3 travels continuously in the opposite direction to its endmost position wherein $s_8 = 22.048$, while $s_3 = 54.030$. The focal length of the lens system is then 105.98 mm.

When the movable members are thus disposed, the image magnification given by the member C_2 is $g_2 = 1.000$, and the image enlargement given by the member C_3 is $g_3 = 1.000$.

In the various forms of embodiment of the lens system of this invention the second member gives a magnification less than 0.50 when it has completed its forward stroke, while simultaneously the third member, which at that time has completed its front to rear stroke, produces a magnification also lower than 0.50.

WHAT I CLAIM IS:—

1. A variable focal length lens system comprising a first frontal convergent member, which is fixed for focusing on an object at any given distance, a second axially movable divergent member and a third axially movable convergent member, all these members being aligned on a common optical axis in front of a fixed correcting member also aligned on the same optical axis, characterised in that said second member produces a magnification lower than .5 when it has completed its forward stroke while simultaneously said third member, which has then completed its backward stroke, produces a magnification also lower than .5, said third member consisting of at least three lens elements among which are a divergent lens element having a concave rear face and a convergent lens element located behind the rear face of said divergent lens element at a distance which at minimum is zero and at maximum is 5% of the focal length of the third member, the front face of said convergent lens element being convex and having a radius of curvature at least equal to that of the rear face of said divergent lens element, this last-named radius being greater than half the focal length of said third member.

2. A variable focal length lens system according to claim 1, characterised in that said first and second members each comprise, like said third member, at least three lens elements among which two constitute an arrangement consisting likewise of a divergent lens element having a concave rear face located at a distance which at minimum is zero and at maximum is 5% of the focal length of the third member in front of a convergent lens element having a convex front face, the radius of curvature of the front face of said last-named lens element being at least equal to that of the rear face of the preceding lens element.

3. A variable focal length lens system according to claims 1 or 2, characterised in that the ratio of the focal length of said third member to that of said second member ranges from 1 to 1.6

4. A variable focal length lens system according to claims 1 or 2, characterised in that said third member consists of a first frontal divergent lens element having a concave rear face, of a second biconvex lens element located behind said first lens element at a distance which at minimum is zero and at maximum 5% of the focal length of the third member, and of a third convergent lens element.

5. A variable focal length lens system according to claims 1 or 2, characterised in that said third member consists of a front convergent doublet and of a convergent rear lens element, said doublet consisting in turn of a divergent frontal lens element having a concave rear face and of a biconvex lens element cemented to said divergent frontal lens element, said divergent frontal lens element having an index of refraction greater than that of said biconvex lens element.

6. A variable focal length lens system according to claims 1 or 2, characterised in that said second member comprises three lens elements divided into two components, the front component comprising a divergent meniscus-shaped lens element having a convex front face with a radius of curvature greater than twice the focal length of said second member, the rear component comprising a cemented surface having its convexity facing forward and providing a convergent optical effect.

7. A variable focal length lens system according to claim 6, characterised in that said second group of said second member consists of two cemented lens elements, of which the front one is biconcave and has an index of refraction for the spectrum line D lower than that of the lens element associated therewith, said last-named lens element being convergent.

8. A variable focal length lens system according to claims 1 or 2, characterised in that said correcting member comprises at the front a biconcave lens element having its rear face cemented to the next lens element, the cemented surface providing a convergent optical effect.

9. A variable focal length lens system according to claim 8, characterised in that the radius of curvature of said cemented surface ranges from 50 per cent to 150 per cent of the focal length of said biconcave lens element.

10. A variable focal length lens system according to claim 8, characterised in that the Abbe number of the glass constituting said biconcave lens element is greater than the Abbe number of the glass constituting the lens cemented thereto, the Abbe number of the glass of said biconcave lens element being greater than 40.

11. A variable focal length lens system substantially as described hereinabove with reference to the accompanying drawings.

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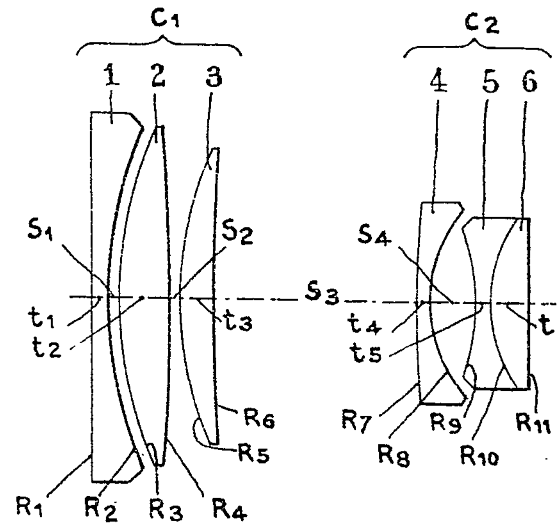

Fig.1

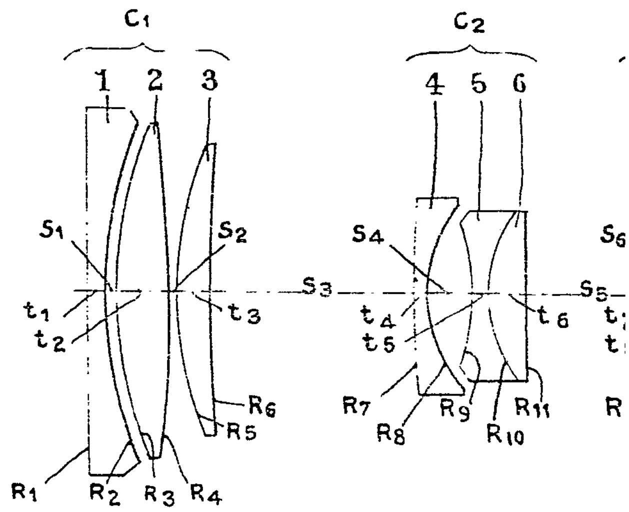

Fig.2

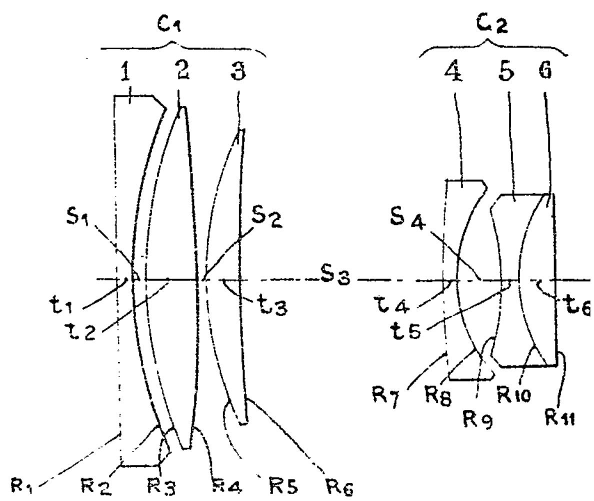

Fig.3

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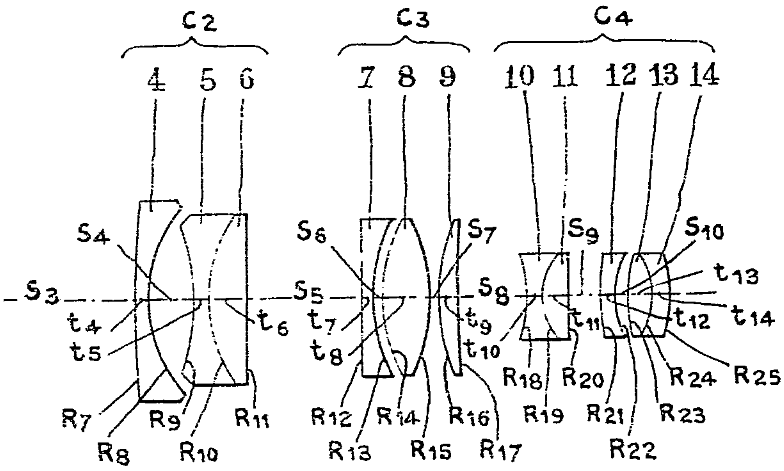

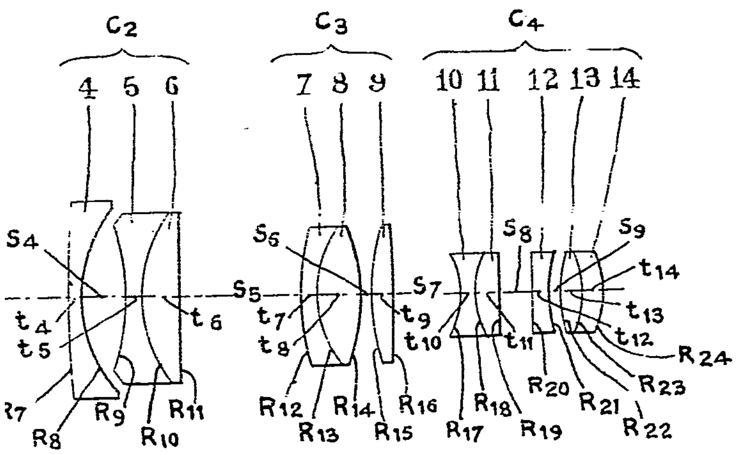

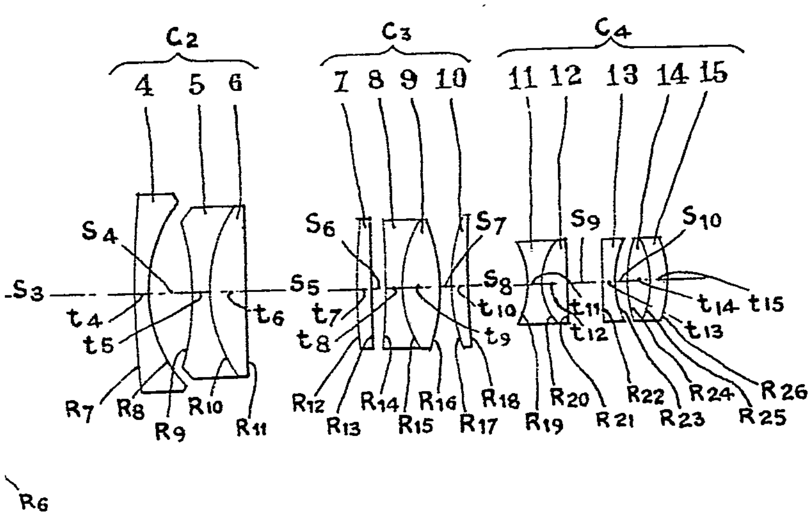

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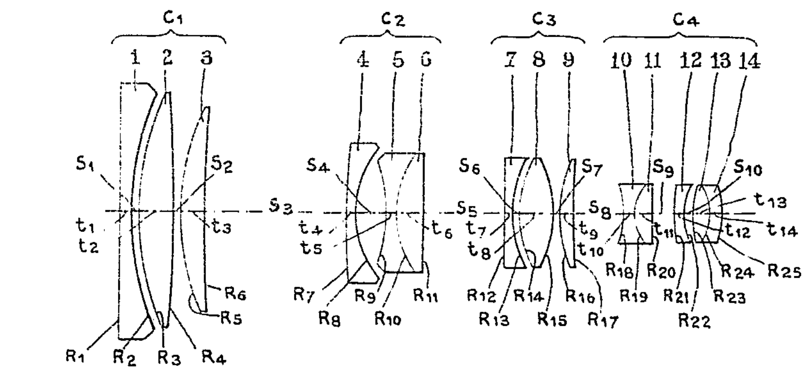

Fig.1

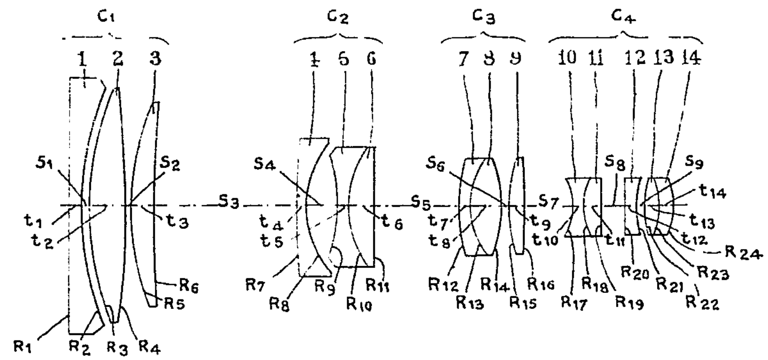

Fig.2

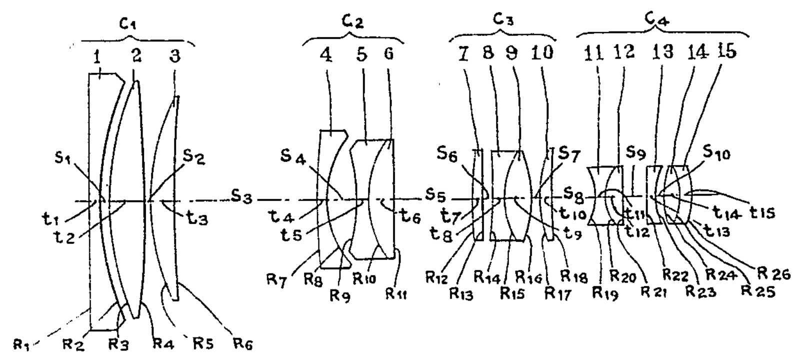

Fig.3