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DEFORMED COLLECTIVE LENS.

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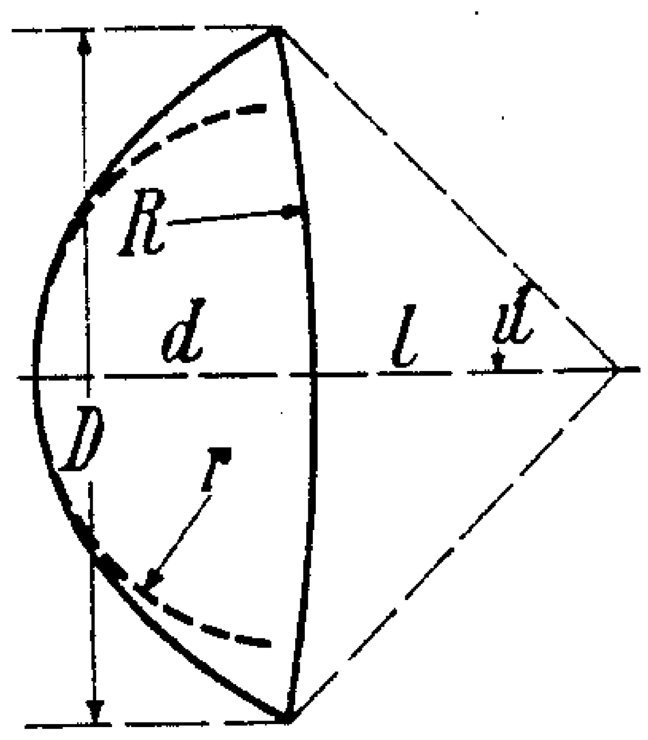

Fig.1

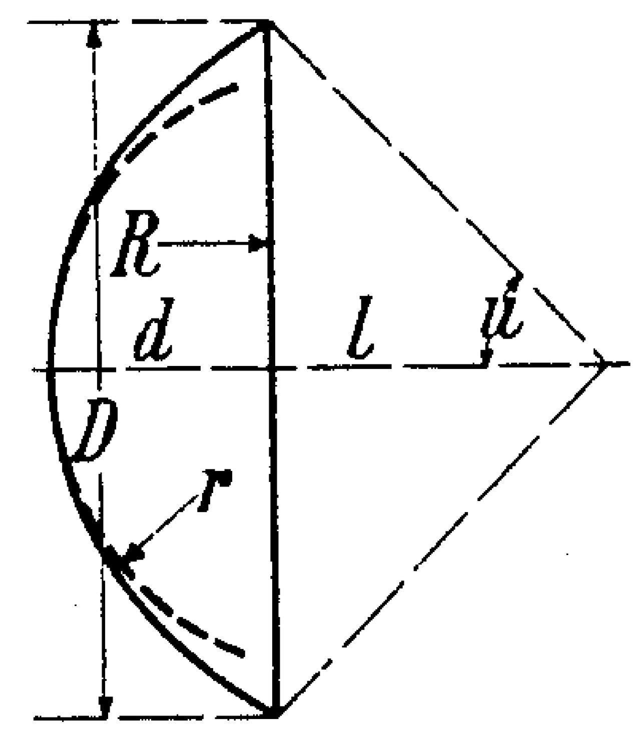

Fig.2

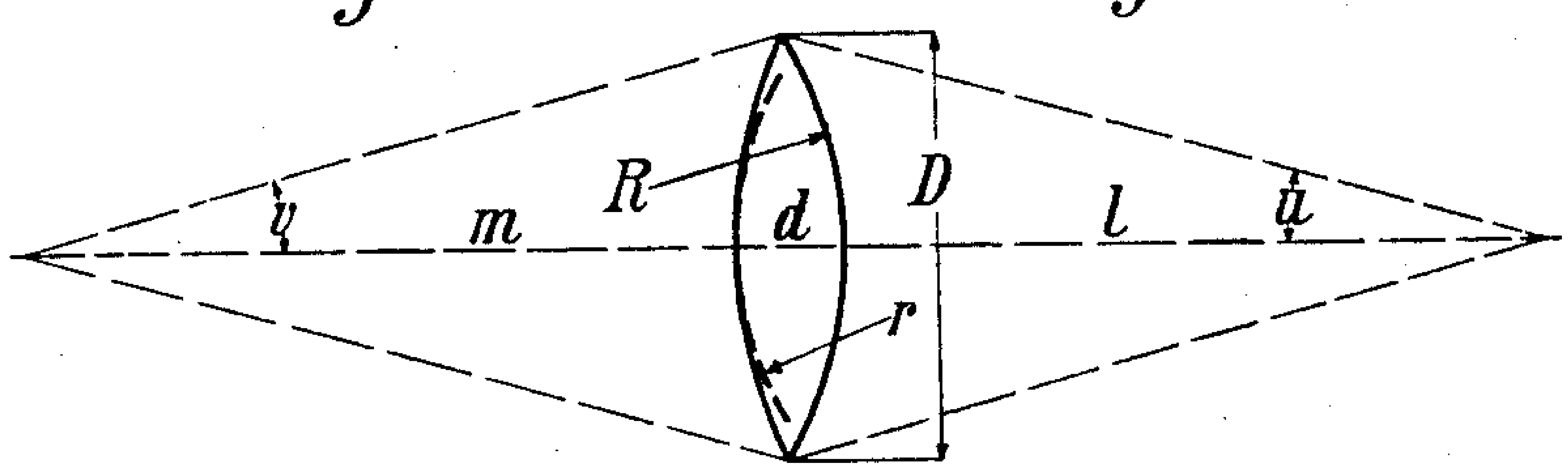

Fig.3

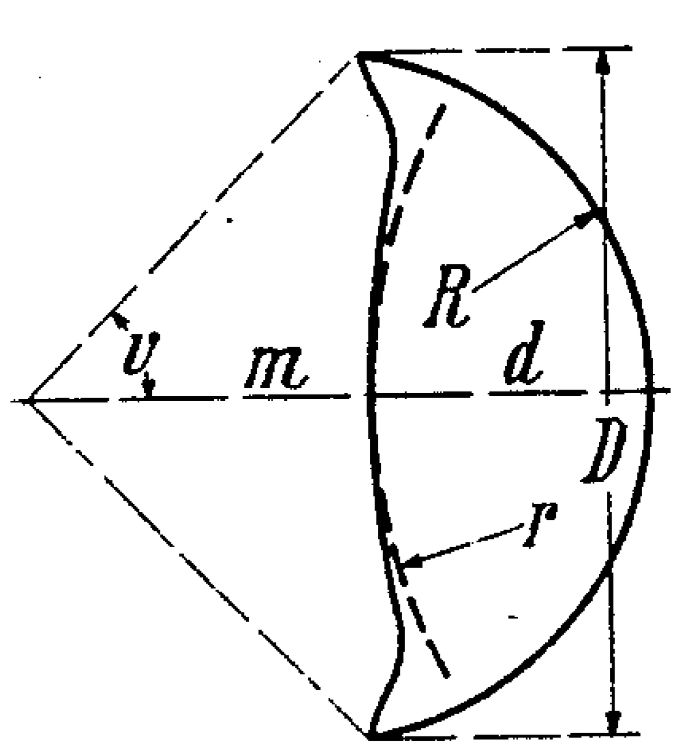

Fig.4

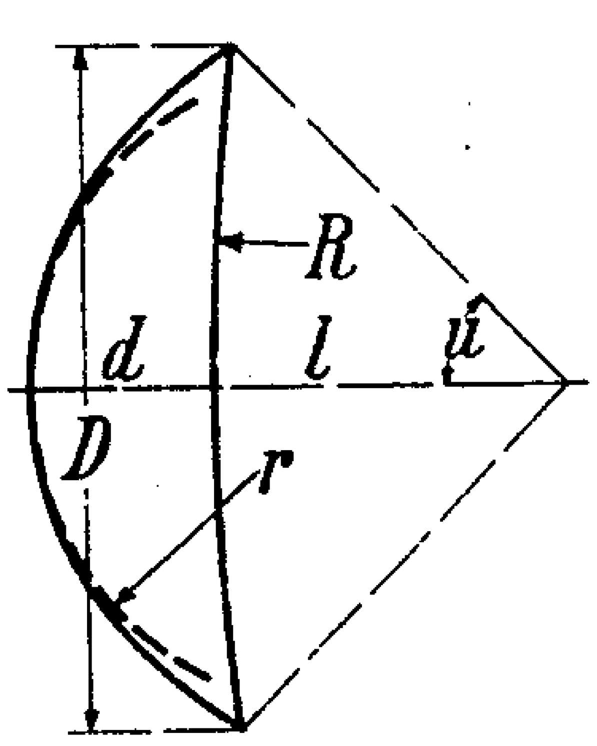

Fig.5

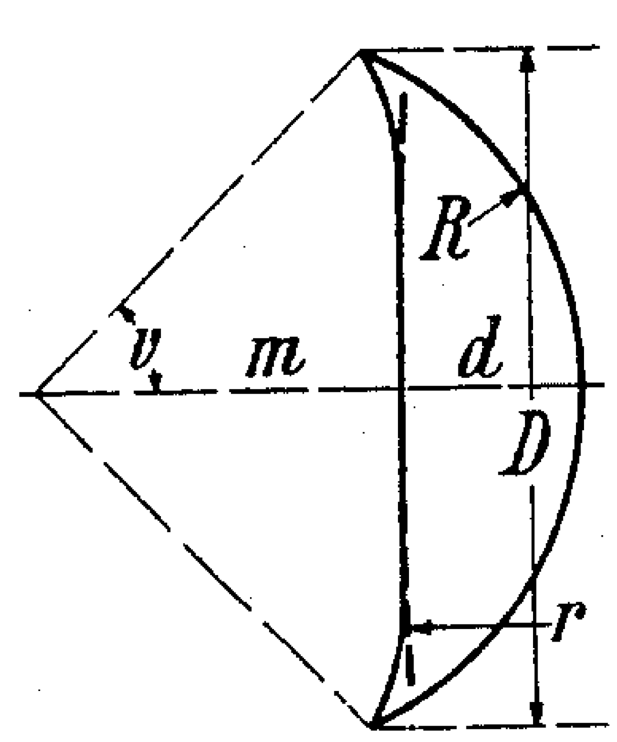

Fig.6

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UNITED STATES PATENT OFFICE.

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DEFORMED COLLECTIVE LENS.

934,579. Specification of Letters Patent. **Patented Sept. 21, 1909.**

Application filed April 1, 1909. Serial No. 487,241.

To all whom it may concern:

Be it known that we, RUDOLF STRAUBEL and MORITZ VON ROHR, citizens of the German Empire, and residing at Carl-Zeiss-strasse, Jena, in the Grand-Duchy of Saxe-Weimar, Germany, have invented a new and useful Deformed Collective Lens, of which the following is a specification.

The invention consists in an improvement in collective lenses of large relative aperture, and particularly in those, which by virtue of deformation of one surface are perfectly or nearly perfectly spherically corrected.

The expression deformation as applied to lens surfaces is as is well known to be understood in that narrower sense to mean a conversion of the spherical surface into a non-spherical surface of revolution, the axis of which is the axis of the lens. The invention covers not only collective lenses which are produced in one piece, but extends also to those comprising a converging lens and a diverging lens of different dispersion which are cemented together with a view to chromatic correction. With spherical correction, that is to say, with the homocentric reproduction of a point on the axis, there is, however, only a moderate requirement in a lens system satisfied, because for the points next the point on the axis and lateral to it errors of reproduction are still left, which are often of considerable magnitude, when the system, as is here supposed, has a large relative aperture. If then a small region around the axis of a surface at right angles to the axis is still to be reproduced free of error for any one color, there is still the well known sine condition to be fulfilled, in consequence of which the ratio between the sine of the angle of convergence in the object space and that of the angle of convergence in the image space must be constant for all zones.

Collective lenses satisfying not only the requirement of spherical correction but also the last-mentioned condition have become known through a paper on non-spherical objectives by M. Linnemann (Göttingen, 1905). The author succeeds in his object by deforming the second lens surface also. According to the present invention essentially the same object is attainable with a single deformed surface. This is of practical value on account of the considerably higher cost of a deformed surface as compared with that of a spherical one and because it is more difficult to bring the axes of the two deformed surfaces into coincidence, than to lay the axis of a single deformed surface through the center of curvature of the spherical surface.

In order to bring about spherical correction and at the same time fulfil the sine condition, without employing a second deformed surface, a suitable selection of the axial elements of the lens is required, that is to say, of the thickness of the lens and of two radii of curvature, of that of the spherical surface and of the vertex radius of the deformed surface. Since these suitable values of the axial elements depend not only upon the angular aperture but also upon the refractive index, and, moreover, not in a simple manner, the details of the invention cannot otherwise be explained than by examples. For this purpose the problem is in the first place to be still more accurately specified. It is impossible with only one deformed surface to fulfil both requirements of correction perfectly, although quite sufficient for practical purposes. Granted that one of the two requirements be fulfilled perfectly, the fulfilment of the other can be so nearly approached, that with regard to any eligible zone the correction is strictly attained and with regard to the other zones attained to a high degree, that consequently the second requirement is realized through a correction which at all events is a good one. In the following examples the problem is solved in the sense, that spherical aberration is completely eliminated and the sine condition strictly fulfilled for the marginal zone.

In the annexed drawing: Figure 1 is a diagram of a bi-convex lens constructed according to the invention. Fig. 2 is a diagram of a convexo-plane lens. Fig. 3 is a diagram of a second bi-convex lens. Fig. 4 is a diagram of a third bi-convex lens. Fig. 5 is a diagram of a convexo-concave lens. Fig. 6 is a diagram of a fourth bi-convex lens.

In these figures r is the vertex radius of the deformed surface, R the radius of the spherical surface, u half the angle of aperture of the pencil belonging to the spherical surface, v half the angle of aperture of the pencil belonging to the deformed surface, l the distance of the point of intersection of the pencil from the lens for the angle of aperture 2 u, m the same distance for 2 v, d the thickness of the lens on the axis and D its diameter, which as is well known is found from the other magnitudes.

In the following table the values of the six examples drawn as well as eighteen others are given along with the index of refraction n, the linear dimensions being adapted to the focal length $f=100$. The radii of convex surfaces have positive signs, those of concave surfaces negative ones. The half angles of aperture v and u are treated as negative, when the point of intersection of the pencil lies on the side of the spherical surface or of the deformed surface respectively. The same holds good for the respective distance m and l.

No.	n	v deg.	u deg.	r	R	d	m	l	Fig.
1.	1.5	−15	45	36	−104	21	−167	44	......
2.	1.5	0	30	55	448	27	∞	84	......
3.	1.5	15	15	87	105	29	191	189	3
4.	1.5	30	0	228	62	27	85	∞	......
5.	1.5	45	−15	− 137	38	21	45	−168	......
6.	1.618	0	30	62	∞	22	∞	87	......
7.	1.75	−15	45	40	− 71	14	−165	48	......
8.	1.75	0	30	68	−605	18	∞	89	......
9.	1.75	15	15	137	155	19	195	194	......
10.	1.75	30	0	−1260	71	18	89	∞	......
11.	1.75	45	−15	− 75	41	14	48	−165	......
12.	1.5	−15	60	40	−131	42	−224	36	......
13.	1.5	0	45	55	390	59	∞	64	1
14.	1.5	15	30	66	138	68	277	117	......
15.	1.5	30	15	80	96	67	128	265	......
16.	1.5	45	0	121	72	59	73	∞	4
17.	1.5	60	−15	− 904	48	42	41	−233	......
18.	1.618	0	45	62	∞	47	∞	71	2
19.	1.75	−15	60	44	− 78	28	−219	43	......
20.	1.75	0	45	68	−540	39	∞	75	5
21.	1.75	15	30	98	253	45	286	132	......
22.	1.75	30	15	165	121	45	136	281	......
23.	1.75	45	0	2300	77	39	78	∞	6
24.	1.75	60	−15	− 96	47	28	45	−222	......

The table embraces two main groups of examples, one comprising Nos. 1 to 11, and the other Nos. 12 to 24. In the examples of the first main group the algebraic sum of the two half angles of aperture v and u amounts to 30°, in the examples of the second group to 45°. In both main groups the examples follow one another in 15°—steps of v and u. It will be noticed, that the same pairs of v and u appear twice over in each main group, the first time (Nos. 1 to 5 and 12 to 17) in combination with the refractive index 1.5, the second time (Nos. 7 to 11 and 19 to 24) in combination with the refractive index 1.75. Furthermore the refractive index 1.618 is employed in Nos. 6 and 18 in the case where $v=0°$.

Carrying out the invention is through the values in the table, in twenty four different cases, directly—in every other case after suitable interpolation—reduced to the problem: How to deform a spherical lens, for which the values n, v, u, r, R, d, m and l together with the focal length f are given, in its surface of radius r so that the lens is spherically corrected. For this problem there are, however, well known methods of solution in vogue. For instance, the Patent Specification 697959 contains upon its first and second pages a section designated I, from the rules of which one of these methods of solution is obvious.

The refractive index 1.618 has in two examples been taken into account in combination with the half angle of aperture $v=0°$, because it produces—for the case, which is perhaps the most important in practice, viz. that the pencils on one side of the lens are formed of parallel rays—a plane surface instead of a spherical surface and as vertex radius r of the deformed surface a value independent of the half angle of aperture u. If the refractive index be smaller, as in the kinds of glass most commonly employed, for a region, the limits of which go a little on the one hand beyond $v=0°$ and on the other beyond $u=0°$, and which includes consequently the Examples Nos. 2 to 4 and 13 to 16, both radii r and R are positive, that is to say, the corresponding surfaces are convex. If from this region such pairs of v and u be further excluded, in which v is considerably greater than u, that is if only Nos. 2 and 3 and 13 to 15 of the examples be taken into consideration, the result is, that r is always smaller than R. On the other hand, in pairs of v and u, in which u has about the value zero, r is greater than R, as is seen from the two examples Nos. 4 and 16.

We claim:

1. A collective lens of large relative aperture with one deformed surface, this lens being corrected for spherical aberration as well as to fulfil the sine condition.

2. A bi-convex lens of large relative aperture with one deformed surface, this lens having a refractive index n below 1.618 and being corrected for spherical aberration as well as to fulfil the sine condition.

3. A bi-convex lens of large relative aperture with one deformed surface, the vertex radius r of which is smaller than the radius R of the spherical surface, this lens having a refractive index n below 1.618 and being corrected, spherically and with regard to the sine condition, for an angle of aperture 2 v on the side of the deformed surface at most so large that it slightly exceeds the angle of aperture 2 u on the side of the spherical surface.

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