

PATENT SPECIFICATION

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(54) AN IMPROVED TRIPLET LENS

(71) We, EASTMAN KODAK COMPANY, a Company organized under the Laws of the State of New Jersey, United States of America, of 343 State Street, Rochester, New York 14650, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to lenses and in particular to modified triplets with reduced secondary spectrum which may be used in printers.

The aberration known as secondary spectrum is the inability of a lens, even when achromatically corrected i.e. for longitudinal chromatic aberration in two colours, to focus all wavelengths of light at the same point. In monochromatic prints, secondary spectrum tends to reduce the contrast of the final print, particularly in fine detail areas. In colour prints, secondary spectrum is seen as a spreading of colour from dark areas into adjacent light areas, a phenomenon known as colour fringing or halo.

It is known to use modified triplets of the type having two outer positive components sandwiching a middle negative component for photographic printing lenses. Many such lenses are well corrected for monochromatic and longitudinal chromatic aberrations. Secondary spectrum is limited in such triplets by careful selection of the materials used in each element of the triplet.

It is an object of the present invention to provide a modified triplet having reduced secondary spectrum aberration the triplet being of the type having two outer positive components sandwiching a middle negative component.

According to the present invention there is provided a lens comprising a front positive doublet, a middle negative component and a rear positive doublet, wherein the following inequality is satisfied:

[Price 25p]

$$(P_m - P_s)/(V_s - V_m) \leq 0.00120$$

wherein P_s and V_s are respectively the partial dispersion and Abbé number of the middle negative component and P_m and V_m are respectively the mean equivalent partial dispersion and mean equivalent Abbé number for the front and the rear doublets.

In the detailed description of the preferred embodiments, reference is made to the accompanying drawing, wherein:

Fig. 1 is a diagrammatic axial cross-section of a lens according to the present invention;

Fig. 2 is a graph of partial dispersion P against Abbé number V , for the elements in the lens of the present invention; and

Fig. 3 is the spherical aberration curve for a lens according to the present invention.

The term lens as used herein, is used to describe a complete lens and not elements or components thereof. The long conjugate side of the lens is considered to be in front of the lens and is shown on the left of the lens in Figure 1. The term partial dispersion P for a refractive material shall refer to the partial dispersion for the g-line of mercury and may be calculated from the following formula:

$$(1) \quad P = (N_g - N_F)/(N_F - N_D)$$

The term secondary spectrum shall be defined as the difference between the focus for the g line of mercury and the common focus for the C and F-lines of hydrogen.

Primary colour correction in a positive doublet is obtained by using a refractive material of low dispersion for the positive element of the doublet and a refractive material of high dispersion for the negative element. Thus, a positive doublet which is well corrected for primary colour is characterized by a large difference in Abbé number between its two elements. Secondary spectrum for a doublet is known to be proportional to the slope of the line on a plot of partial dispersion versus Abbé number which is defined

by the parameters of the elements of the doublet. This slope is given by the following relationship:

$$(2) \quad \text{slope} = (P_b - P_a) / (V_a - V_b)$$

- 5 where the subscripts a and b refer to the two elements of the doublet. It may be seen that the best correction of secondary spectrum results from equality of partial dispersion for the positive and negative elements of the doublet. Thus a doublet, to be well corrected for both primary and secondary spectrum, should have elements with a large difference in Abbé number and equal partial dispersion.

10 Fig. 2 is a graph of partial dispersion, P versus Abbé number, V. Most available glasses lie along or near the line K of Fig. 2, which has a slope of 0.00170. Included are the glasses represented by the points 10, 12, 16 and 18 which are the glasses selected for use in the triplet of the present invention as will be more fully described hereinafter. Because of this restriction on the parameters of available glasses it may be seen that the two conditions required for a doublet to be well corrected cannot be presently met. Selection of a pair of glasses with widely differing Abbé numbers ensures a wide difference in partial dispersion. Selection of glasses with equal partial dispersion ensures near equality of Abbé numbers.

15 A similar restriction holds true for the correction of a simple triplet. Primary correction again requires a large difference in dispersion between the positive and negative elements of the triplet. Secondary spectrum of the triplet is proportional to the slope of the line defined on the plot of P versus V by the mean parameters P_m , V_m of the positive components and the parameters P_s and V_s of the negative element. This slope is given by the following relationship:

$$(3) \quad \text{slope} = (P_m - P_s) / (V_s - V_m)$$

20 It may be seen from an analysis of line K of Figure 2 that the large difference in Abbé number which is required to make primary colour corrections in a simple triplet results in a large difference in partial dispersion. In order substantially to reduce the secondary spectrum of the triplet, it has been found to be necessary for some of the components of the triplet to be compound, with the selection of element glasses and focal lengths for the compound components being performed in a manner which is now to be described.

25 In the present invention, as illustrated in Figure 1, component I is a positive doublet consisting of a front positive biconvex element 1 and a rear negative biconcave element 2. Component II consists of a negative biconcave element 3. Component III is a positive doublet consisting of a front meniscus negative

element 4, concave to the rear, and a rear positive biconvex element 5.

A doublet, consisting of two elements a and b, may be considered as equivalent to a single element of equivalent focal length F_{eq} made from a hypothetical glass having equivalent V_{eq} and P_{eq} values defined by the following equations:

$$(4) \quad F_{eq} = F_a F_b / (F_a + F_b)$$

$$(5) \quad V_{eq} = V_a V_b (F_a + F_b) / (V_a F_a + V_b F_b)$$

$$(6) \quad P_{eq} = (P_a V_b F_b + P_b V_a F_a) / (V_a F_a + V_b F_b)$$

30 where the subscripts a and b again refer to the two elements of the doublet. The equivalent P_{eq} and V_{eq} values for the hypothetical glass will lie along a straight line on the P-V plot of Fig. 2 which is defined by the P and V parameters of the element glasses of the doublet. Thus, component I consists of a front element 1 with parameters represented on Fig. 2 by point 10 and a rear element 2 with parameters represented on Fig. 2 by point 12. Points 10 and 12 define a line L along which lies point 14, representing the equivalent parameters of the hypothetical glass of component I. Component III consists of a front element 4 with parameters represented in Fig. 2 by point 16 and a rear element 5 with parameters represented on Fig. 2 by point 18. Points 16 and 18 define a line M along which lies point 20, representing the equivalent parameters of the hypothetical glass of component III. The exact values of P_{eq} and V_{eq} are determined by the selected element focal lengths for given glasses and may be positioned to the right, to the left or in between the points representing the element glasses.

35 Dotted line N on Fig. 2 is defined by points 14 and 20, representing the equivalent partial dispersion and equivalent Abbé number of the hypothetical glasses found in components I and III. The mean value of these hypothetical parameters, represented by point 22 on line N of Fig. 2, may be seen to lie substantially away from line K, which represents the ordinarily available glasses. Secondary spectrum for the triplet is then proportional to the slope of the line O, defined by the mean equivalent parameters represented by point 22 and the parameters for negative component II. By proper selection of the mean equivalent parameters and of the parameters for negative component II of the triplet, the slope of the PV line for the triplet may be substantially reduced to below that available in a simple triplet, thereby ensuring substantially improved correction of secondary spectrum. Thus, an improved triplet according to the present invention will have a PV line of slope ≤ 0.00120 . The selection of these glasses and focal lengths will now be described in more detail with reference to Example 1.

In all of the following examples, the lens components are numbered from front to rear with Roman numerals; the lens elements are numbered from front to rear with Arabic numerals. The element focal lengths F , the indexes of refraction N for the D line of the spectrum, the Abbé numbers V , the radii of curvature R , the thicknesses T and the separa-

tions S , and the partial dispersions P are numbered by subscript from front to rear. Radii of curvature having centres of curvature to the rear of the surface are considered positive; those with centres of curvature to the front of the surface are considered negative. All parameters are based upon a lens focal length of 100mm.

EXAMPLE 1

$f/5.00$

$F = 100\text{mm}$

Magnification = 6.125x

Element	N_D	V_D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	$R_1 = 31.787$	$T_1 = 10.449$	0.542	28.8
2	1.51700	64.5	$R_2 = -35.676$	$T_2 = 2.216$	0.534	-62.6
3	1.65317	39.7	$R_3 = 353.24$	$S_1 = 3.080$	0.568	
			$R_4 = -50.341$	$T_3 = 4.824$		
			$R_5 = 29.561$	$S_2 = 5.846$		
4	1.65317	39.7	$R_6 = 249.41$	$T_4 = 2.546$	0.568	-44.1
5	1.74500	46.4	$R_7 = 25.732$	$T_5 = 5.594$	0.561	24.1
			$R_8 = -53.754$			

Component	Equiv. V	Equiv. P
I	62.7	0.549
III	58.2	0.549
Mean	60.45	0.549

$$(P_s - P_m)/(V_m - V_s) = 0.00092$$

As may be seen from the table of Example 1, front component I consists of a front element 1 which is characterized by a Abbé number of 63.5 and a partial dispersion of 0.542 with an element focal length of 28.8. Rear element 2 of front component I is characterized by a Abbé number of 64.5 and a partial dispersion of 0.534 with an element focal length of -62.6. By application of formulas (4), (5) and (6) above, the equivalent Abbé number and equivalent partial dispersion of front component I are calculated and found to be 62.7 and 0.549 respectively. These parameters have been plotted in Fig. 2 with the

parameters of element 1 defining point 10 and the parameters of element 2 defining point 12. Points 10 and 12 define a straight line L on which the parameters of the resulting equivalent hypothetical glass are represented by point 14. Analogous computations may be performed on the parameters of rear component III with a resulting equivalent Abbé number and partial dispersion of 58.2 and 0.549 respectively. Rear component III is represented on Fig. 2 by line M with the parameters of front element 4 of rear component III represented by point 16 and the parameters of rear element 5 of rear component III represented

- by point 18. The equivalent Abbé number and equivalent partial dispersion of the resulting hypothetical glass of rear component III are represented by point 20 on line M. The mean equivalent Abbé number and mean equivalent partial dispersion of front and rear components I and III lie at 22 along line N, defined by points 14 and 20, and are calculated to be 60.45 and 0.549 respectively.
- 10 A glass for negative component II is now selected using the mean equivalent Abbé number and mean equivalent partial dispersion of components I and III in such a manner as to ensure proper primary colour correction by utilizing a large difference in Abbé number while simultaneously ensuring good secondary colour correction by minimizing the slope of the P—V line for the triplet as described above. The glass selected for element 3 in Example I, which is the same glass as used for element 4, results in a slope for normal glasses, which is .00170. Fig. 3 illustrates the

improved secondary spectrum correction achieved by the design of the present invention. Not only is the secondary spectrum reduced to 0.10% of the effective focal length of the lens, but it may be seen that spherical aberration has also been substantially reduced from available lenses. Thus both primary and secondary colour aberration corrections have been improved by the selection of glasses as described above.

Additional printer lenses which are well corrected for secondary spectrum may be made according to the present invention by following the procedure in the examples presented below. In each example, the design parameters for the lens are followed by the equivalent and mean Abbé numbers and equivalent and mean partial dispersions for that lens and by the calculated slope of the V—P line indicating, in each example, the improved secondary spectrum correction achieved.

EXAMPLE 2

f/4.5

F = 100mm

Mag. = 2.911x

Element	N _D	V _D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	R ₁ = 33.085	T ₁ = 8.214	0.542	28.3
2	1.51700	64.5	R ₂ = -33.832	T ₂ = 2.535	0.534	-59.8
3	1.65317	39.7	R ₃ = 351.47 R ₄ = -44.453 R ₅ = 33.379	S ₁ = 3.712 T ₃ = 4.432 S ₂ = 5.435	0.568	
4	1.65317	39.7	R ₆ = 750.18 R ₇ = 29.064	T ₄ = 2.667	0.568	-46.4
5	1.74500	46.4	R ₈ = -46.451	T ₅ = 5.649	0.561	24.8

Component	Equiv. V	Equiv. P
I	62.6	0.549
III	57.6	0.549
Mean	59.1	0.549

$$(P_s - P_m) / (V_m - V_s) = 0.00098$$

Example 2 is similar to Example 1, as may be seen by a comparison of the corresponding parameters. Example 2 illustrates that variation in these parameters does not prevent good secondary spectrum correction, so long as the conditions established above for selection of element glasses and focal lengths are satisfied.

EXAMPLE 3

Element	N _D	V _D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	R ₁ = 33.747	T ₁ = 8.322	0.542	27.8
2	1.51700	64.5	R ₂ = -31.891	T ₂ = 2.540	0.534	-61.4
			R ₃ = 4155.83	S ₁ = 3.587		
3	1.65317	39.7	R ₄ = -41.187	T ₃ = 4.379	0.568	
			R ₅ = 34.769	S ₂ = 5.395		
4	1.65317	39.7	R ₆ = 566.75	T ₄ = 2.032	0.568	-48.5
			R ₇ = 29.892			
5	1.7445	45.8	R ₈ = -42.892	T ₅ = 5.639	0.563	24.5

Component	Equiv. V	Equiv. P
I	62.7	0.549
III	54.4	0.553
Mean	58.6	0.550

$$(P_s - P_m)/(V_m - V_s) = 0.00095$$

10 Example 3 is a modification of Example 2 in which a different glass is utilized in element 5 of component III. Example 3 illustrates that selection of different glasses does not prevent good secondary spectrum correction, so long as the conditions established above for selection of element glasses and focal 15 lengths are satisfied.

EXAMPLE 4

 $f/6.3$ $F = 100\text{mm}$ $\text{Mag} = 6.561\times$

Element	N_D	V_D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	$R_1 = 27.655$	$T_1 = 9.879$	0.542	25.5
2	1.51700	64.5	$R_2 = -31.981$	$T_2 = 2.184$	0.534	-53.7
			$R_3 = 212.51$	$S_1 = 2.052$		
3	1.65317	39.7	$R_4 = -52.949$	$T_3 = 1.920$	0.568	
			$R_5 = 26.977$	$S_2 = 4.848$		
4	1.65317	39.7	$R_6 = 144.72$	$T_4 = 4.931$	0.568	-70.5
5	1.74500	46.4	$R_7 = 34.469$	$T_5 = 5.808$	0.561	31.0
			$R_8 = -63.586$			

Component	Equiv. V	Equiv. P
I	62.6	0.550
III	53.4	0.553
Mean	58.0	.05515

$$(P_s - P_m)/(V_m - V_s) = .00091$$

EXAMPLE 5

f/5.0

F = 100mm

Mag. = 10.370x

Element	N _D	V _D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	R ₁ = 28.345	T ₁ = 10.126	0.542	26.2
2	1.51700	64.5	R ₂ = -32.779	T ₂ = 2.239	0.534	-54.9
			R ₃ = 217.81	S ₁ = 2.103		
3	1.65317	39.7	R ₄ = -54.270	T ₃ = 1.967	0.568	
			R ₅ = 27.650	S ₂ = 4.970		
4	1.65317	39.7	R ₆ = 148.33	T ₄ = 5.054	0.568	-71.2
5	1.74500	46.4	R ₇ = 35.330	T ₅ = 5.953	0.561	31.4
			R ₈ = -63.468			

Component	Equiv. V	Equiv. P
I	62.6	0.549
III	53.6	0.554
Mean	58.1	0.5515

$$(P_s - P_m) / (V_m - V_s) = 0.00090$$

V	V	V	V	V	V
8.10	10.10	12.10	14.10	16.10	18.10
10.10	12.10	14.10	16.10	18.10	20.10
12.10	14.10	16.10	18.10	20.10	22.10
14.10	16.10	18.10	20.10	22.10	24.10
16.10	18.10	20.10	22.10	24.10	26.10
18.10	20.10	22.10	24.10	26.10	28.10
20.10	22.10	24.10	26.10	28.10	30.10
22.10	24.10	26.10	28.10	30.10	32.10
24.10	26.10	28.10	30.10	32.10	34.10
26.10	28.10	30.10	32.10	34.10	36.10
28.10	30.10	32.10	34.10	36.10	38.10
30.10	32.10	34.10	36.10	38.10	40.10
32.10	34.10	36.10	38.10	40.10	42.10
34.10	36.10	38.10	40.10	42.10	44.10
36.10	38.10	40.10	42.10	44.10	46.10
38.10	40.10	42.10	44.10	46.10	48.10
40.10	42.10	44.10	46.10	48.10	50.10
42.10	44.10	46.10	48.10	50.10	52.10
44.10	46.10	48.10	50.10	52.10	54.10
46.10	48.10	50.10	52.10	54.10	56.10
48.10	50.10	52.10	54.10	56.10	58.10
50.10	52.10	54.10	56.10	58.10	60.10
52.10	54.10	56.10	58.10	60.10	62.10
54.10	56.10	58.10	60.10	62.10	64.10
56.10	58.10	60.10	62.10	64.10	66.10
58.10	60.10	62.10	64.10	66.10	68.10
60.10	62.10	64.10	66.10	68.10	70.10
62.10	64.10	66.10	68.10	70.10	72.10
64.10	66.10	68.10	70.10	72.10	74.10
66.10	68.10	70.10	72.10	74.10	76.10
68.10	70.10	72.10	74.10	76.10	78.10
70.10	72.10	74.10	76.10	78.10	80.10
72.10	74.10	76.10	78.10	80.10	82.10
74.10	76.10	78.10	80.10	82.10	84.10
76.10	78.10	80.10	82.10	84.10	86.10
78.10	80.10	82.10	84.10	86.10	88.10
80.10	82.10	84.10	86.10	88.10	90.10
82.10	84.10	86.10	88.10	90.10	92.10
84.10	86.10	88.10	90.10	92.10	94.10
86.10	88.10	90.10	92.10	94.10	96.10
88.10	90.10	92.10	94.10	96.10	98.10
90.10	92.10	94.10	96.10	98.10	100.10

EXAMPLE 6

f/5.0

F = 100mm

Mag. = 6.497x

Element	N _D	V _D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	R ₁ = 27.984	T ₁ = 9.997	0.542	25.9
2	1.51700	64.5	R ₂ = -32.361	T ₂ = 2.210	0.534	-54.3
			R ₃ = 215.04	S ₁ = 2.076		
3	1.65317	39.7	R ₄ = -53.579	T ₃ = 1.942	0.568	
			R ₅ = 27.298	S ₂ = 4.906		
4	1.65317	39.7	R ₆ = 146.44	T ₄ = 4.990	0.568	-69.9
5	1.74500	46.4	R ₇ = 34.880	T ₅ = 5.877	0.561	31.0
			R ₈ = -63.529			

Component	Equiv. V	Equiv. P
I	62.5	0.550
III	53.7	0.554
Mean	58.1	0.552

$$(P_s - P_m)/(V_m - V_s) = 0.00084$$

EXAMPLE 7

f/4.5

F = 100mm

Mag. = 7.102x

Element	N _D	V _D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	R ₁ = 25.965	T ₁ = 9.302	0.542	24.8
2	1.51700	64.5	R ₂ = -30.171	T ₂ = 2.069	0.534	-53.7
			R ₃ = 199.56	S ₁ = 1.932		
3	1.65317	39.7	R ₄ = -50.476	T ₃ = 1.813	0.568	
			R ₅ = 25.392	S ₂ = 4.466		
4	1.65317	39.7	R ₆ = 136.88	T ₄ = 4.634	0.568	-65.7
5	1.74500	46.4	R ₇ = 32.437	T ₅ = 5.489	0.561	28.6
			R ₈ = -59.838			

Component	Equiv. V	Equiv. P
I	62.6	0.550
III	53.4	0.554
Mean	38.0	0.552

$$(P_s - P_m)/(V_m - V_s) = 0.00087$$

EXAMPLE 8

f/4.5

F = 100mm

Mag. = 7.096x

Element	N _D	V _D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	R ₁ = 28.256	T ₁ = 10.123	0.542	26.2
2	1.51700	64.5	R ₂ = -32.834	T ₂ = 2.252	0.534	-55.1
3	1.65317	39.7	R ₃ = 217.17 R ₄ = -54.260	S ₁ = 2.103 T ₃ = 1.973	0.568	
4	1.65317	39.7	R ₅ = 27.633 R ₆ = 148.96	S ₂ = 4.769 T ₄ = 5.043	0.568	-70.9
5	1.74500	46.4	R ₇ = 35.299 R ₈ = -63.712	T ₅ = 5.973	0.561	31.3

Component	Equiv. V	Equiv. P
I	62.4	0.549
III	53.7	0.554
Mean	58.1	0.552

$$(P_s/P_m)/(V_m - V_s) = 0.00086$$

EXAMPLE 9

f/4.5

F = 100mm

Mag. = 11.188x

Element	N _D	V _D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	R ₁ = 33.041	T ₁ = 11.738	0.542	29.7
2	1.51700	64.5	R ₂ = -36.123	T ₂ = 3.137	0.534	-69.6
3	1.65317	39.7	R ₃ = 11588.	S ₁ = 2.274	0.568	
			R ₄ = -51.346	T ₃ = 2.640		
			R ₅ = 32.317	S ₂ = 5.987		
4	1.65317	39.7	R ₆ = 482.92	T ₄ = 2.614	0.568	-53.4
5	1.74500	46.4	R ₇ = 32.502	T ₅ = 7.816	0.561	28.3
			R ₈ = -55.434			

Component	Equiv. V	Equiv. P
I	62.8	0.552
III	57.3	0.551
Mean	60.0	0.5515

$$(P_s - P_m)/(V_m - V_s) = 0.00082$$

EXAMPLE 10

f/5.0

F = 100mm

Mag. = 9.120x

Element	N _D	V _D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	R ₁ = 35.072	T ₁ = 16.710	0.542	27.5
2	1.51700	64.5	R ₂ = -27.200	T ₂ = 2.247	0.534	-45.8
3	1.65317	39.7	R ₃ = 185.47	S ₁ = 1.590	0.568	
			R ₄ = -38.939	T ₃ = 1.911		
			R ₅ = 32.308	S ₂ = 3.608		
4	1.65317	39.7	R ₆ = 214.87	T ₄ = 1.987	0.568	-40.7
5	1.74500	46.4	R ₇ = 23.630	T ₅ = 7.139	0.561	21.5
			R ₈ = -43.542			

Component	Equiv. V	Equiv. P
I	62.0	0.554
III	57.3	0.550
Mean	59.7	0.552

$$(P_s - P_m)/(V_m - V_s) = 0.00080$$

EXAMPLE 11

f/4.5

F = 100mm

Mag. = 12,000x

Element	N _D	V _D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	R ₁ = 35.170	T ₁ = 13.784	0.542	29.7
2	1.51700	64.5	R ₂ = -32.836	T ₂ = 2.667	0.534	-55.3
			R ₃ = 220.47	S ₁ = 2.056		
3	1.65317	39.7	R ₄ = -44.142	T ₃ = 2.074	0.568	
			R ₅ = 33.670	S ₂ = 3.035		
4	1.65317	39.7	R ₆ = 314.75	T ₄ = 4.840	0.568	-44.4
5	1.74500	46.4	R ₇ = 26.483	T ₅ = 6.870	0.561	23.4
			R ₈ = -45.368			

Component	Equiv. V	Equiv. P
I	62.4	0.550
III	57.2	0.550
Mean	59.8	0.550

$$(P_s - P_m)/(V_m - V_s) = 0.000795$$

EXAMPLE 12

f/7.09

F = 100mm

Mag. = 7.250x

Element	N _D	V _D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	R ₁ = 32.352	T ₁ = 8.104	0.542	28.8
2	1.51700	64.5	R ₂ = -36.418	T ₂ = 4.645	0.534	-53.0
			R ₃ = 107.20	S ₁ = 2.002		
3	1.65317	39.7	R ₄ = -42.253	T ₃ = 2.976	0.568	
			R ₅ = 32.096	S ₂ = 2.220		
4	1.65317	39.7	R ₆ = 218.36	T ₄ = 4.795	0.568	-41.2
5	1.74500	46.4	R ₇ = 23.861	T ₅ = 4.796	0.561	21.1
			R ₈ = -42.009			

Component	Equiv. V	Equiv. P
I	62.4	0.550
III	56.5	0.550
Mean	59.5	0.550

$$(P_s - P_m)/(V_m - V_s) = 0.00081$$

EXAMPLE 13

f/4.5

F = 100mm

Mag. = 12.000x

Element	N _D	V _D	Radius mm	Thickness or Separation mm	P	F
1	1.62005	63.5	R ₁ = 36.544	T ₁ = 14.461	0.542	30.2
2	1.51700	64.5	R ₂ = -32.632	T ₂ = 2.699	0.534	-57.1
			R ₃ = 314.64	S ₁ = 2.120		
3	1.65317	39.7	R ₄ = -42.913	T ₃ = 3.144	0.568	
			R ₅ = 34.025	S ₂ = 3.689		
4	1.65317	39.7	R ₆ = 351.12	T ₄ = 2.304	0.568	-40.6
5	1.74500	46.4	R ₇ = 24.732	T ₅ = 7.083	0.561	22.3
			R ₈ = -44.503			

Component	Equiv. V	Equiv. P
I	62.3	0.553
III	58.5	0.549
Mean	60.4	0.551

$$(P_s - P_m)/(V_m - V_s) = 0.00082$$

Examples 4—13 are further examples of printer lenses characterized by reduced secondary spectrum which were designed in accordance with the principles of the present invention.

While the present invention has been described as particularly usable in a printer application, it will be understood that the present invention can be applied to lenses designed for other applications.

WHAT WE CLAIM IS:—

1. A lens comprising a front positive doublet, a middle negative component and a rear positive doublet, wherein the following inequality is satisfied:

$$(P_m - P_s)/(V_s - V_m) \leq 0.00120$$

wherein P_s and V_s are respectively the partial dispersion and Abbé number of the middle negative component and P_m and V_m are respectively the mean equivalent partial dispersion and mean equivalent Abbé number for the front and rear doublets.

2. A lens according to Claim 1, wherein the front and rear doublets consist of one or more refractive materials such that each element in the rear doublet has a lower Abbé number and a higher partial dispersion than either of the elements in the front doublet; the focal lengths of each element in the front doublet being selected so that the front doublet has a lower

equivalent Abbé number and a higher equivalent partial dispersion than either of the elements in the front doublet; and the focal lengths of each element in the rear doublet being selected so that the rear doublet has a higher equivalent Abbé number and a lower equivalent partial dispersion than either of the elements in the rear doublet.

3. A lens according to Claim 1 wherein the lens elements, numbered from the front side of the lens, are made of refractive materials having substantially the following parameters, V being the Abbé number and P being the partial dispersion:

Element	V	P
1	63.5	.542
2	64.5	.543
3	39.7	.568
4	39.7	.568
5	46.4	.561

the front doublet having an equivalent Abbé number less than 63.5 and an equivalent partial dispersion greater than .542 and the rear doublet having an equivalent Abbé number greater than 46.4 and an equivalent partial dispersion less than .561.

4. Lenses substantially as hereinbefore described and exemplified in Examples 1 to 13.

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Component	Equiv. V	Equiv. P
I	62.3	0.553
III	58.5	0.549
Mean	60.4	0.551

$$(P_s - P_m)/(V_m - V_s) = 0.00082$$

Examples 4—13 are further examples of printer lenses characterized by reduced secondary spectrum which were designed in accordance with the principles of the present invention.

While the present invention has been described as particularly usable in a printer application, it will be understood that the present invention can be applied to lenses designed for other applications.

WHAT WE CLAIM IS:—

1. A lens comprising a front positive doublet, a middle negative component and a rear positive doublet, wherein the following inequality is satisfied:

$$(P_m - P_s)/(V_s - V_m) \leq 0.00120$$

wherein P_s and V_s are respectively the partial dispersion and Abbé number of the middle negative component and P_m and V_m are respectively the mean equivalent partial dispersion and mean equivalent Abbé number for the front and rear doublets.

2. A lens according to Claim 1, wherein the front and rear doublets consist of one or more refractive materials such that each element in the rear doublet has a lower Abbé number and a higher partial dispersion than either of the elements in the front doublet; the focal lengths of each element in the front doublet being selected so that the front doublet has a lower

equivalent Abbé number and a higher equivalent partial dispersion than either of the elements in the front doublet; and the focal lengths of each element in the rear doublet being selected so that the rear doublet has a higher equivalent Abbé number and a lower equivalent partial dispersion than either of the elements in the rear doublet.

3. A lens according to Claim 1 wherein the lens elements, numbered from the front side of the lens, are made of refractive materials having substantially the following parameters, V being the Abbé number and P being the partial dispersion:

Element	V	P
1	63.5	.542
2	64.5	.543
3	39.7	.568
4	39.7	.568
5	46.4	.561

the front doublet having an equivalent Abbé number less than 63.5 and an equivalent partial dispersion greater than .542 and the rear doublet having an equivalent Abbé number greater than 46.4 and an equivalent partial dispersion less than .561.

4. Lenses substantially as hereinbefore described and exemplified in Examples 1 to 13.

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