350-476 SR

OR 3,694,057

United States Price

[15] 3,694,057

[45] Sept. 26, 1972

[54] **MODIFIED TRIPLETS WITH REDUCED SECONDARY SPECTRUM**

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[22] Filed: **Oct. 1, 1971**

[21] Appl. No.: **185,496**

[52] **U.S. Cl.**..........350/227

[51] **Int. Cl.**..........G02b 9/26

[58] **Field of Search**..........350/226, 227

[56] **References Cited**

UNITED STATES PATENTS

2,279,384 4/1942 Altman..........350/227

2,419,804 4/1947 Warmisham et al..........350/227

2,645,154 7/1953 Tronnier..........350/226 X

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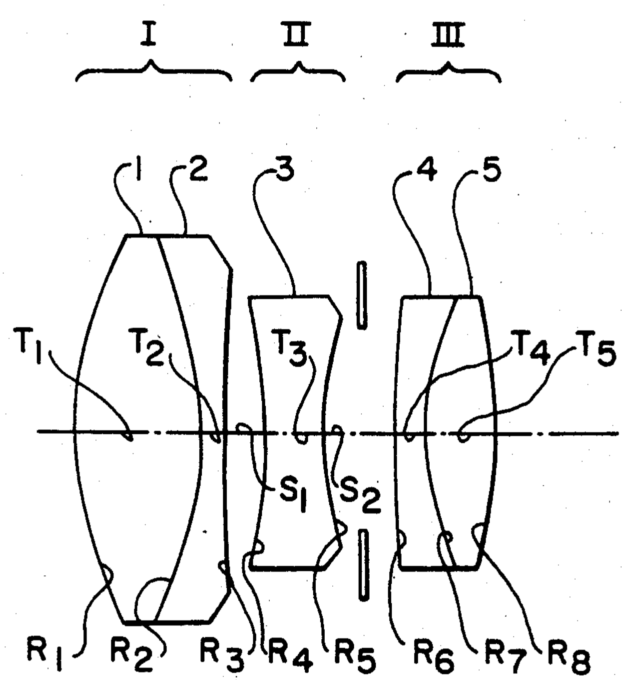
[57] **ABSTRACT**

A lens, particularly usable in a printer, consists of a middle negative component surrounded by two positive doublets. Secondary spectrum is reduced by choosing refractive materials and element focal lengths to minimize the expression $(P_m - P_3/V_3 - V_m)$, where P_3 and V_3 are the partial dispersion and Abbe number for the negative component and P_m and V_m are the mean equivalent partial dispersion and mean equivalent Abbe number for the doublets.

6 Claims, 3 Drawing Figures



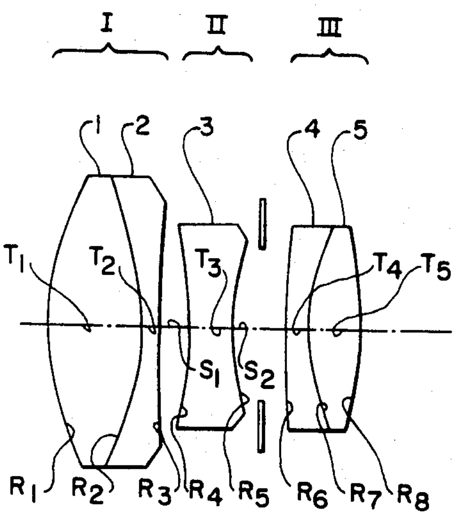


FIG.1

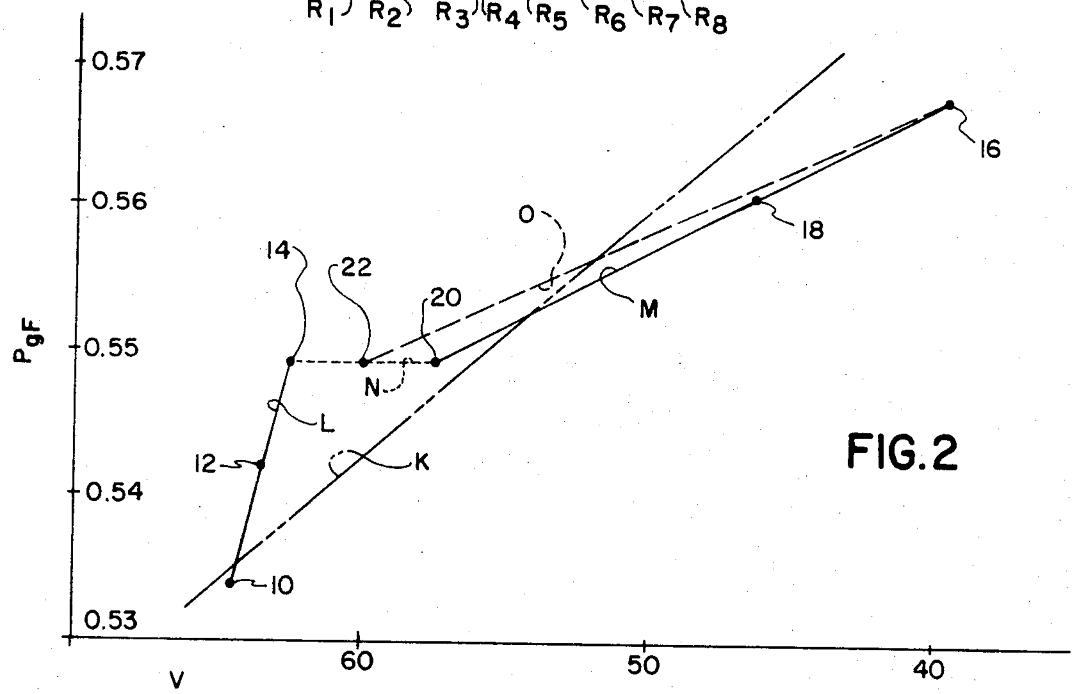


FIG.2

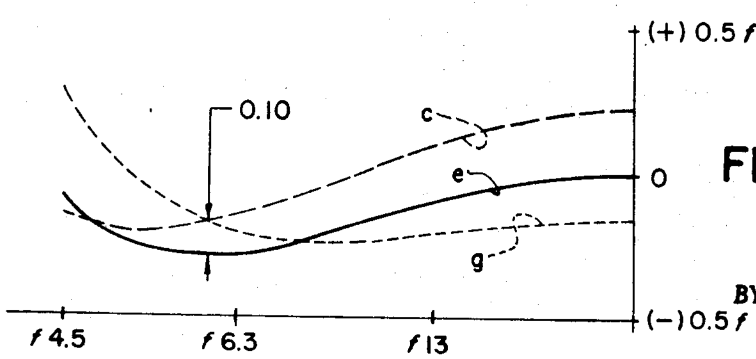


FIG.3

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MODIFIED TRIPLETS WITH REDUCED SECONDARY SPECTRUM

CROSS REFERENCE TO RELATED APPLICATIONS

Reference is made to commonly assigned and copending U. S. patent applications; Ser. No. 185,602, entitled "Printer Lens," filed Oct. 1,1971, in the name of W. H. Vangraafeiland; Ser. No. 185630, entitled "-Printer Lens," filed Oct. 1,1971, in the name of C. J. Melech.

BACKGROUND OF THE INVENTION

1. Field of the Invention

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

2. Description of the Prior Art

Secondary spectrum is the inability of a lens, even when corrected for longitudinal chromatic aberration, to focus all wavelengths of light at the same point. In a design which improves only the monochromatic aberration corrections of an achromatized lens, secondary spectrum becomes the limiting aberration of the lens. In monochromatic prints, secondary spectrum tends to reduce the contrast of the final print, particularly in fine detail areas. In color prints, secondary spectrum is manifested as a spreading of color from dark areas into adjacent light areas, a phenomenon known as color fringing or halo.

It has been known to use modified triplets of the type having two outer positive components surrounding 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. Examples of such materials may be found in U. S. Pat. Nos. 2,645,154 and 2,645,156.

SUMMARY OF THE INVENTION

It is an object of this invention to reduce the secondary spectrum of a modified triplet of the type having two outer positive components surrounding a middle negative component.

It is another object of the present invention to provide a printer lens having substantially improved secondary spectrum correction.

It is still another object of the present invention to provide such a printer lens with improved secondary spectrum correction which also is well corrected for other aberrations such as axial and oblique spherical aberration, coma, field curvature and astigmatism.

These and other objects are accomplished according to the present invention by a new discovery in the choice of refractive materials and element focal lengths for such a modified triplet. More specifically, it has been found that improved secondary spectrum correction is obtained when the refractive materials and element focal lengths used in the doublets and the refractive material used in the negative component are selected so that the expression $(P_m - P_3)/(V_3 - V_m)$ is minimized, wherein P_3 and V_3 are the partial dispersion and Abbe number for the negative component and P_m and V_m are the mean equivalent partial dispersion and mean equivalent Abbe number for the doublets.

In a preferred embodiment of this invention, it has been found that improved secondary spectrum correction is obtained when the front doublet has a lower equivalent Abbe number and a higher equivalent partial dispersion than either of its constituent elements and the rear doublet has a higher equivalent Abbe number and a lower equivalent partial dispersion than either of its constituent elements and the middle negative component is made of a refractive material having an Abbe number V_3 and a partial dispersion P_3 which satisfy the following inequality:

$$\frac{P_m - P_3}{V_3 - V_m} < .00120$$

wherein P_m and V_m are the mean equivalent partial dispersion and mean equivalent Abbe number for the doublets.

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. 1 is a diagrammatic axled cross-section of a lens according to the invention;

FIG. 2 is a graph of partial dispersion P_{gF} against Abbe number V, illustrating the selection of the refractive materials and focal lengths for the elements in the lens of this invention; and

FIG. 3 is the spherical aberration curve for the lens of Example 1, illustrating the improved secondary spectrum correction achieved by this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

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

$$P_{gF} = (N_g - N_F)/(N_F - N_C) \quad (1)$$

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

Primary color 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 color is characterized by a large difference in Abbe 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 Abbe number which is defined by the parameters of the elements of the doublet. This slope is given by the following relationship:

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

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 with equality of partial dispersion for the positive and negative elements of the doublet. Thus a doublet, to be well corrected for both primary sand secondary color, should have elements with a large difference in Abbe number and equal partial dispersion.

FIG. 2 is a graph of partial dispersion, P_{gF}, versus Abbe 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 this invention as will be more fully described hereinafter. Because of this restriction of 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 Abbe numbers insures a wide difference in partial dispersion. Selection of glasses with equal partial dispersion insures near equality of Abbe numbers.

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_{gF} versus V by the mean parameters of the positive components and the parameters of the negative element. This slope is given by the following relationship:

$$\text{slope} = (P_m - P_3)/(V_3 - V_m) \quad (3)$$

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

In all embodiments of the invention, as illustrated in FIG. 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:

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

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

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

where the subscripts a and b again refer to the two element of the doublet. The equivalent P_{eq} and V_{eq} values for the hypothetical glass will lie along a straight line on the P_{gF}-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.

Dotted line N on FIG. 2 is defined by points **14** and **20**, representing the equivalent partial dispersion and equivalent Abbe 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 below that available in a simple triplet, thereby insuring substantially improved correction of secondary spectrum. 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 Abbe numbers V, the radii of curvature R, the thicknesses T and the separations S, and the partial dispersions P_{gF} are numbered by subscript from front to rear. Radii of curvature having centers of curvatures to the rear of the surface are considered positive; those with centers 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 = 100mm Mag. = 6.125x

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

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

$$(P_3 - P_m)/(V_m - V_3) = 0.00092$$

As may be seen from the table of Example 1, front component I consists of a front element **1** which is characterized by a Abbe 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 Abbe 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 Abbe number and equivalent partial dispersion of front component I may be calculated and are 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 Abbe 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 Abbe 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 Abbe number and mean equivalent partial dispersion of front and rear components I and III lies along line N, defined by points **14** and **20**, and are calculated to be 60.45 and 0.549 respectively.

A glass for negative component II may now be selected using the mean equivalent Abbe number and mean equivalent partial dispersion of components I and III in such a manner as to assure proper primary color correction by utilizing a large difference in Abbe number while simultaneously assuring good secondary color correction by minimizing the slope of the P_{gF}-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 of the P_{gF}-V line of 0.00092, a substantial improvement over the slope for the normal glasses which it is to be remembered is 0.00170. FIG. **3** illustrates the improved secondary spectrum correction achieved by the design of this invention. Not only is the secondary spectrum reduced to 0.10 percent 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 color aberrations have been corrected by the selection of glasses as described above.

Additional printer lenses which are well corrected for secondary spectrum may be made according to this invention by following the specification in the examples presented below. In each example, the design parameters for the lens are followed by the equivalent and mean Abbe 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 correction achieved in the lenses of this invention.

EXAMPLE 2

f/4.5 F = 100mm Mag. = 2.911x

Ele.	N_D	V_D	Radius mm	Thickness or Separation mm	PgF	F
			R_1 = 33.085			
1	1.62005	63.5		T_1 = 8.214	0.542	28.3
			R_2 = −33.832			
2	1.51700	64.5		T_2 = 2.535	0.534	−58.7
			R_3 = 351.47			
				S_1 = 3.712		
			R_4 = −44.453			
3	1.65317	39.7		T_3 = 4.432	0.568	
			R_5 = 33.379			
				S_2 = 5.435		
			R_6 = 750.18			
4	1.65317	39.7		T_4 = 2.667	0.568	−46.4
			R_7 = 29.064			
5	1.74500	46.4		T_5 = 5.649	0.561	24.8
			R_8 = −46.451			

Component	Equiv. V	Equiv. PgF
I	62.6	0.549
III	57.6	0.549
Mean	60.1	0.549

$$(P_3 - P_m)/(V_m - V_3) = 0.00093$$

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

Ele.	N_D	V_D	Radius mm	Thickness or Separation mm	PgF	F
			R_1 = 33.747			
1	1.62005	63.5		T_1 = 8.322	0.542	27.8
			R_2 = −31.891			
2	1.51700	64.5		T_2 = 2.540	0.534	−61.4
			R_3 = 4155.83			
				S_1 = 3.587		
			R_4 = −41.187			
3	1.65317	39.7		T_3 = 4.379	0.568	
			R_5 = 34.769			
				S_2 = 5.395		
			R_6 = 566.75			
4	1.65317	39.7		T_4 = 2.032	0.568	−48.5
			R_7 = 29.892			
5	1.7445	45.8		T_5 = 5.639	0.563	24.5
			R_8 = −42.892			

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

$$(P_3 - P_m)/(V_m - V_3) = 0.00095$$

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 lengths are satisfied.

EXAMPLE 4

f/6.3 F = 100mm Mag. = 6.561x

Thickness or

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

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

$$(P_3 - P_m)/(V_m - V_3) = 0.00091$$

EXAMPLE 5

f/5.0 F = 100mm Mag. = 10.370x

Ele.	N_D	V_D	Radius mm	Thickness or Separation mm	PgF	F
			$R_1 = 28.345$			
1	1.62005	63.5		$T_1 = 10.126$	0.542	26.2
			$R_2 = -32.779$			
2	1.51700	64.5		$T_2 = 2.239$	0.534	−54.9
			$R_3 = 217.81$			
				$S_1 = 2.103$		
			$R_4 = -54.270$			
3	1.65317	39.7		$T_3 = 1.967$	0.568	
			$R_5 = 27.650$			
				$S_2 = 4.970$		
			$R_6 = 148.33$			
4	1.65317	39.7		$T_4 = 5.054$	0.568	−71.2
			$R_7 = 35.330$			
5	1.74500	46.4		$T_5 = 5.953$	0.561	31.4
			$R_8 = -63.468$			

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

$$(P_3 - P_m)/(V_m - V_3) = 0.00090$$

EXAMPLE 6

f/5.0 F = 100mmMag. = 6.497x

Ele.	N_D	V_D	Radius mm	Thickness or Separation mm	PgF	F
			$R_1 = 27.984$			
1	1.62005	63.5		$T_1 = 9.997$	0.542	25.9
			$R_2 = -32.361$			
2	1.51700	64.5		$T_2 = 2.210$	0.534	−54.3
			$R_3 = 215.04$			
				$S_1 = 2.076$		
			$R_4 = -53.579$			
3	1.65317	39.7		$T_3 = 1.942$	0.568	
			$R_5 = 27.298$			
				$S_2 = 4.906$		
			$R_6 = 146.44$			
4	1.65317	39.7		$T_4 = 4.990$	0.568	−69.9
			$R_7 = 34.880$			
5	1.74500	46.4		$T_5 = 5.877$	0.561	31.0
			$R_8 = -63.529$			

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

$$(P_3 - P_m)/(V_m - V_3) = 0.00084$$

EXAMPLE 7

f/4.5 F = 100mm Mag. = 7.102x

Ele.	N_D	V_D	Radius mm	Thickness or Separation mm	PgF	F
			$R_1 = 25.965$			
1	1.62005	63.5		$T_1 = 9.302$	0.542	24.8
			$R_2 = -30.171$			
2	1.51700	64.5		$T_2 = 2.069$	0.534	−53.7
			$R_3 = 199.56$			
				$S_1 = 1.932$		
			$R_4 = -50.476$			
3	1.65317	39.7		$T_3 = 1.813$	0.568	
			$R_5 = 25.392$			
				$S_2 = 4.466$		
			$R_6 = 136.88$			
4	1.65317	39.7		$T_4 = 4.634$	0.568	−65.7
			$R_7 = 32.437$			
5	1.74500	46.4		$T_5 = 5.489$	0.561	28.6
			$R_8 = -59.838$			

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

$$(P_3 - P_m)/(V_m - V_3) = 0.00087$$

EXAMPLE 8

f/4.5 F = 100mm Mag. = 7.096x

Ele.	N_D	V_D	Radius mm	Thickness or Separation mm	PgF	F
			$R_1 = 28.256$			
1	1.62005	63.5		$T_1 = 10.123$	0.542	26.2
			$R_2 = -32.834$			
2	1.51700	64.5		$T_2 = 2.252$	0.534	−55.1
			$R_3 = 217.17$			
				$S_1 = 2.103$		
			$R_4 = -54.260$			
3	1.65317	39.7		$T_3 = 1.973$	0.568	
			$R_5 = 27.633$			
				$S_2 = 4.769$		
			$R_6 = 148.96$			
4	1.65317	39.7		$T_4 = 5.043$	0.568	−70.9
			$R_7 = 35.299$			
5	1.74500	46.4		$T_5 = 5.973$	0.561	31.3
			$R_8 = -63.712$			

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

$$(P_3 - P_m)/(V_m - V_3) = 0.00086$$

EXAMPLE 9

f/4.5 F = 100mm Mag. = 11. 188x

Ele.	N_D	V_D	Radius mm	Thickness or Separation mm	PgF	F

Ele.	N_D	V_D	Radius mm	Thickness or Separation mm	PgF	F
			$R_1 = 33.041$			
1	1.62005	63.5		$T_1 = 11.738$	0.542	29.7
			$R_2 = -36.123$			
2	1.51700	64.5		$T_2 = 3.137$	0.534	−69.6
			$R_3 = 11588.$			
				$S_1 = 2.274$		
			$R_4 = -51.346$			
3	1.65317	39.7		$T_3 = 2.640$	0.568	
			$R_5 = 32.317$			
				$S_2 = 5.987$		
			$R_6 = 482.92$			
4	1.65317	39.7		$T_4 = 2.614$	0.568	−53.4
			$R_7 = 32.502$			
5	1.74500	46.4		$T_5 = 7.816$	0.561	28.3
			$R_8 = -55.434$			

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

$$(P_3 - P_m)/(V_m - V_3) = 0.00082$$

EXAMPLE 10

f/5.0 F = 100mm Mag. = 9.120x

Ele.	N_D	V_D	Radius mm	Thickness or Separation mm	PgF	F
			$R_1 = 35.072$			
1	1.62005	63.5		$T_1 = 16.710$	0.542	27.5
			$R_2 = -27.200$			
2	1.51700	64.5		$T_2 = 2.247$	0.534	−45.8
			$R_3 = 185.47$			
				$S_1 = 1.590$		
			$R_4 = -38.939$			
3	1.65317	39.7		$T_3 = 1.911$	0.568	
			$R_5 = 32.308$			
				$S_2 = 3.608$		
			$R_6 = 214.87$			
4	1.65317	39.7		$T_4 = 1.987$	0.568	−40.7
			$R_7 = 23.630$			
5	1.74500	46.4		$T_5 = 7.139$	0.561	21.5
			$R_8 = -43.542$			

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

$$P_3 - P_m/V_m - V_3 = 0.00080$$

Examples 4–8, 9 and 10 are further examples of printer lenses characterized by reduced secondary spectrum which were designed by W. H. Vangraffeiland in accordance with the principals of this invention and which are disclosed and claimed in copending U. S. application Ser. No. 185,602.

EXAMPLE 11

f/4.5 F = 100mm Mag. = 12.000x

Ele.	N_D	V_D	Radius mm	Thickness or Separation mm	PgF	F
			$R_1 = 35.170$			
1	1.62005	63.5		$T_1 = 13.784$	0.542	29.7
			$R_2 = -32.836$			
2	1.51700	64.5		$T_2 = 2.667$	0.534	−55.3
			$R_3 = 220.47$			
				$S_1 = 2.056$		
			$R_4 = -44.142$			
3	1.65317	39.7		$T_3 = 2.074$	0.568	
			$R_5 = 33.670$			
				$S_2 = 3.035$		
			$R_6 = 314.75$			
4	1.65317	39.7		$T_4 = 4.840$	0.568	−44.4
			$R_7 = 26.483$			
5	1.74500	46.4		$T_5 = 6.870$	0.561	23.4
			$R_8 = -45.368$			

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

$$(P_3 - P_m)/(V_m - V_3) = 0.000795$$

EXAMPLE 12

f/ 7.09 F = 100mm Mag. = 7.250x

Ele.	N_D	V_D	Radius mm	Thickness or Separation mm	PgF	F
			$R_1 = 32.352$			
1	1.62005	63.5		$T_1 = 8.104$	0.542	28.8
			$R_2 = -36.418$			
2	1.51700	64.5		$T_2 = 4.645$	0.534	−53.0
			$R_3 = 107.20$			
				$S_1 = 2.002$		
			$R_4 = -42.253$			
3	1.65317	39.7		$T_3 = 2.976$	0.568	
			$R_5 = 32.096$			
				$S_2 = 2.220$		
			$R_6 = 218.36$			
4	1.65317	39.7		$T_4 = 4.795$	0.568	−41.2
			$R_7 = 23.861$			
5	1.74500	46.4		$T_5 = 4.796$	0.561	21.1
			$R_8 = -42.009$			

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

$$(P_3 - P_m)/(V_m - V_3) = 0.00081$$

EXAMPLE 13

f/4.5 F = 100mm Mag. = 12.000x

Ele.	N_d	V_D	Radius mm	Thickness or Separation mm	PgF	F
			$R_1 = 36.544$			
1	1.62005	63.5		$T_1 = 14.461$	0.542	30.2
			$R_2 = -32.632$			
2	1.51700	64.5		$T_2 = 2.699$	0.534	−57.1
			$R_3 = 314.64$			
				$S_1 = 2.120$		
			$R_4 = -42.913$			
3	1.65317	39.7		$T_3 = 3.144$	0.568	
			$R_5 = 34.025$			
				$S_2 = 3.689$		
			$R_6 = 351.12$			
4	1.65317	39.7		$T_4 = 2.304$	0.568	−40.6
			$R_7 = 24.732$			
5	1.74500	46.4		$T_5 = 7.083$	0.561	22.3
			$R_8 = -44.503$			

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

$$(P_3 - P_m)/(V_m - V_3) = 0.00082$$

Examples 11–13 are still further examples of printer lenses characterized by reduced secondary spectrum which were designed by C. J. Melech in accordance with the principals of this invention and which are disclosed and claimed in copending U. S. application Ser. No. 185,630.

While this invention is described as particularly usable in a printer application, it will be understood that the invention can be applied to lenses designed for other applications as well and that variations and modifications can be effected within the spirit and scope of the invention.

I claim:

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

$$\frac{P_m - P_3}{V_3 - V_m} < 0.00120$$

wherein P_3 and V_3 are respectively the partial dispersion and Abbe number of said middle negative component and P_m and V_m are respectively the mean equivalent partial dispersion and mean equivalent Abbe number for said front and said rear doublets.

2. A lens comprising a front positive doublet, a middle negative component, and a rear positive doublet, said front and rear doublets consisting of one or more refractive materials such that each element in said rear doublet has a lower Abbe number and a higher partial dispersion than either of the elements in said front doublet; the focal lengths of each element in said front doublet being selected so that said front doublet has a lower equivalent Abbe number and a higher equivalent partial dispersion than either of the elements in said front doublet; the focal lengths of each element in said rear doublet being selected so that said rear doublet has a higher equivalent Abbe number and a lower equivalent partial dispersion than either of the elements in said rear doublet; and said negative component consisting of a refractive material having an Abbe number V_3 and a partial dispersion P_3 which satisfy the following inequality;

$$\frac{P_m - P_3}{V_3 - V_m} < 0.00120$$

wherein P_m and V_m are the mean equivalent partial dispersion and the mean equivalent Abbe number for said front and said rear doublets.

3. A lens comprising a front positive doublet, a middle negative component, and a rear positive doublet, in which the lens elements, numbered from the front side of the lens, are made of refractive materials having substantially the following parameters, wherein V is the Abbe number and P_{gF} is the partial dispersion:

Element	V	PgF
1	63.5	.542
2	64.5	.534
3	39.7	.568
4	39.7	.568
5	46.1	.561

said front doublet having an equivalent Abbe number less than 63.5 and an equivalent partial dispersion greater than 0.542 and said rear doublet having an equivalent Abbe number greater than 46.1 and an equivalent partial dispersion less than 0.561.

4. A lens having a middle negative singlet surrounded by two positive doublets, said lens being constructed according to the following table:

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

wherein, from front to rear, the lens elements are numbered from 1–5, the corresponding indexes of refraction and Abbe numbers are for the *D* line of the spectrum, the radii are numbered from R_1 to $R_8$the thicknesses are numbered from T_1 to T_5 and the air spaces are numbered from S_1 to S_2.

5. A lens having a middle negative singlet surrounded by two positive doublets, said lens being constructed according to the following table:

Element	N_D	V_D	Radius mm	Thickness or Separation mm
			R_1 = 33.085	
1	1.62005	63.5		T_1 = 8.214
			R_2 = −33.832	
2	1.51700	64.5		T_2 = 2.535
			R_3 = 351.47	
				S_1 = 3.712
			R_4 = −44.453	
3	1.65317	39.7		T_3 = 4.432
			R_5 = 33.379	
				S_2 = 5.435
			R_6 = 750.18	
4	1.65317	39.7		T_4 = 2.667
			R_7 = 29.064	
5	1.74500	46.4		T_5 = 5.649
			R_8 = −46.451	

wherein, from front to rear, the lens elements are numbered from 1–5, the corresponding indexes of refraction and Abbe numbers are for the *D* line of the spectrum, the radii are numbered from R_1 to R_8, the thicknesses are numbered from T_1 to T_5 and the air spaces are numbered from S_1 to S_2.

6. A lens having a middle negative singlet surrounded by two positive doublets, said lens being constructed according to the following table:

Element	N_D	V_D	Radius mm	Thickness or Separation mm
			R_1 = 33.747	
1	1.62005	63.5		T_1 = 8.322
			R_2 = −31.891	
2	1.51700	64.5		T_2 = 2.540
			R_3 = 4155.83	
				S_1 = 3.587
			R_4 =, −41.187	
3	1.65317	39.7		T_3 = 4.379
			R_5 = 34.769	
				S_2 = 5.395
			R_6 = 566.75	
4	1.65317	39.7		T_4 = 2.032
			R_7 = 29.892	
5	1.7445	45.8		T_5 = 5.639
			R_8 = −42.892	

wherein, from front to rear, the lens elements are numbered from 1–5, the corresponding indexes of refraction and Abbe numbers are for the *D* line of the spectrum, the radii are numbered from R_1 to R_8, the thicknesses are numbered from T_1 to T_5 and the air spaces are numbered from S_1 to S_2.

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