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(54) **OPTICAL SYSTEM, OPTICAL APPARATUS AND METHOD FOR MANUFACTURING THE OPTICAL SYSTEM**

(71) Applicant: **NIKON CORPORATION**, Minato-ku, Tokyo (JP)

(72) Inventors: **Tomoyuki SASHIMA**, Tokyo (JP); **Kosuke MACHIDA**, Tokyo (JP)

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G02B 15/14 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 15/144107*** (2019.08)

(57) **ABSTRACT**

An optical system (OL) comprises a front group (GA), an intermediate group (GM), and a rear group (GR). The intermediate group (GM) comprises a first focusing lens group (GF**1**) and a second focusing lens group (GF**2**). During focusing, the first focusing lens group (GF**1**) and the second focusing lens group (GF**2**) move along the optical axis on different trajectories from each other. The front group (GA) and the rear group (GR) are fixed in relation to an image plane (I). The rear group (GR) has a negative lens disposed closest to the image plane. The following conditional formula is satisfied.

$$0.01 < fF2/fF1 < 10.00;$$

$$0.50 < Y/Bf < 5.00.$$

where,

fF1: the focal length of the first focusing lens group (GF1),

fF2: the focal length of the second focusing lens group (GF2),

Y: the image height of the optical system (OL),

Bf: the back focus of the optical system (OL).

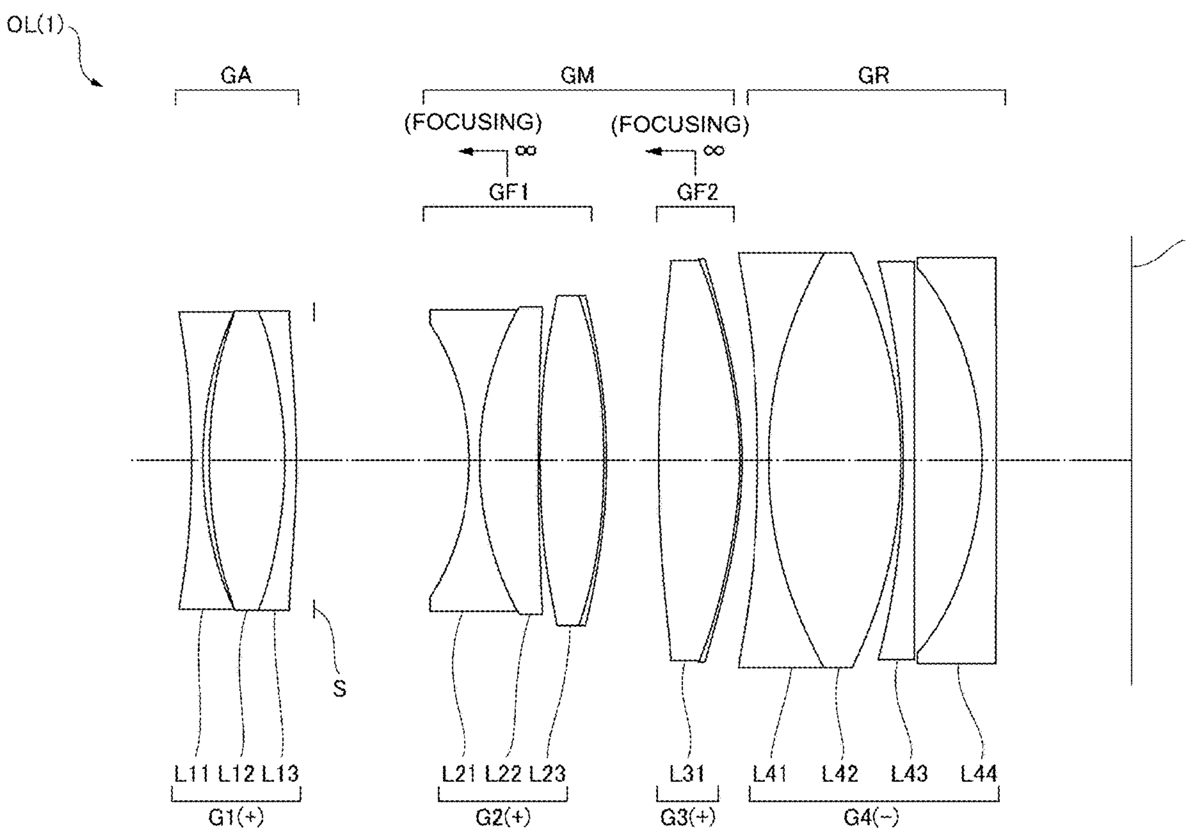
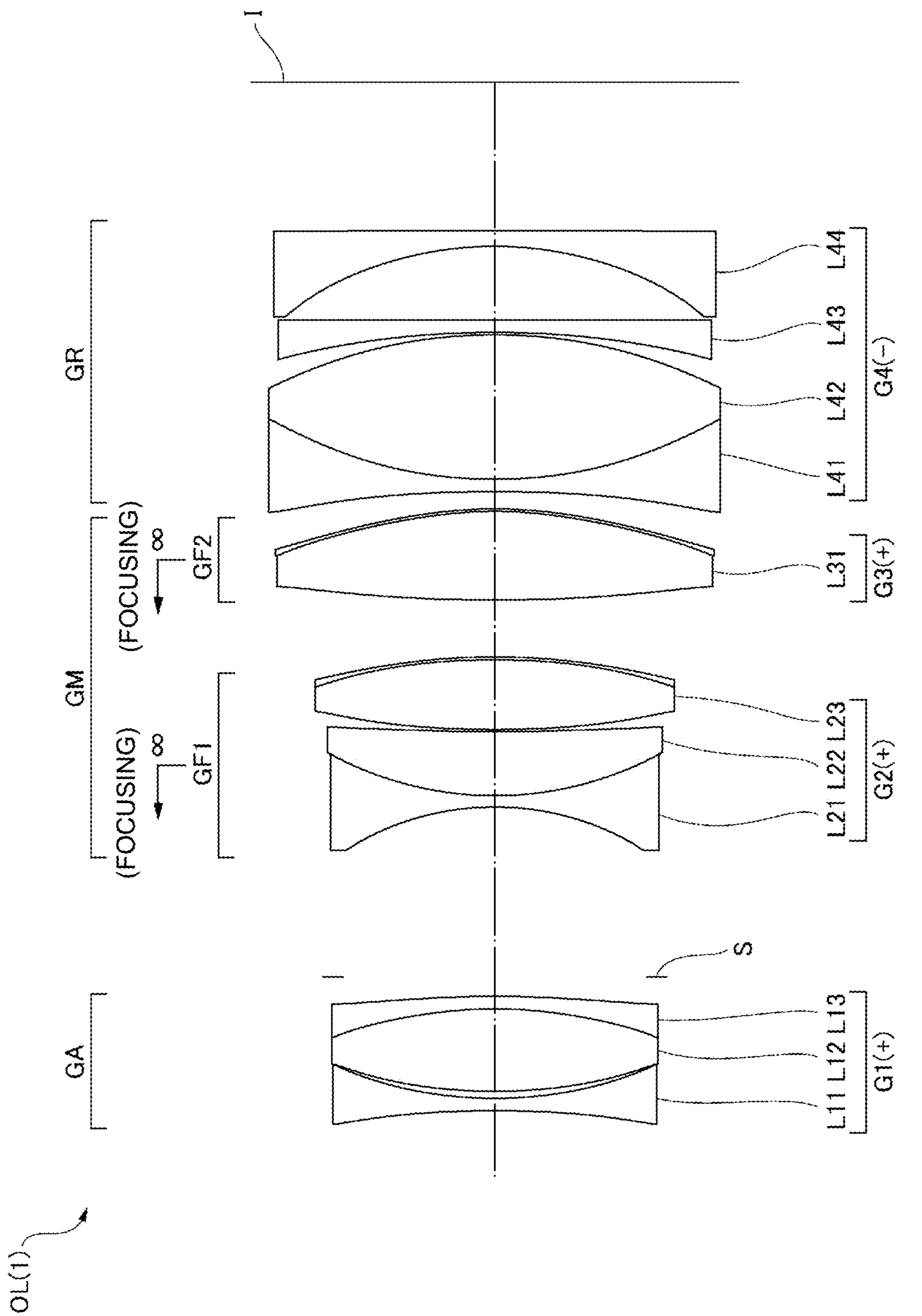


FIG.1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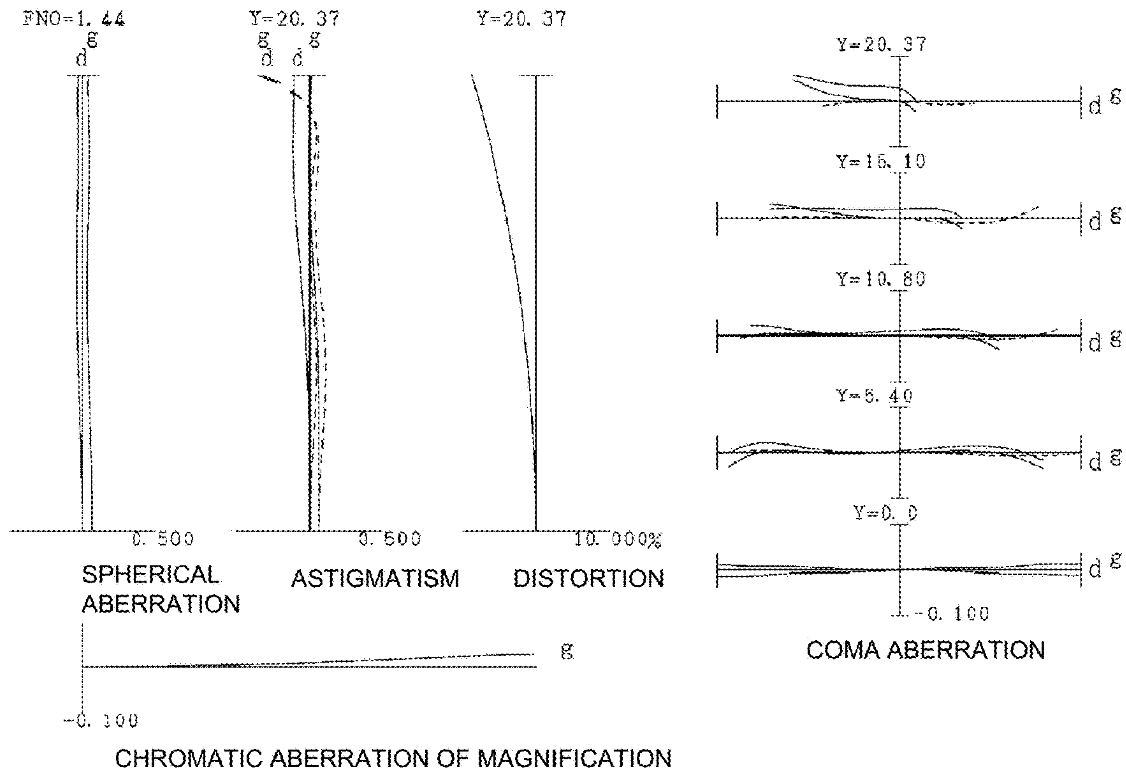
GR
GM
GA
(FOCUSING)
∞
GF2
GF1
S
L44
L43
L42
L41
G4(−)
L31
G3(+)
L21 L22 L23
G2(+)
L11 L12 L13
G1(+)
OL(1)

FIG.2A



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0.500
10.000%
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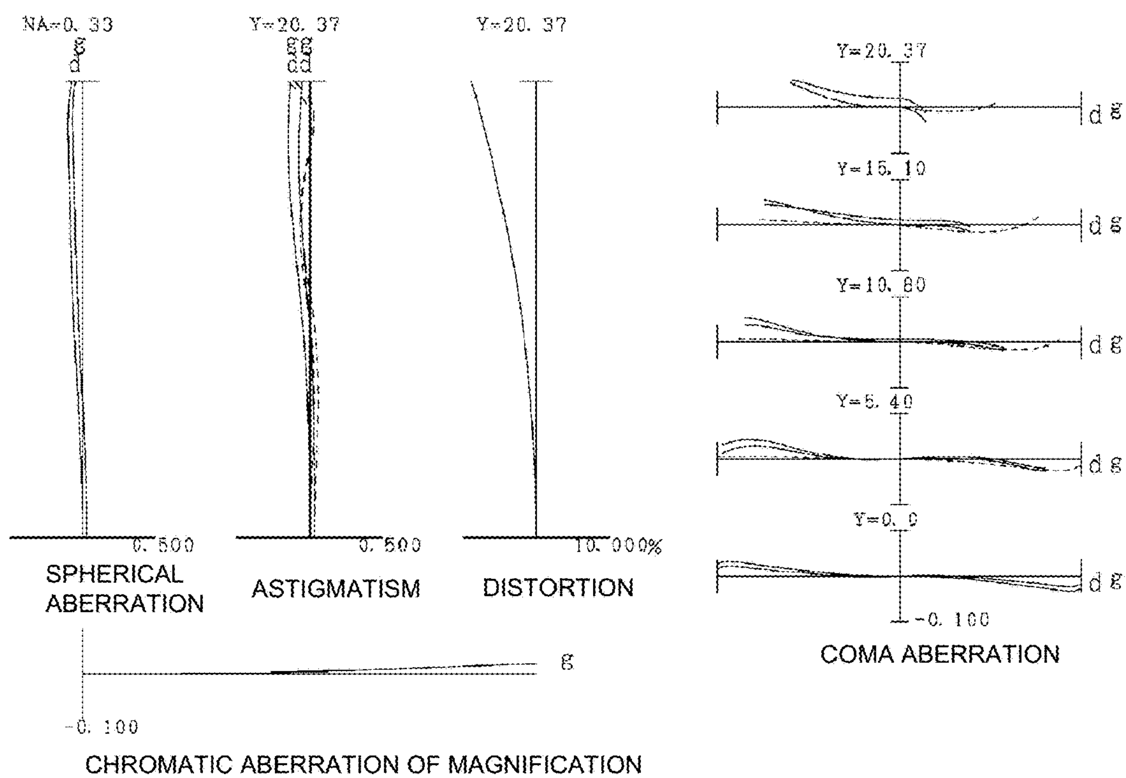
ASTIGMATISM
DISTORTION
Y=20.37
Y=15.10
Y=10.80
Y=6.40
Y=0.0
-0.100
COMA ABERRATION
-0.100
CHROMATIC ABERRATION OF MAGNIFICATION

FIG.2B



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0.500
10.000%
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
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Y=15.10
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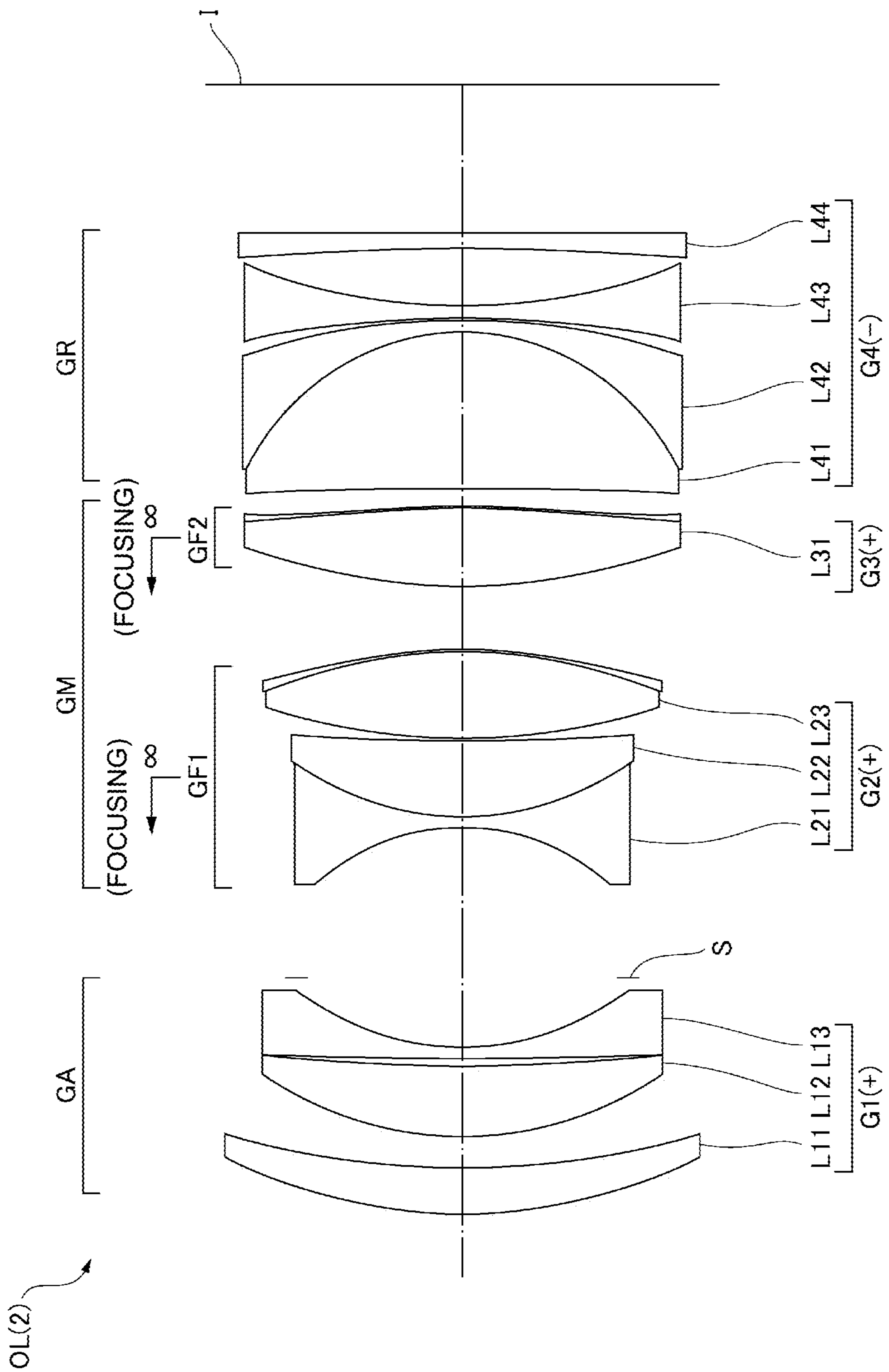
-0.100
COMA ABERRATION
-0.100
CHROMATIC ABERRATION OF MAGNIFICATION

FIG.3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GM
GA
(FOCUSING)
GF2
GF1
S
L44
L43
L42
L41
L31
L23
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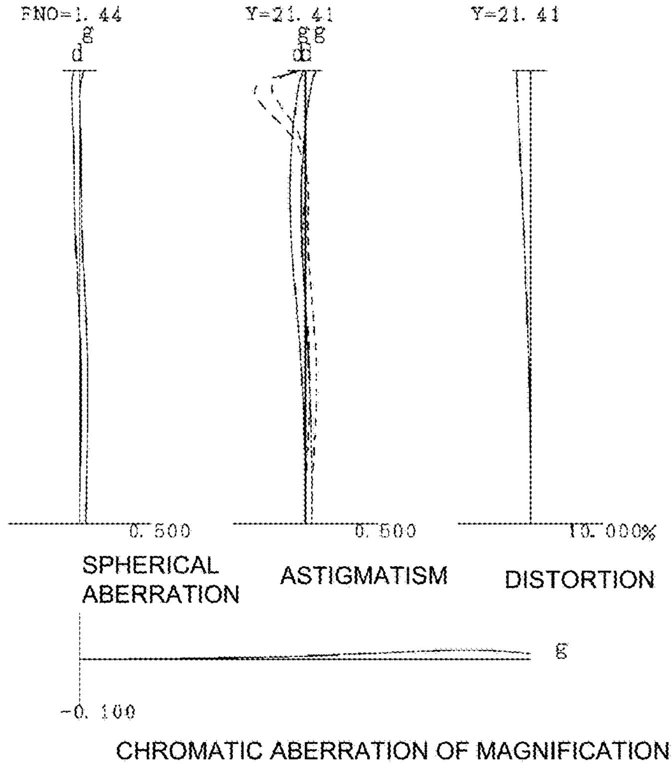
L21
L13
L12
L11
G4(−)
G3(+)
G2(+)
G1(+)
OL(2)

FIG.4A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10.000%
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ASTIGMATISM
DISTORTION
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CHROMATIC ABERRATION OF MAGNIFICATION
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Y=5.40
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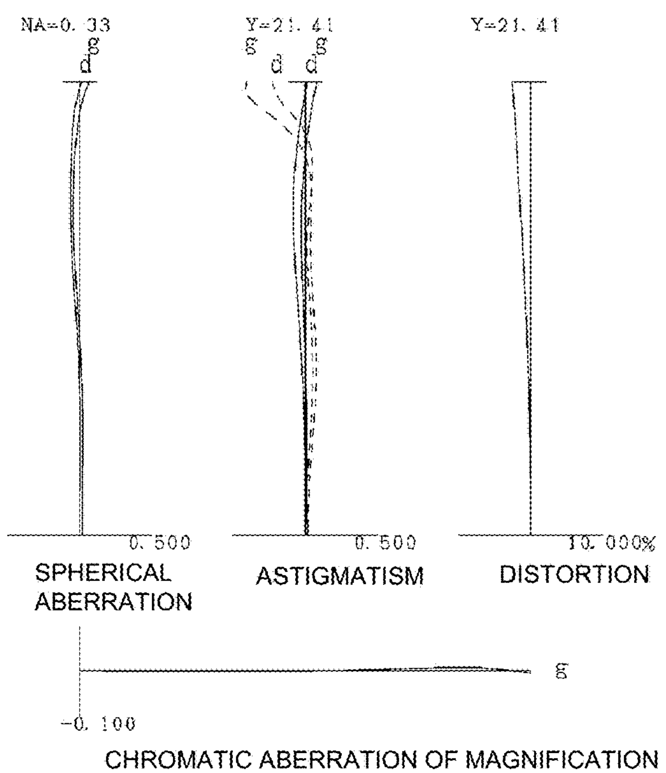
-0.100
COMA ABERRATION

FIG.4B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SPHERICAL ABERRATION
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DISTORTION
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CHROMATIC ABERRATION OF MAGNIFICATION
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Y=10.80
Y=5.40
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-0.100
COMA ABERRATION

FIG.5

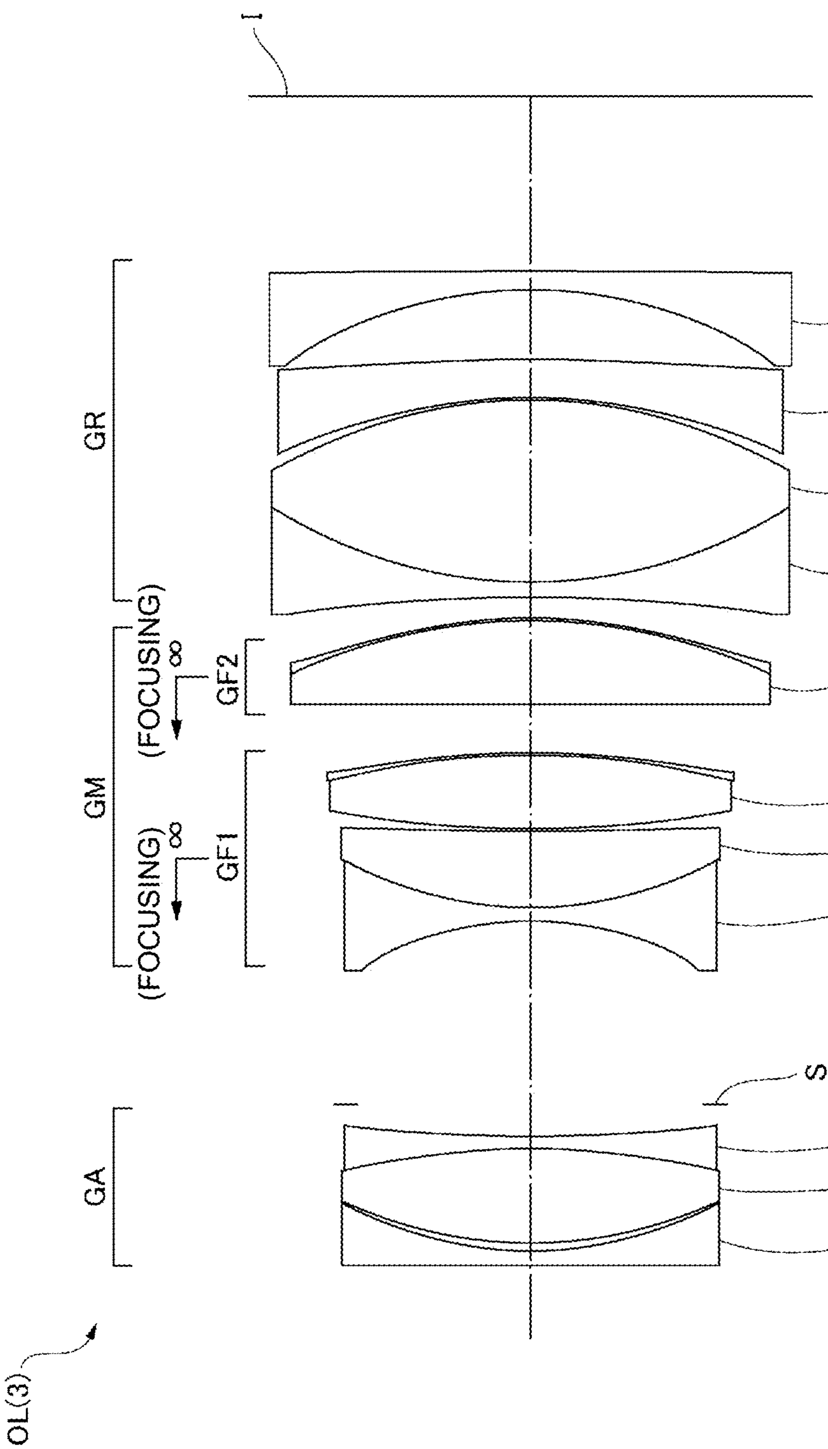
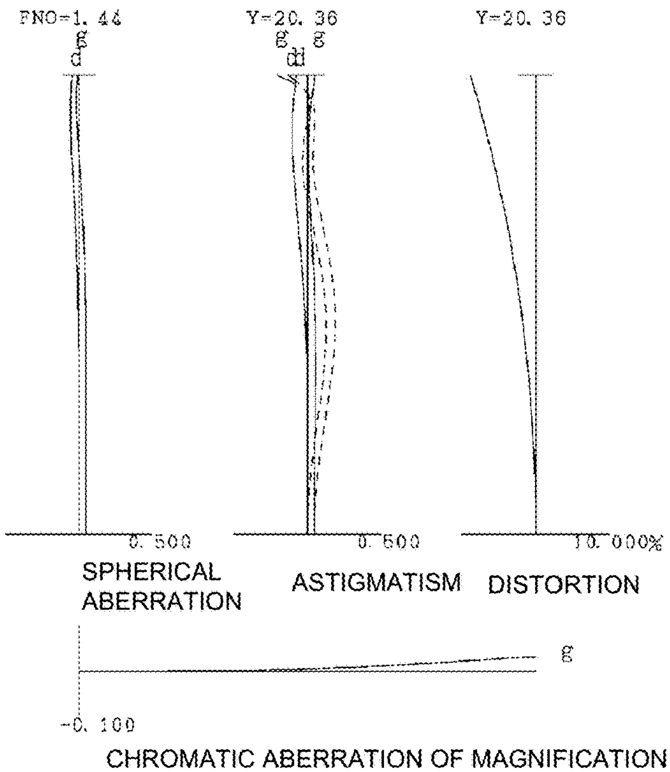

I
GR
GM
GA
(FOCUSING)
∞
GF2
(FOCUSING)
∞
GF1
L44
L43
L42
L41
G4(−)
L31
G3(+)
L23
L22
L21
G2(+)
S
L13
L12
L11
G1(+)
OL(3)

FIG.6A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COMA ABERRATION
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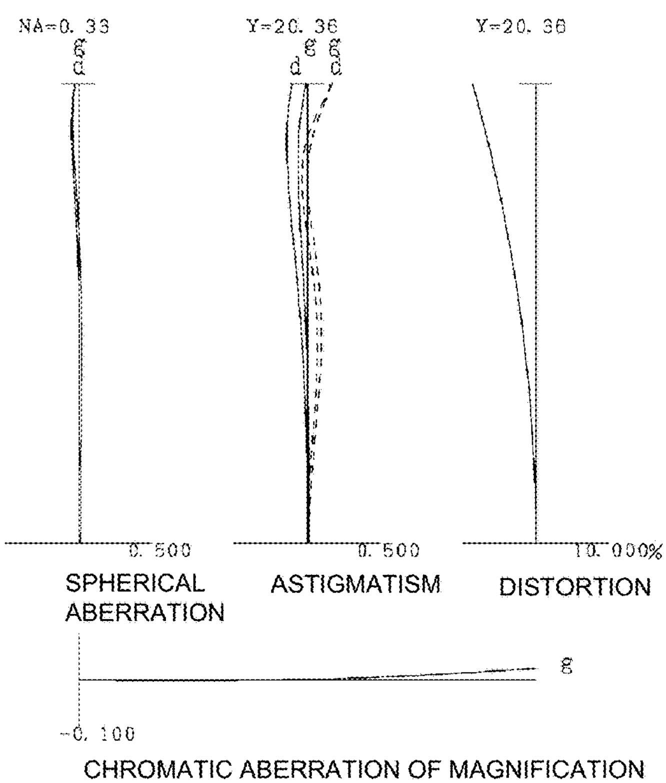
CHROMATIC ABERRATION OF MAGNIFICATION

FIG.6B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DISTORTION
Y=20. 36
Y=15. 10
Y=10. 80
Y=5. 40
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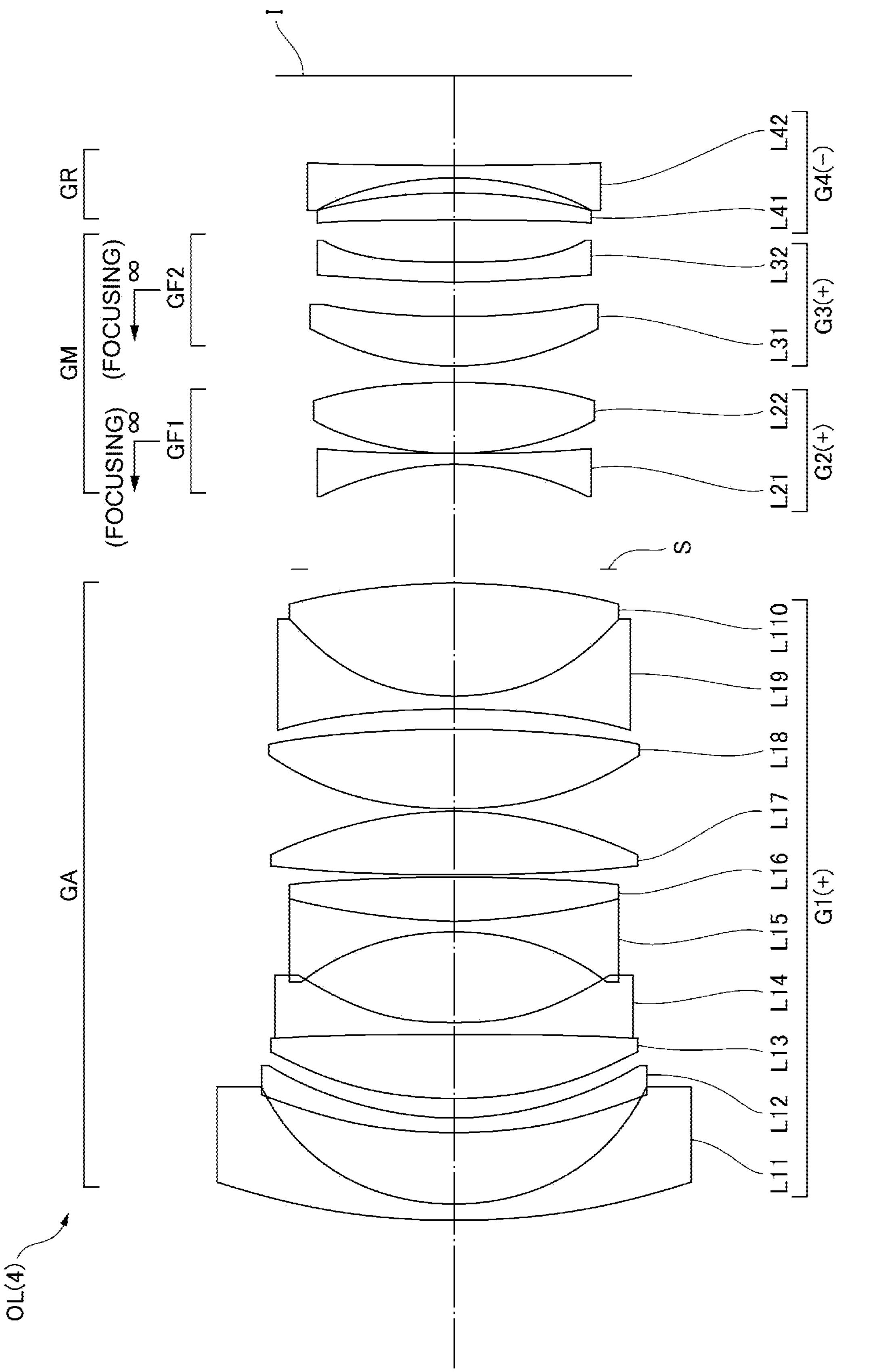
-0. 100
COMA ABERRATION
g
-0. 100
CHROMATIC ABERRATION OF MAGNIFICATION

FIG.7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∞
GF2
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GF1
GA
S
OL(4)
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G3(+)
L22
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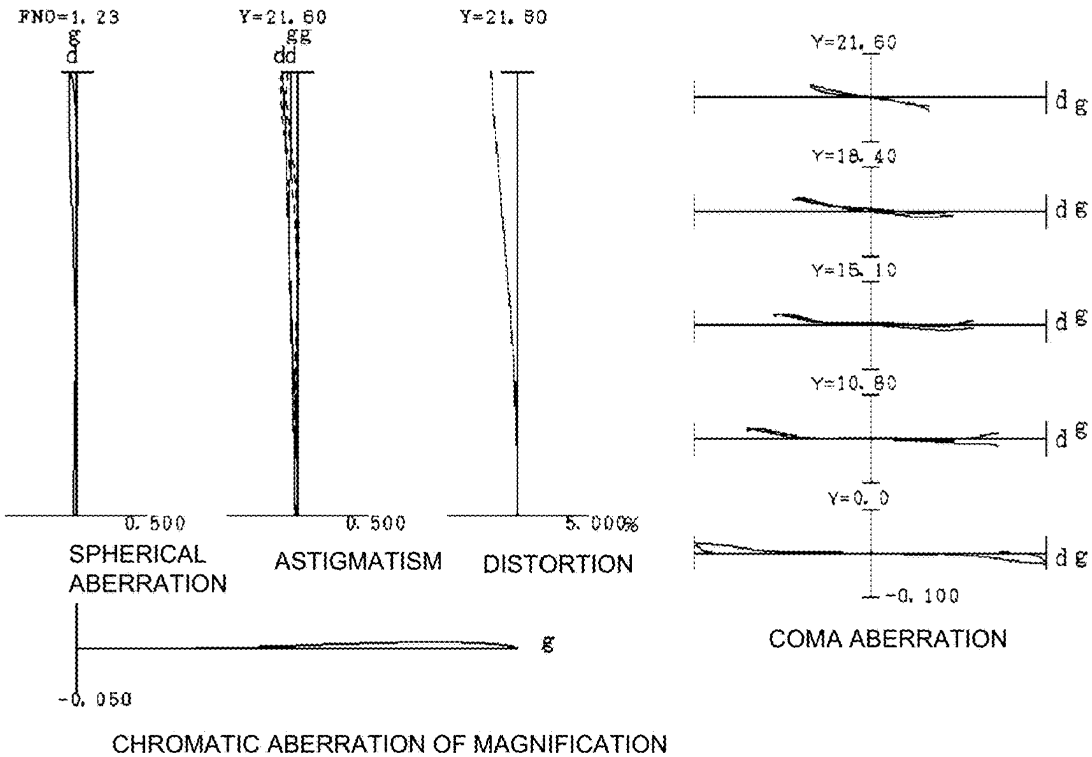
L11
G1(+)

FIG.8A



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COMA ABERRATION
g
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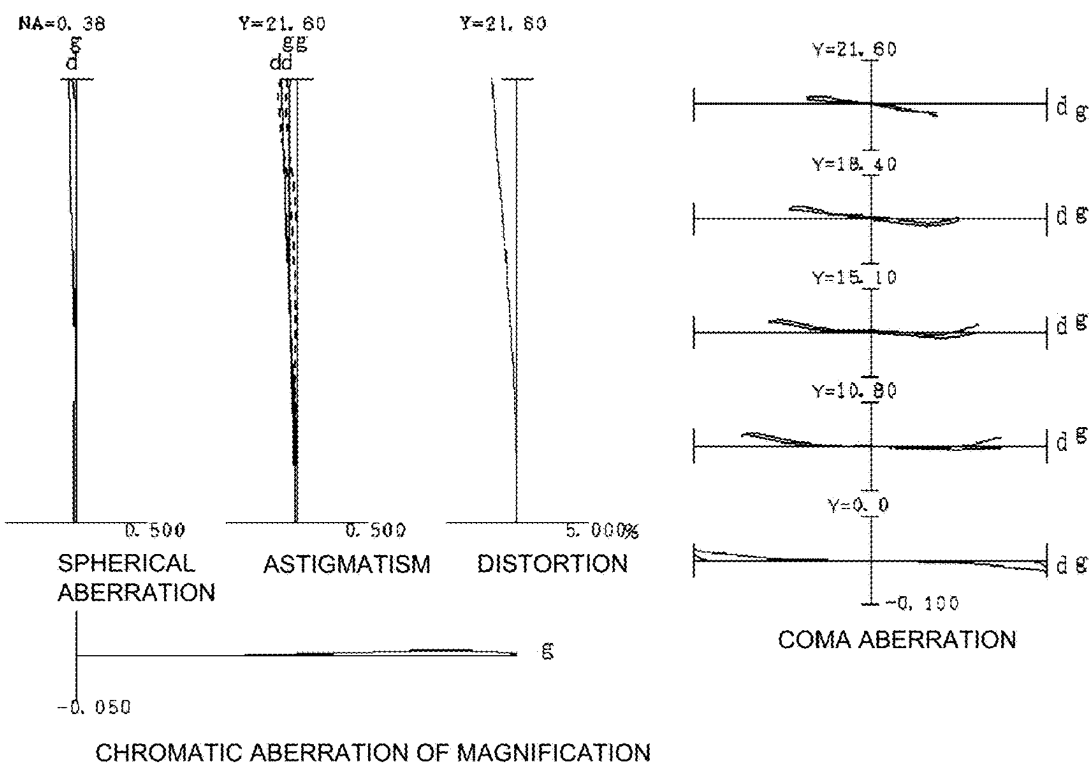
CHROMATIC ABERRATION OF MAGNIFICATION

FIG.8B



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Y=15. 10
Y=10. 80
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d g
-0. 100
COMA ABERRATION
g
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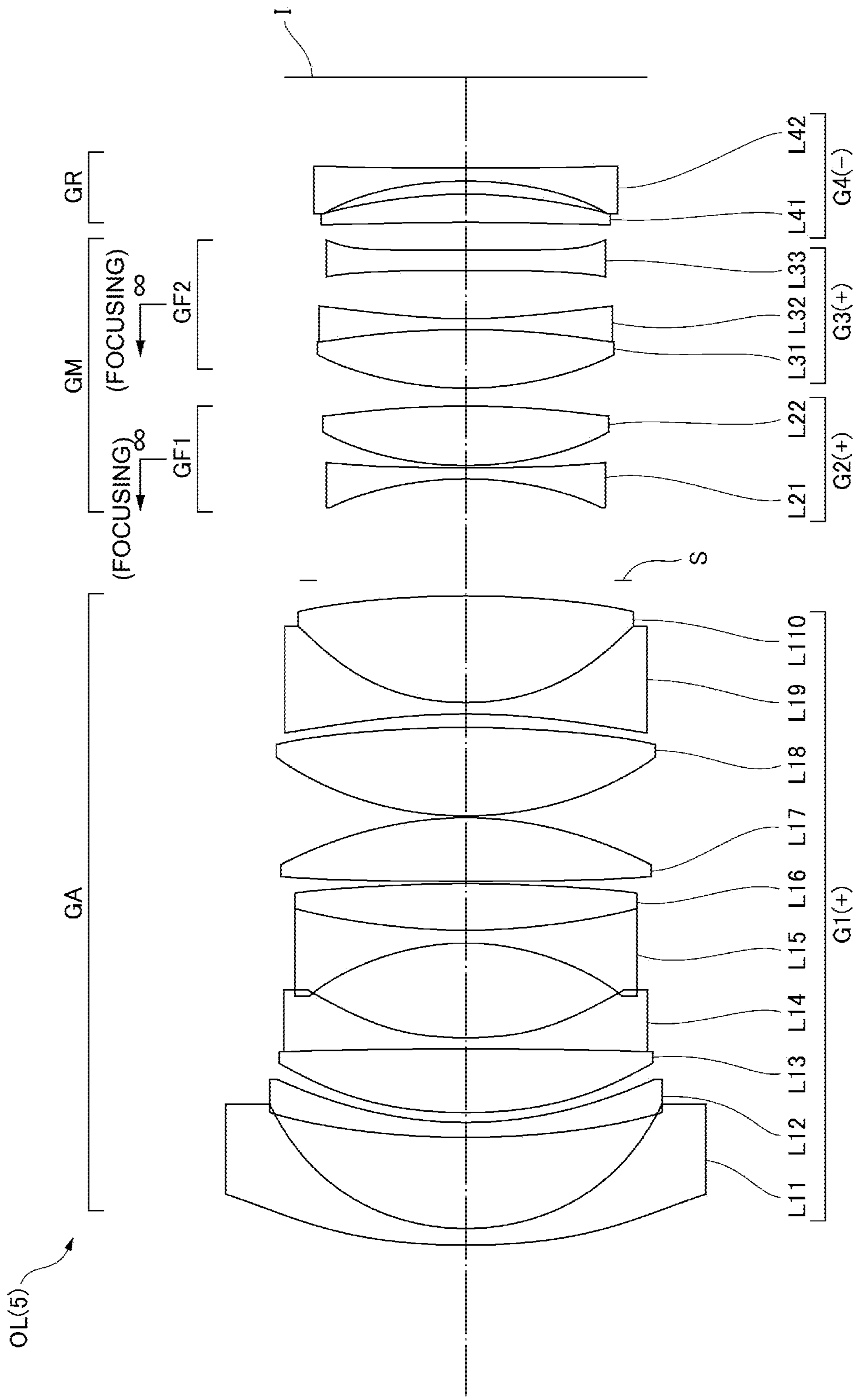
CHROMATIC ABERRATION OF MAGNIFICATION

FIG.9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GF1
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G4(−)
L33
L32
L31
G3(+)
L22
L21
G2(+)
L110
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L18
L17
L16
L15
L14
L13
L12
L11
G1(+)
OL(5)

FIG.10A

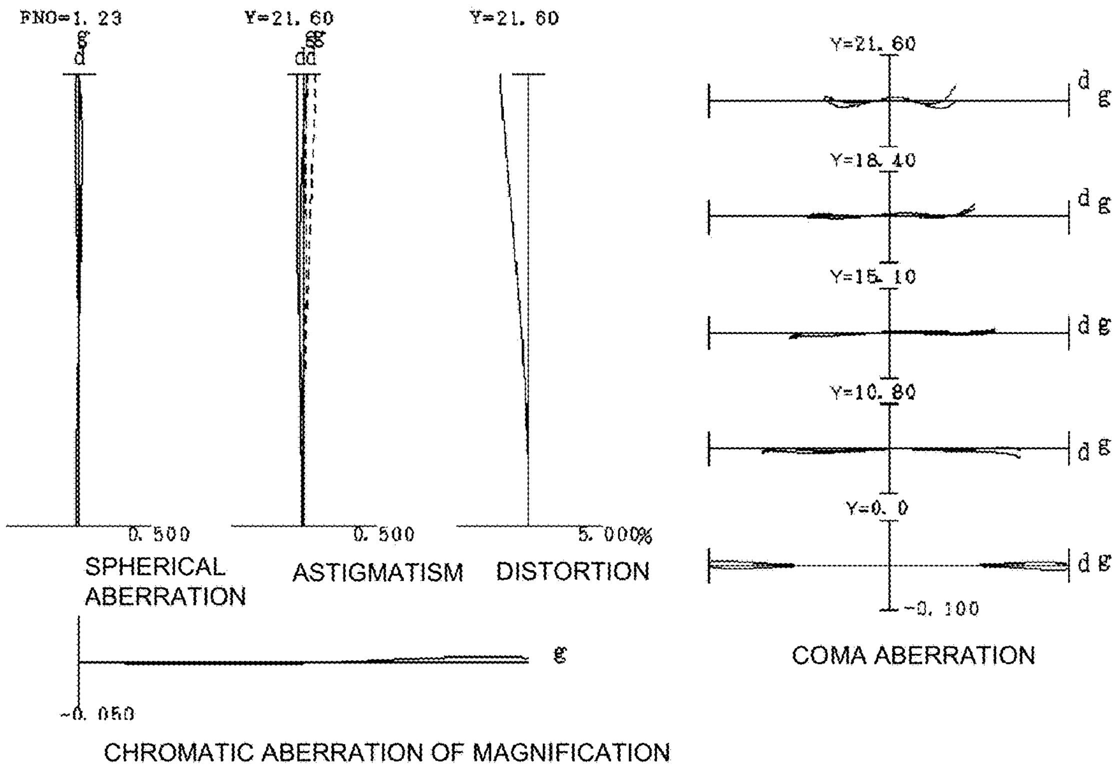


FIG.10B

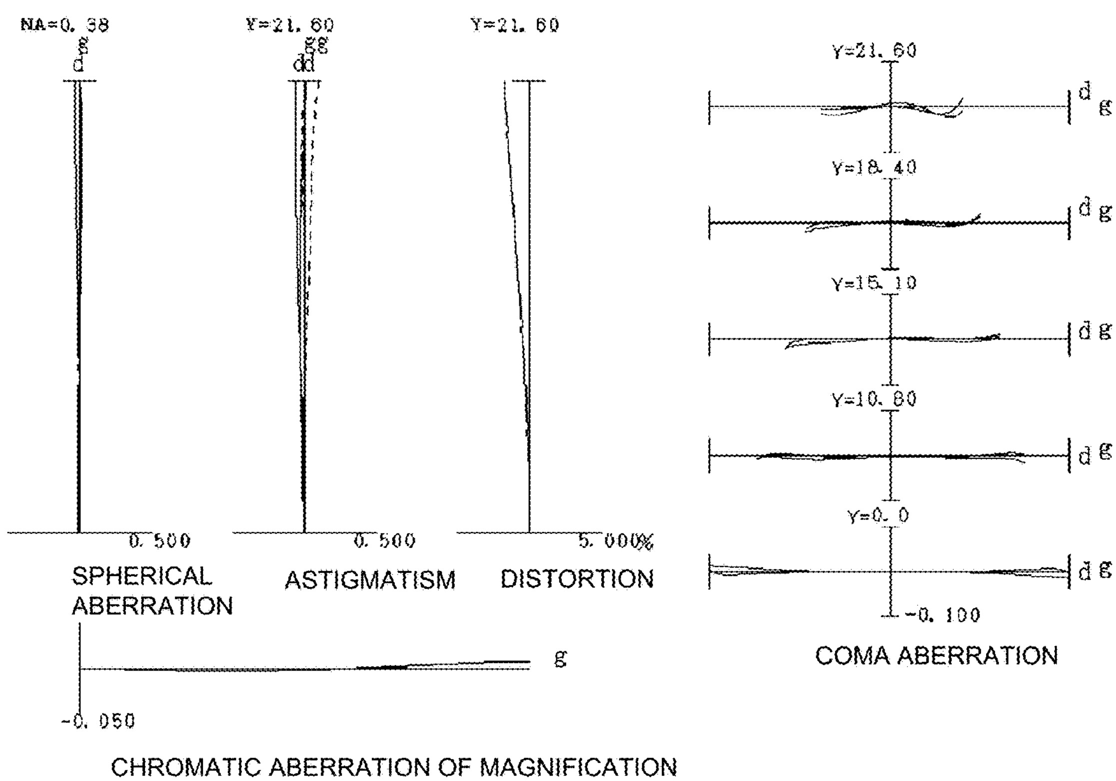
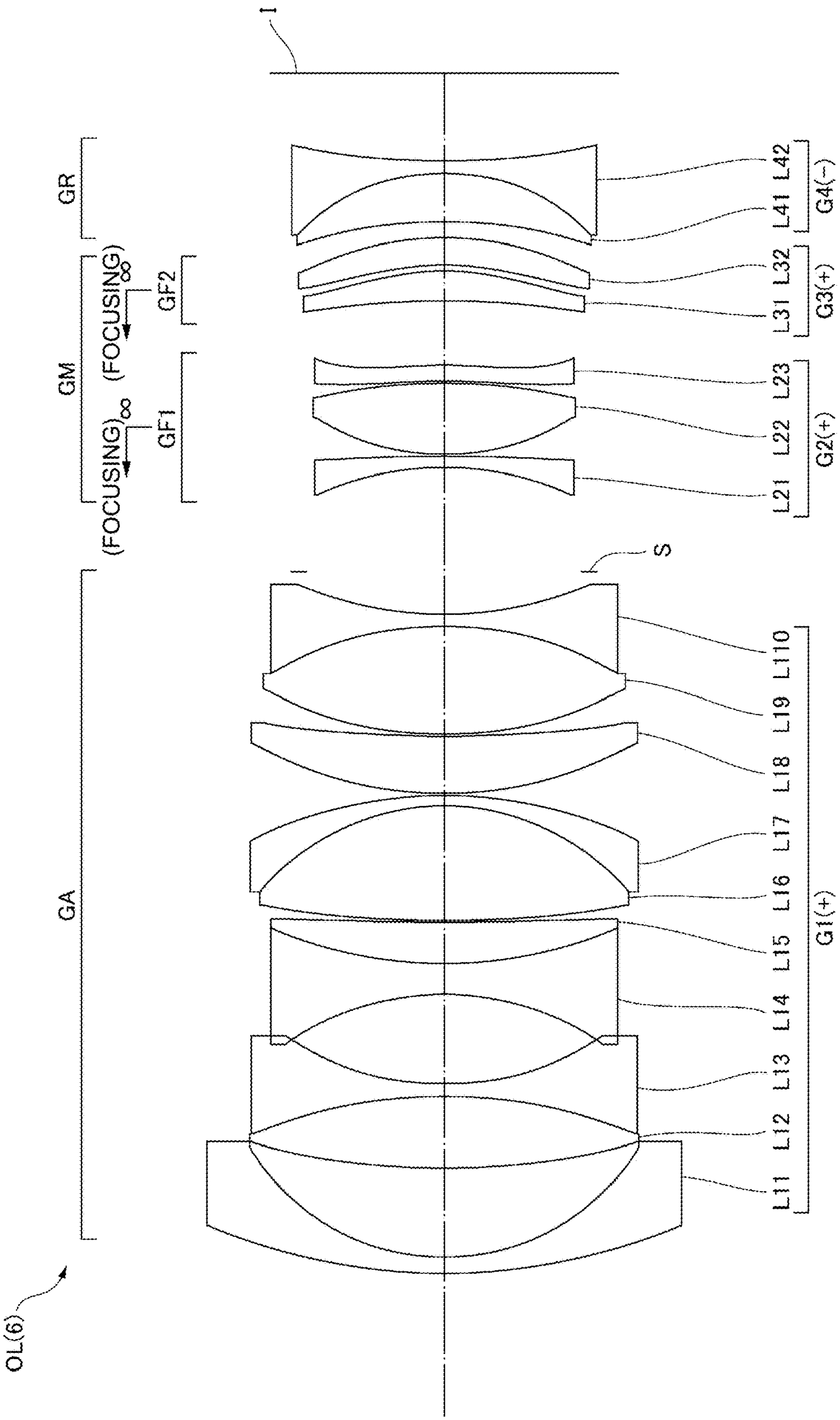


FIG.11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L31
G3(+)
L23
L22
L21
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L110
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L17
L16
L15
L14
L13
L12
L11
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OL(6)

FIG.12A

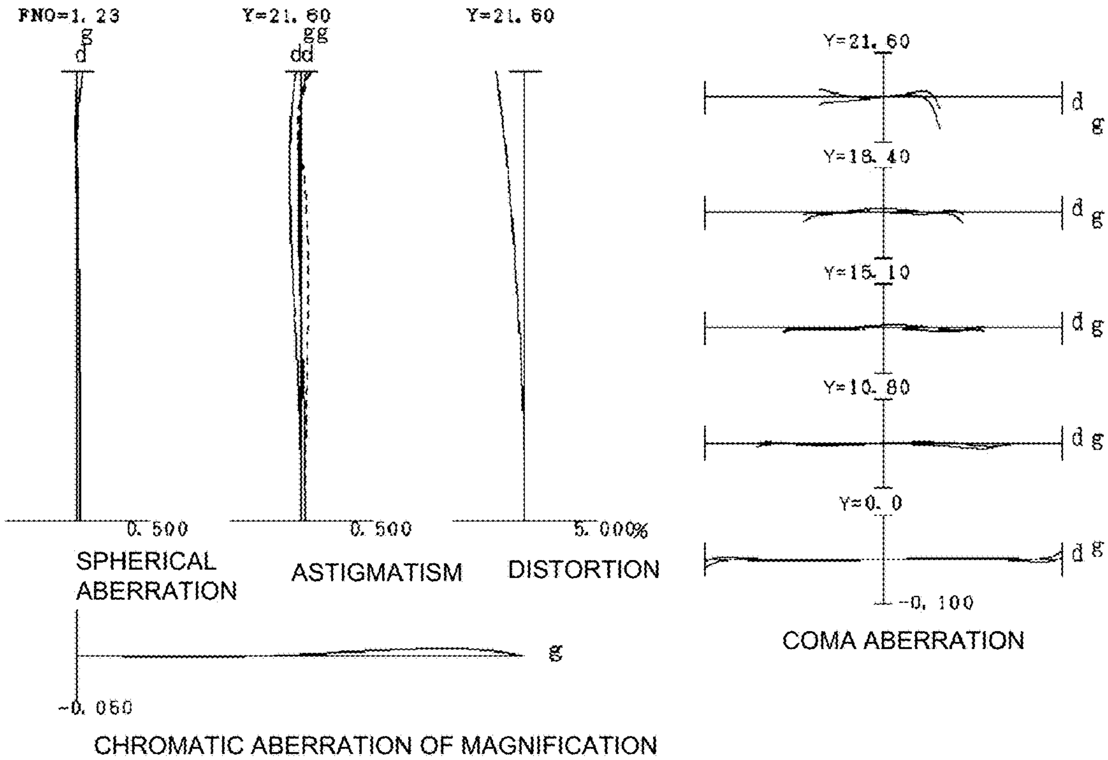


FIG.12B

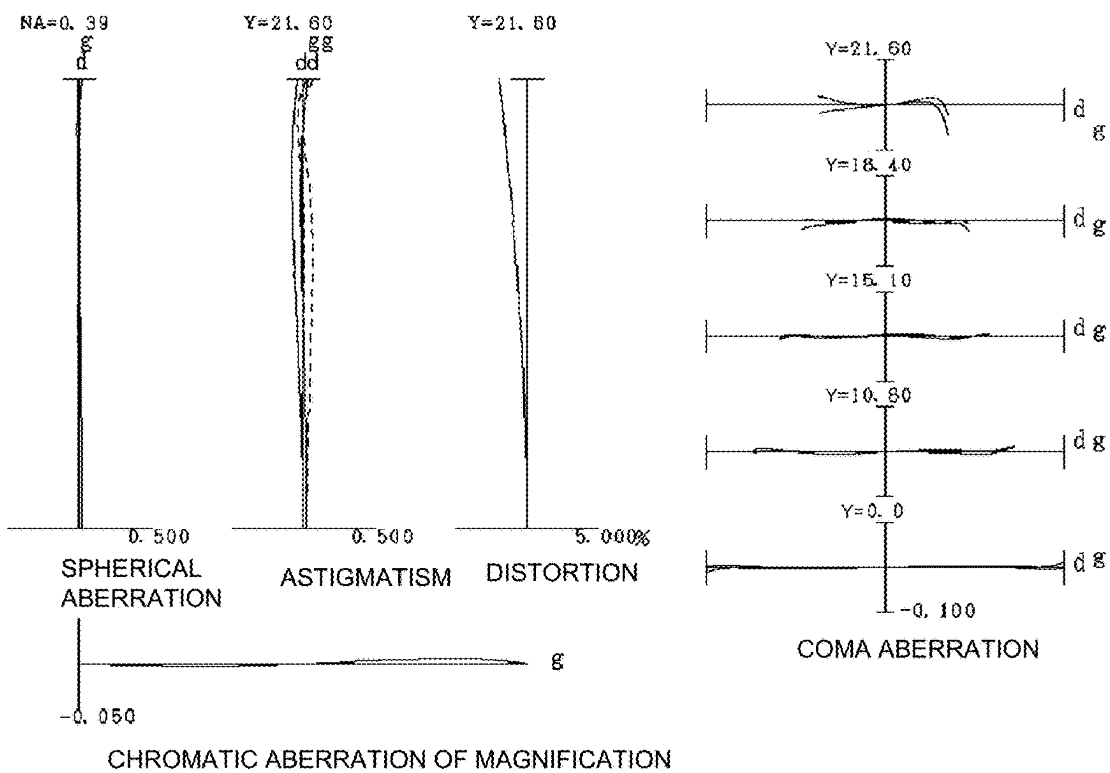
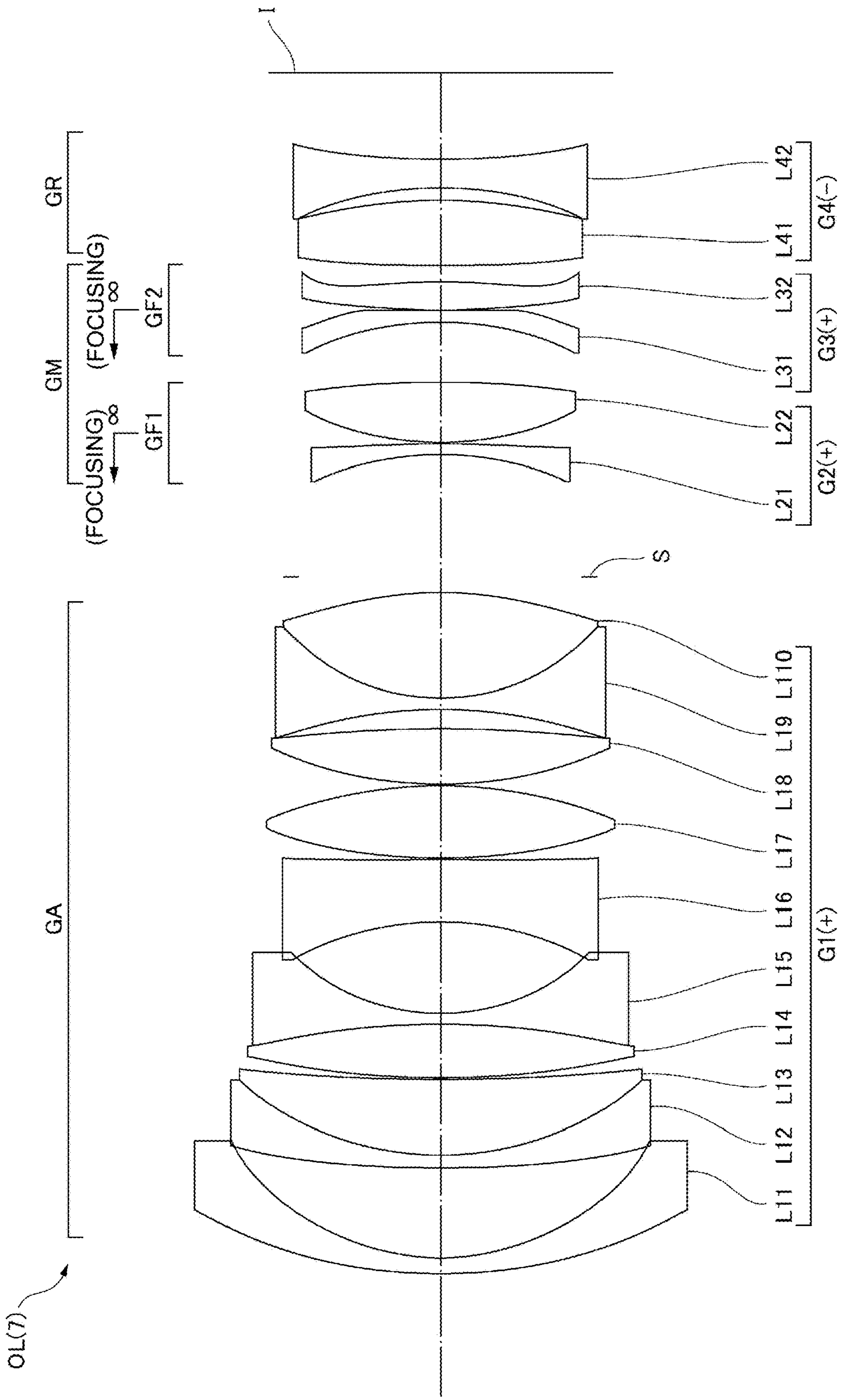


FIG.13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∞
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∞
GF1
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G4(−)
L32
L31
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L22
L21
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L15
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L12
L11
G1(+)
OL(7)

FIG.14A

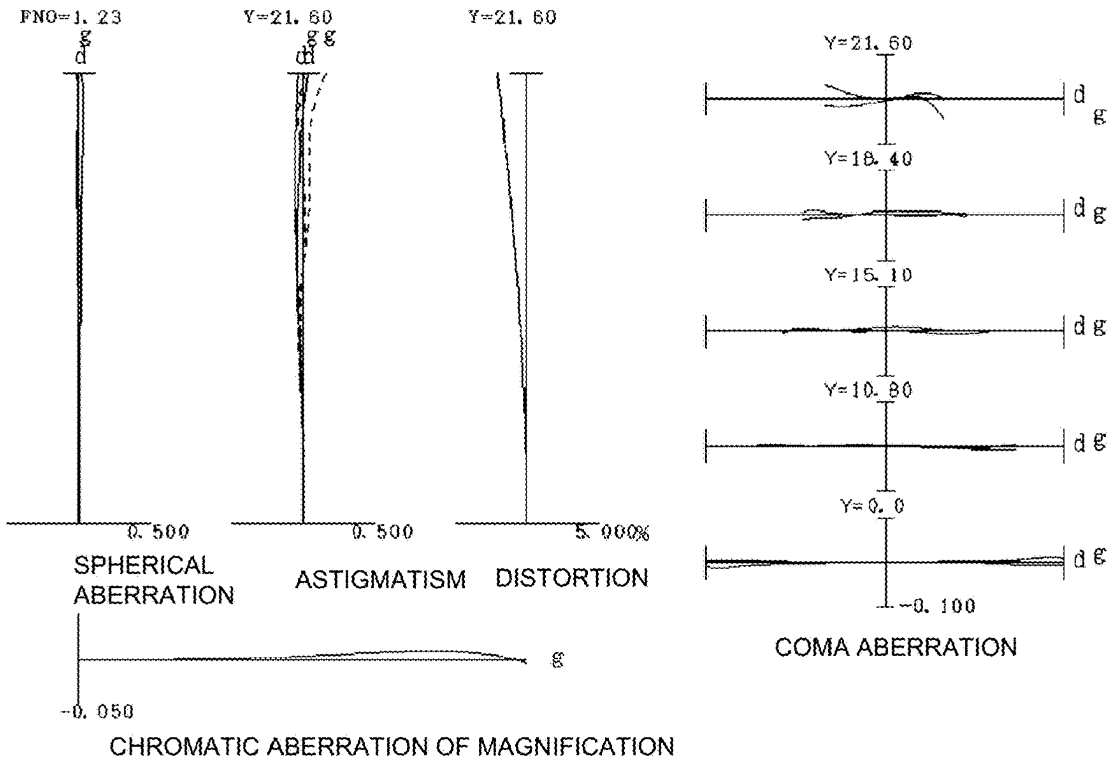


FIG.14B

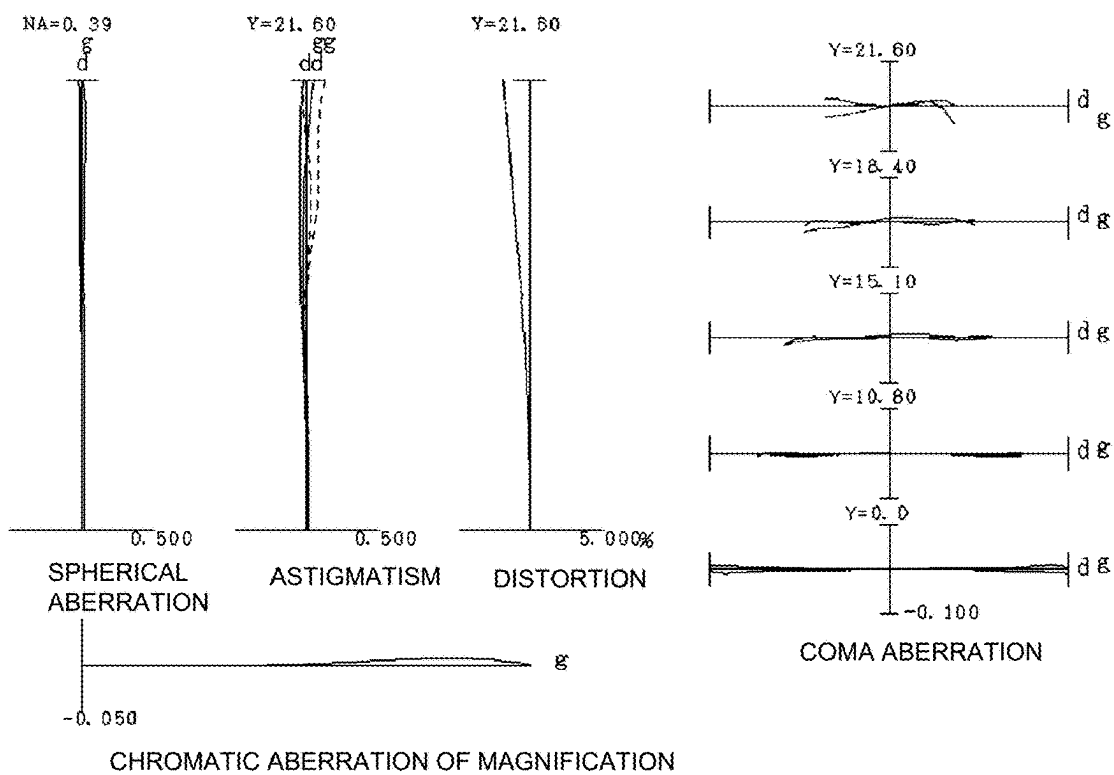
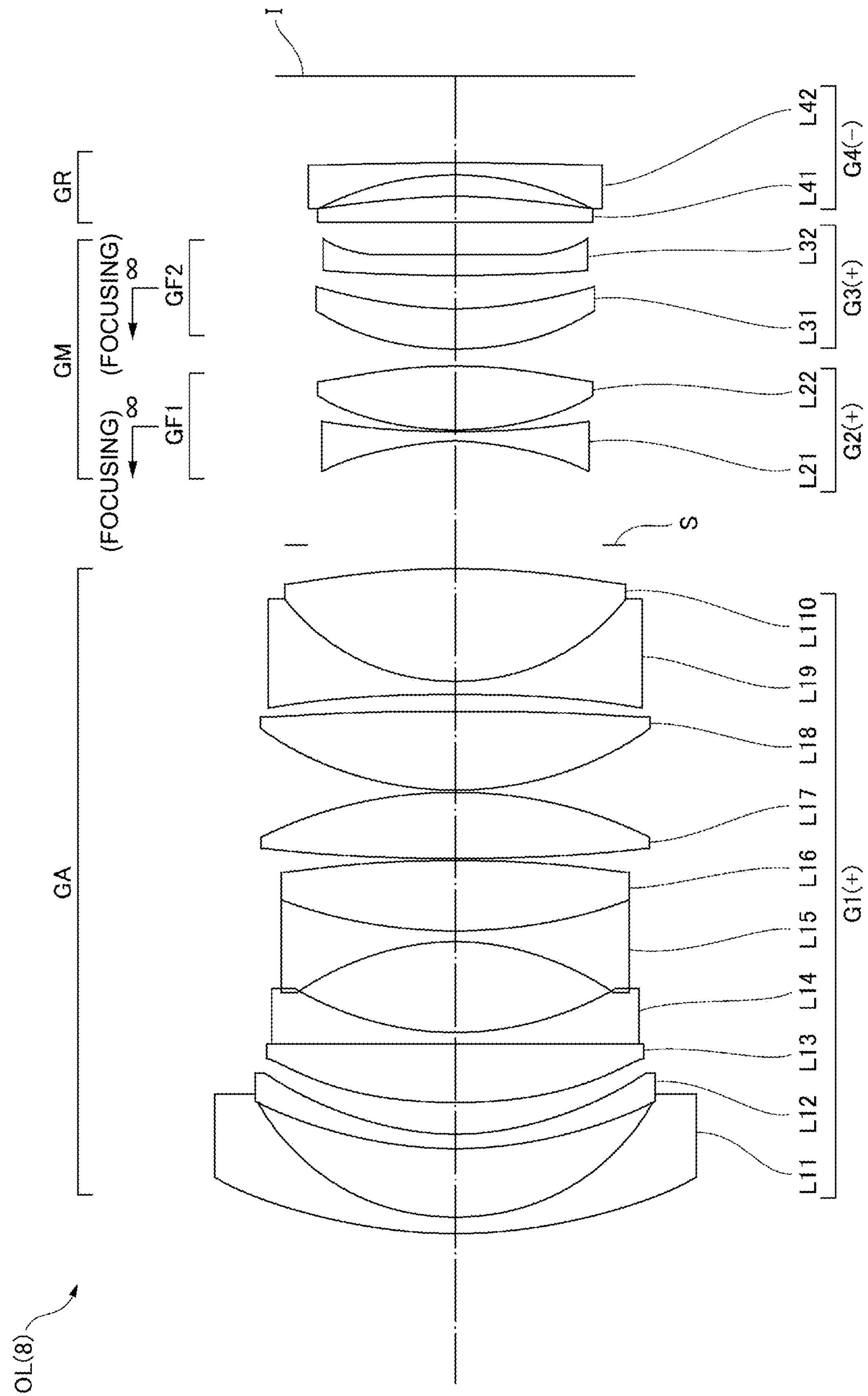


FIG.15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GA
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GF1
GF2
S
L11
L12
L13
L14
L15
L16
L17
L18
L19
L110
L21
L22
L31
L32
L41
L42
G1(+)
G2(+)
G3(+)
G4(−)
OL(8)

FIG.16A

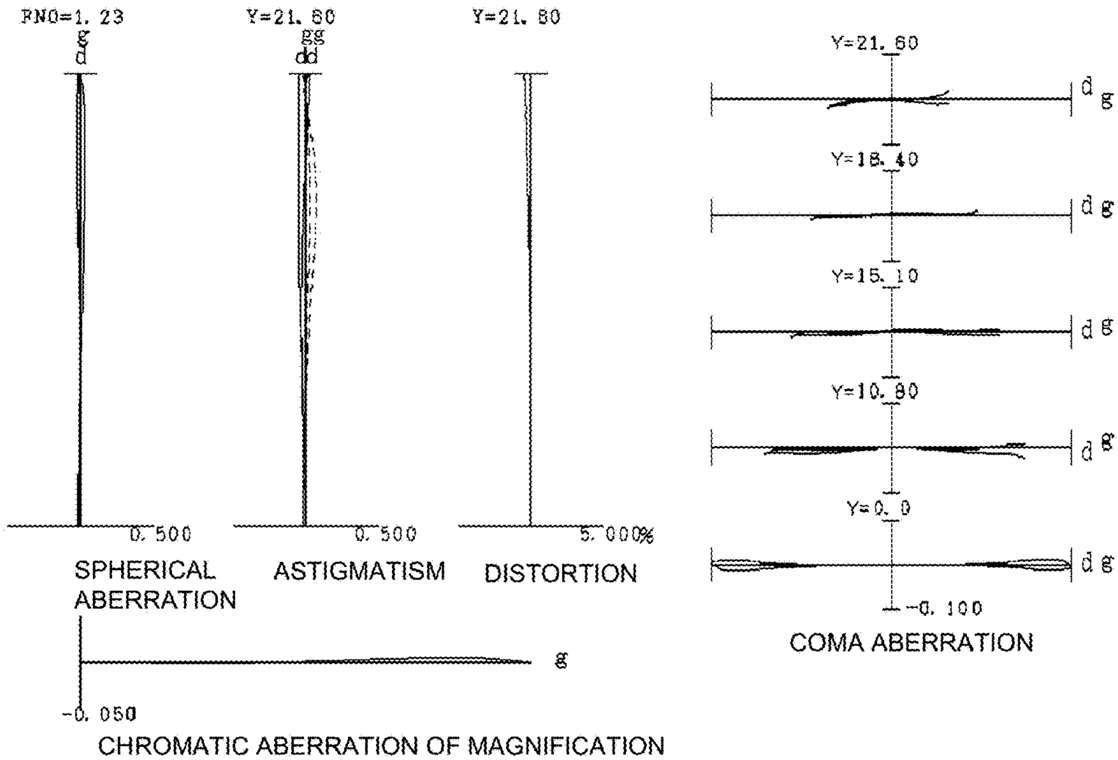


FIG.16B

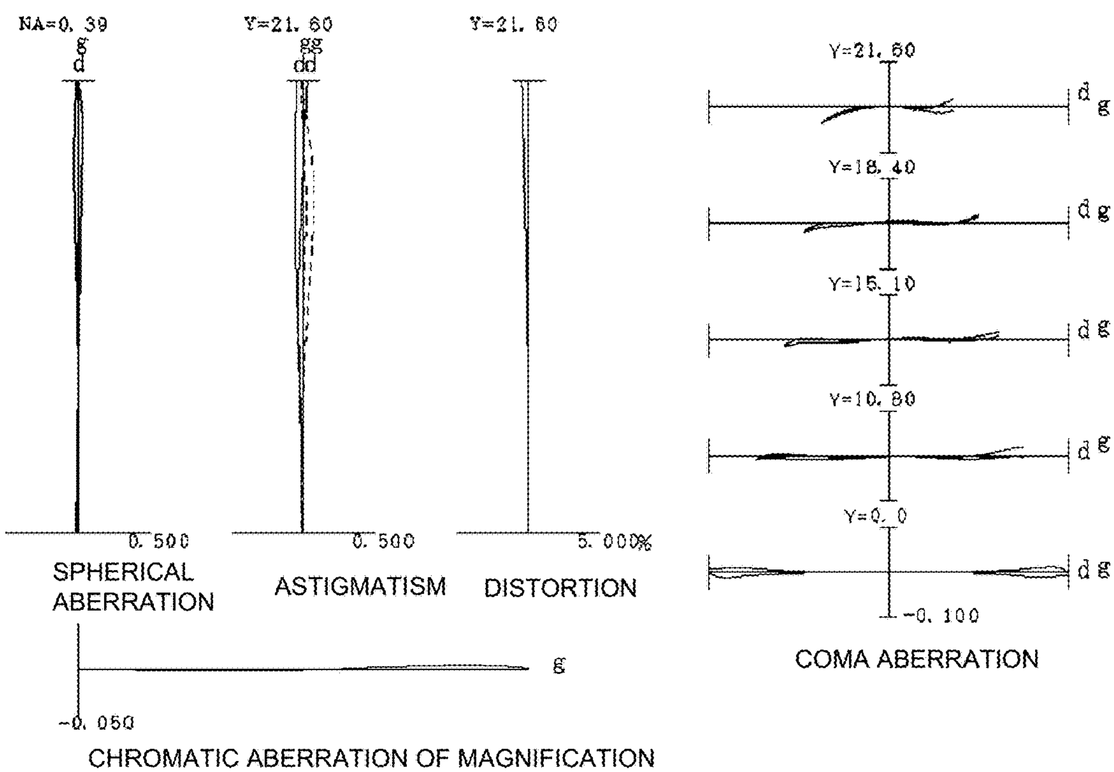


FIG.17

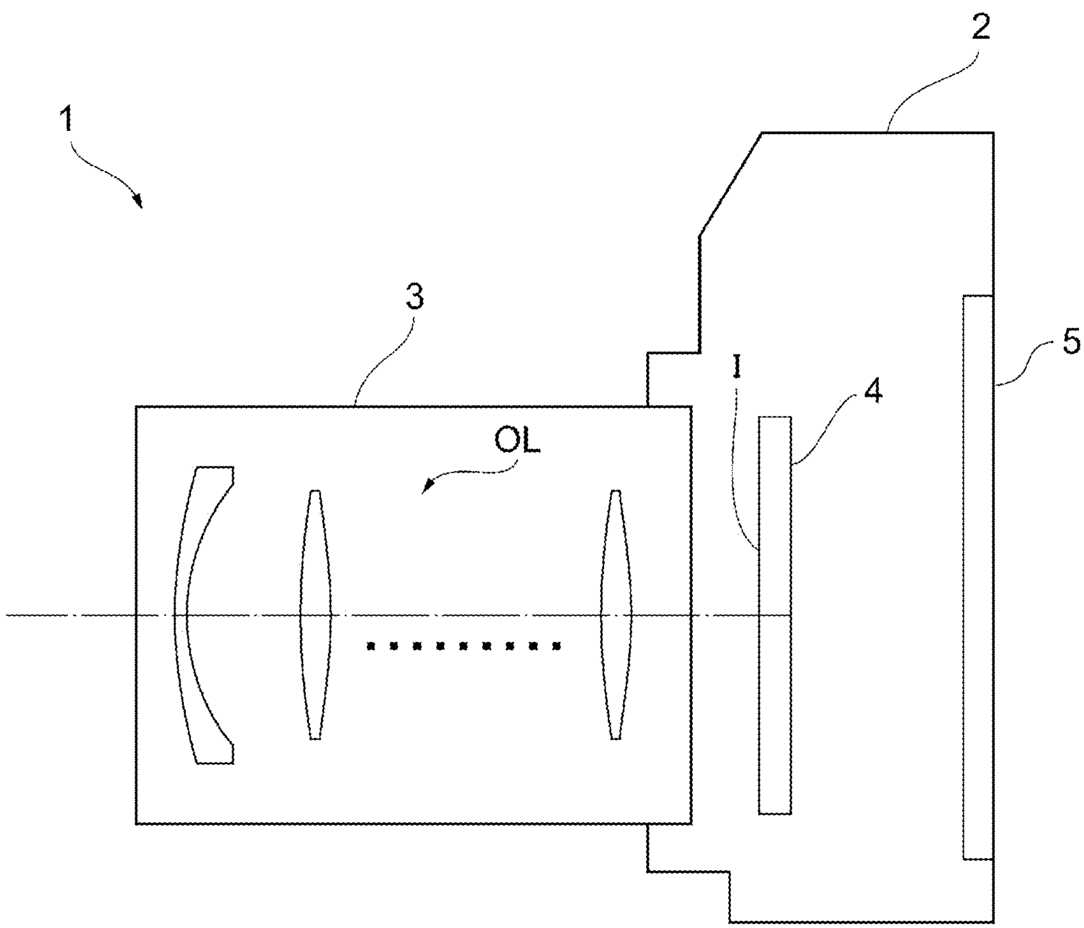
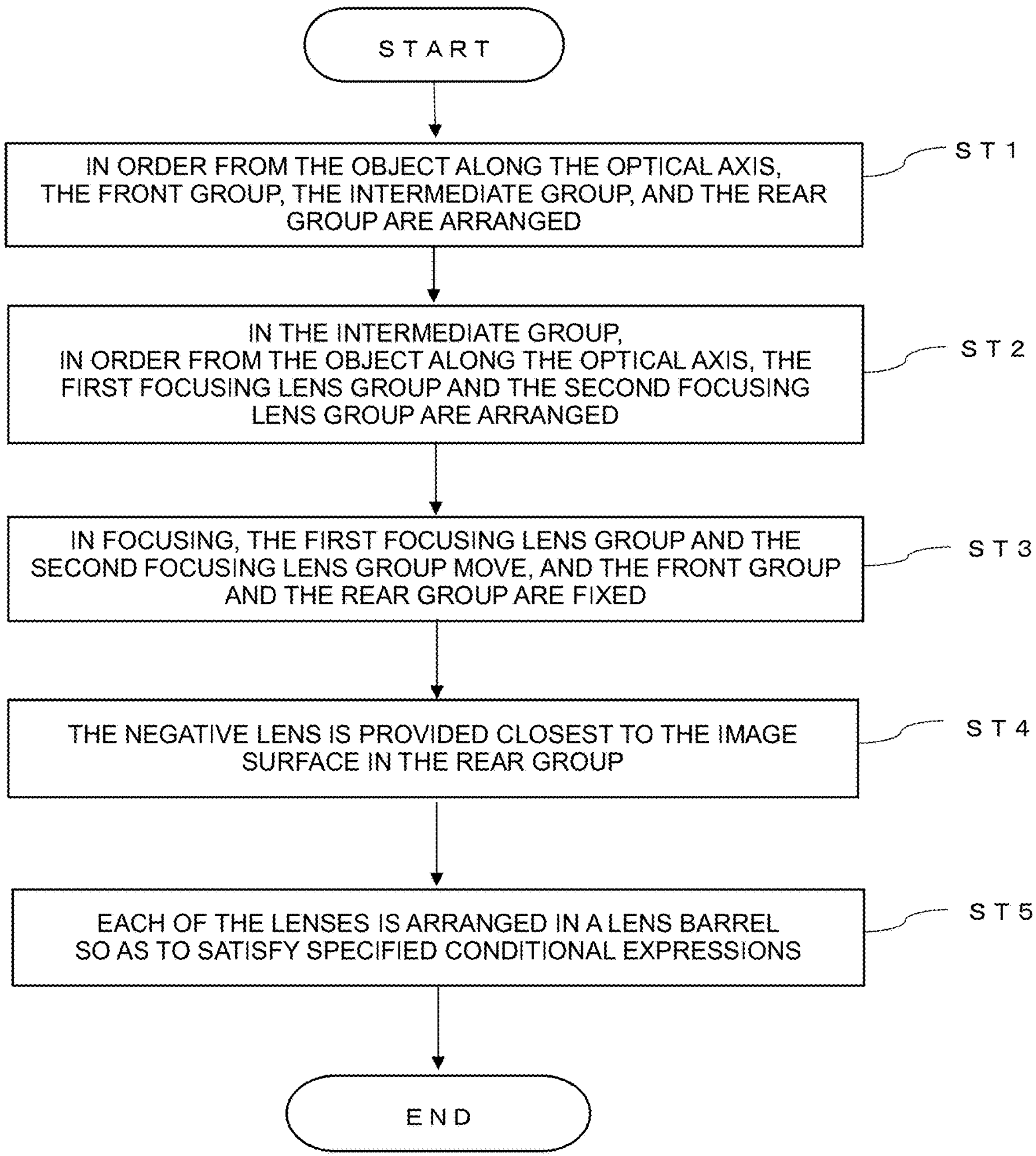


FIG.18


START
IN ORDER FROM THE OBJECT ALONG THE OPTICAL AXIS, THE FRONT GROUP, THE INTERMEDIATE GROUP, AND THE REAR GROUP ARE ARRANGED
ST1
IN THE INTERMEDIATE GROUP, IN ORDER FROM THE OBJECT ALONG THE OPTICAL AXIS, THE FIRST FOCUSING LENS GROUP AND THE SECOND FOCUSING LENS GROUP ARE ARRANGED
ST2
IN FOCUSING, THE FIRST FOCUSING LENS GROUP AND THE SECOND FOCUSING LENS GROUP MOVE, AND THE FRONT GROUP AND THE REAR GROUP ARE FIXED
ST3
THE NEGATIVE LENS IS PROVIDED CLOSEST TO THE IMAGE SURFACE IN THE REAR GROUP
ST4
EACH OF THE LENSES IS ARRANGED IN A LENS BARREL SO AS TO SATISFY SPECIFIED CONDITIONAL EXPRESSIONS
ST5
END

OPTICAL SYSTEM, OPTICAL APPARATUS AND METHOD FOR MANUFACTURING THE OPTICAL SYSTEM

TECHNICAL FIELD

[0001] The present invention relates to an optical system, an optical apparatus, and a method for manufacturing the optical system.

TECHNICAL BACKGROUND

[0002] In related art, an optical system suitable for a photographic camera, an electronic still camera, a video camera, or the like has been proposed (for example, see Patent Document 1). In such an optical system, it is difficult to obtain bright and favorable optical performance while achieving a small size.

PRIOR ARTS LIST

Patent Document

[0003] Patent Document 1: Japanese Laid-Open Patent Publication No. 2019-191502 (A)

SUMMARY OF THE INVENTION

[0004] An optical system according to the present invention essentially consists of: a front group; an intermediate group; and a rear group, which are arranged in order from an object side along an optical axis, the intermediate group essentially consists of a first focusing lens group having positive refractive power and a second focusing lens group having positive refractive power, which are arranged in order from the object side along the optical axis, in focusing, the first focusing lens group and the second focusing lens group move along the optical axis differently with different loci from each other, and the front group and the rear group are fixed with respect to an image surface, the rear group comprises a negative lens which is arranged at a position closest to an image surface in the rear lens group, and the following conditional expressions are satisfied:

$$0.01 < fF2/fF1 < 10.00$$

$$0.50 < Y/Bf < 5.00$$

[0005] where

[0006] fF1: a focal length of the first focusing lens group,

[0007] fF2: a focal length of the second focusing lens group,

[0008] Y: an image height of the optical system, and

[0009] Bf: a back focal length of the optical system.

[0010] An optical apparatus according to the present invention comprises the optical system.

[0011] A method for manufacturing an optical system according to the present invention, which essentially consists of: a front group; an intermediate group; and a rear group, which are arranged in order from an object side along an optical axis, comprising a step for arranging the lens groups in a lens barrel so that; the intermediate group essentially consists of a first focusing lens group having positive refractive power and a second focusing lens group having positive refractive power, which are arranged in order from the object along the optical axis, in focusing, the first focusing lens group and the second focusing lens group move along the optical axis differently with different loci from each other, and the front group and the rear group are fixed with respect to an image surface, the rear group comprises a negative lens which is arranged at a position closest to an image surface in the rear lens group, and the following conditional expressions are satisfied:

$$0.01 < fF2/fF1 < 10.00$$

$$0.50 < Y/Bf < 5.00$$

[0012] where

[0013] fF1: a focal length of the first focusing lens group,

[0014] fF2: a focal length of the second focusing lens group,

[0015] Y: an image height of the optical system, and

[0016] Bf: a back focal length of the optical system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. **1** A diagram illustrating a lens configuration of an optical system according to a first example.

[0018] FIG. **2**(A) and FIG. **2**(B) respectively illustrate diagrams of various aberrations of the optical system according to the first example upon focusing on infinity and upon focusing on a short distance object.

[0019] FIG. **3** A diagram illustrating a lens configuration of an optical system according to a second example.

[0020] FIG. **4**(A) and FIG. **4**(B) respectively illustrate diagrams of various aberrations of the optical system according to the second example upon focusing on infinity and upon focusing on a short distance object.

[0021] FIG. **5** A diagram illustrating a lens configuration of an optical system according to a third example.

[0022] FIG. **6**(A) and FIG. **6**(B) respectively illustrate diagrams of various aberrations of the optical system according to the third example upon focusing on infinity and upon focusing on a short distance object.

[0023] FIG. **7** A diagram illustrating a lens configuration of an optical system according to a fourth example.

[0024] FIG. **8**(A) and FIG. **8**(B) respectively illustrate diagrams of various aberrations of the optical system according to the fourth example upon focusing on infinity and upon focusing on a short distance object.

[0025] FIG. **9** A diagram illustrating a lens configuration of an optical system according to a fifth example.

[0026] FIG. **10**(A) and FIG. **10**(B) respectively illustrate diagrams of various aberrations of the optical system according to the fifth example upon focusing on infinity and upon focusing on a short distance object.

[0027] FIG. **11** A diagram illustrating a lens configuration of an optical system according to a sixth example.

[0028] FIG. **12**(A) and FIG. **12**(B) respectively illustrate diagrams of various aberrations of the optical system according to the sixth example upon focusing on infinity and upon focusing on a short distance object.

[0029] FIG. **13** A diagram illustrating a lens configuration of an optical system according to a seventh example.

[0030] FIG. **14**(A) and FIG. **14**(B) respectively illustrate diagrams of various aberrations of the optical system according to the seventh example upon focusing on infinity and upon focusing on a short distance object.

[0031] FIG. **15** A diagram illustrating a lens configuration of an optical system according to an eighth example.

[0032] FIG. **16**(A) and FIG. **16**(B) respectively illustrate diagrams of various aberrations of the optical system according to the eighth example upon focusing on infinity and upon focusing on a short distance object.

[0033] FIG. **17** A diagram illustrating a configuration of a camera which includes the optical system according to the present embodiment.

[0034] FIG. **18** A flowchart illustrating a method for manufacturing the optical system according to the present embodiment.

EMBODIMENTS FOR REALIZING THE INVENTIONS

[0035] A preferable embodiment according to the present invention will hereinafter be described. First, a description will be made, based on FIG. **7**, about a camera (optical apparatus) including an optical system according to the present embodiment. As illustrated in FIG. **17**, this camera **1** is formed from a main body **2** and a photographing lens **3** to be mounted on the main body **2**. The main body **2** includes an image-capturing element **4**, a main-body control part (not illustrated) which controls actions of a digital camera, and a liquid crystal screen **5**. The photographing lens **3** includes an optical system OL which is formed with plural lens groups and a lens position control mechanism (not illustrated) which controls a position of each of the lens groups. The lens position control mechanism is formed from a sensor which detects a position of the lens group, a motor which moves the lens group forward and rearward along an optical axis, a control circuit which drives a motor, and so forth.

[0036] Light from a photographed object is collected by the optical system OL of the photographing lens **3** and reaches an image surface I of the image-capturing element **4**. Light from the photographed object which reaches the image surface I is subjected to photoelectric conversion by the image-capturing element **4** and is recorded as digital image data in a memory which is not illustrated. The digital image data recorded in the memory can be displayed on the liquid crystal screen **5** in response to an operation by a user. Note that this camera may be a mirrorless camera or a single-lens reflex camera having an instant return mirror. Further, the optical system OL illustrated in FIG. **17** schematically illustrates the optical system which is included in the photographing lens **3**, and a lens configuration of the optical system OL is not limited to this configuration.

[0037] Next, the optical system according to the present embodiment will be described. As illustrated in FIG. **1**, an optical system OL(**1**) as one example of the optical system OL according to the present embodiment is formed from a front group GA, an intermediate group GM, and a rear group GR, which are arranged in order from an object side along the optical axis. The intermediate group GM consists of a first focusing lens group GF**1** having positive refractive power and a second focusing lens group GF**2** having positive refractive power, which are arranged in order from the object side along the optical axis. In focusing, the first focusing lens group GF**1** and the second focusing lens group GF**2** move along the optical axis differently with different loci from each other. The front group GA and the rear group GR are fixed with respect to the image surface I. The rear group GR has a negative lens (L**44**) which is arranged at a position closest to an image surface in the rear group GR.

[0038] In the above configuration, the optical system OL according to the present embodiment satisfies the following conditional expression (1) and conditional expression (2).

$$0.01 < fF2/fF1 < 10.00 \tag{1}$$

$$0.50 < Y/Bf < 5.00 \tag{2}$$

[0039] where

[0040] fF1: a focal length of the first focusing lens group GF**1**,

[0041] fF2: a focal length of the second focusing lens group GF**2**,

[0042] Y: an image height of the optical system OL, and

[0043] Bf: a back focal length of the optical system OL.

[0044] In the present embodiment, it becomes possible to obtain an optical system having bright and favorable optical performance while having a small size and an optical apparatus including the optical system. The optical system OL according to the present embodiment may be an optical system OL(**2**) illustrated in FIG. **3**, may be an optical system OL(**3**) illustrated in FIG. **5**, or may be an optical system OL(**4**) illustrated in FIG. **7**. Further, the optical system OL according to the present embodiment may be an optical system OL(**5**) illustrated in FIG. **9**, may be an optical system OL(**6**) illustrated in FIG. **11**, may be an optical system OL(**7**) illustrated in FIG. **13**, or may be an optical system OL(**8**) illustrated in FIG. **15**.

[0045] The conditional expression (1) defines an appropriate relationship between the focal length of the second focusing lens group GF**2** and the focal length of the first focusing lens group GF**1**. By satisfying the conditional expression (1), various aberrations such as a coma aberration can properly be corrected.

[0046] Because when a corresponding value of the conditional expression (1) exceeds an upper limit value, the refractive power of the first focusing lens group GF**1** becomes too strong, it becomes difficult to correct a spherical aberration and the coma aberration in focusing on a short distance object. The upper limit value of the conditional expression (1) is set to 8.50, 7.50, 7.00, 5.00, 4.00, 3.50, 2.50, 2.00, or further 1.50, and effects of the present embodiment can thereby more certainly be obtained.

[0047] Because when the corresponding value of the conditional expression (1) becomes below a lower limit value, the refractive power of the second focusing lens group GF**2** becomes too strong, it becomes difficult to correct the coma aberration and a curvature of field in focusing on a short distance object. The lower limit value of the conditional expression (1) is set to 0.05 or further 0.09, and the effects of the present embodiment can thereby more certainly be obtained.

[0048] The conditional expression (2) defines an appropriate relationship between the image height of the optical system OL and the back focal length of the optical system OL. Note that in the present embodiment, the back focal length of the optical system OL is set as an air equivalent distance, on an optical axis, from a lens surface, which is closest to the image surface, of the optical system OL to the image surface I. By satisfying the conditional expression (2), it becomes possible to obtain an optical system having bright and favorable optical performance while having a small size. The upper limit value of the conditional expression (2) is set to 4.50, 4.00, 3.50, 3.00, 2.50, or further 2.00, and the effects of the present embodiment can thereby more certainly be obtained. Further, the lower limit value of the conditional expression (2) is set to 1.00 or further 1.40, and the effects of the present embodiment can thereby more certainly be obtained.

[0049] It is desirable that the optical system OL according to the present embodiment further have an aperture stop S and satisfy the following conditional expression (3).

$$0.05 < fSr/fSa < 4.00 \tag{3}$$

[0050] where

[0051] fSr: a combined focal length, upon focusing on infinity, of a lens, which is arranged on the image surface side relative to the aperture stop S, in the optical system OL, and

[0052] fSa: the combined focal length, upon focusing on infinity, of a lens, which is arranged on the object side relative to the aperture stop S, in the optical system OL.

[0053] The conditional expression (3) defines an appropriate relationship between the combined focal length, upon focusing on infinity, of the lens, which is arranged on the image surface side relative to the aperture stop S, in the optical system OL and the combined focal length, upon focusing on infinity, of the lens, which is arranged on the object side relative to the aperture stop S, in the optical system OL. By satisfying the conditional expression (3), the spherical aberration, the coma aberration, and the curvature of field can properly be corrected.

[0054] Because when the corresponding value of the conditional expression (3) exceeds the upper limit value, refractive power of the lens, which is arranged on the object side relative to the aperture stop S, in the optical system OL becomes too strong, it becomes difficult to correct the spherical aberration, the coma aberration, and the curvature of field. The upper limit value of the conditional expression (3) is set to 3.50, 3.00, 2.50, or further 2.30, and the effects of the present embodiment can thereby more certainly be obtained.

[0055] Because when the corresponding value of the conditional expression (3) becomes below the lower limit value, refractive power of the lens, which is arranged on the image surface side relative to the aperture stop S, in the optical system OL becomes too strong, it becomes difficult to correct the spherical aberration, the coma aberration, and the curvature of field. The lower limit value of the conditional expression (3) is set to 0.13 or further 0.18, and the effects of the present embodiment can thereby more certainly be obtained.

[0056] It is desirable that the optical system OL according to the present embodiment satisfy the following conditional expression (4).

$$0.05 < fF2/fA < 8.00 \tag{4}$$

[0057] where fA: the focal length of the front group GA.

[0058] The conditional expression (4) defines an appropriate relationship between the focal length of the second focusing lens group **GF2** and the focal length of the front group GA. By satisfying the conditional expression (4), various aberrations such as the coma aberration and the curvature of field can properly be corrected.

[0059] Because when the corresponding value of the conditional expression (4) exceeds the upper limit value, refractive power of the front group GA becomes too strong, it becomes difficult to correct the spherical aberration, the coma aberration, and the curvature of field. The upper limit value of the conditional expression (4) is set to 6.00, 5.00, 4.00, 3.00, 2.00, or further 1.50, and the effects of the present embodiment can thereby more certainly be obtained.

[0060] Because when the corresponding value of the conditional expression (4) becomes below the lower limit value, the refractive power of the second focusing lens group **GF2** becomes too strong, it becomes difficult to correct the coma aberration and a curvature of field in focusing on a short distance object. The lower limit value of the conditional expression (4) is set to 0.10 or further 0.20, and the effects of the present embodiment can thereby more certainly be obtained.

[0061] It is desirable that the optical system OL according to the present embodiment satisfy the following conditional expression (5).

$$0.10 < -fR/fF2 < 8.00 \tag{5}$$

[0062] where fR: the focal length of the rear group GR.

[0063] The conditional expression (5) defines an appropriate relationship between the focal length of the rear group GR and the focal length of the second focusing lens group **GF2**. By satisfying the conditional expression (5), the coma aberration and the curvature of field can properly be corrected.

[0064] Because when the corresponding value of the conditional expression (5) exceeds the upper limit value, the refractive power of the second focusing lens group **GF2** becomes too strong, it becomes difficult to correct the coma aberration and the curvature of field in focusing on a short distance object. The upper limit value of the conditional expression (5) is set to 6.00, 5.00, 4.00, 3.00, or further 2.50, and the effects of the present embodiment can thereby more certainly be obtained.

[0065] Because when the corresponding value of the conditional expression (5) becomes below the lower limit value, refractive power of the rear group GR becomes too strong, it becomes difficult to correct the coma aberration and the curvature of field. The lower limit value of the conditional expression (5) is set to 0.30 or further 0.60, and the effects of the present embodiment can thereby more certainly be obtained.

[0066] It is desirable that the optical system OL according to the present embodiment satisfy the following conditional expression (6).

$$0.02 < fA/fF1 < 4.00 \tag{6}$$

[0067] where fA: the focal length of the front group GA.

[0068] The conditional expression (6) defines an appropriate relationship between the focal length of the front group GA and the focal length of the first focusing lens group **GF1**. By satisfying the conditional expression (6), various aberrations such as the spherical aberration and the coma aberration can properly be corrected.

[0069] Because when the corresponding value of the conditional expression (6) exceeds the upper limit value, the refractive power of the first focusing lens group **GF1** becomes too strong, it becomes difficult to correct the spherical aberration and the coma aberration in focusing on a short distance object. The upper limit value of the conditional expression (6) is set to 3.50, 3.00, 2.50, or further 2.00, and the effects of the present embodiment can thereby more certainly be obtained.

[0070] Because when the corresponding value of the conditional expression (6) becomes below the lower limit value, the refractive power of the front group GA becomes too strong, it becomes difficult to correct the spherical aberration, the coma aberration, and the curvature of field. The lower limit value of the conditional expression (6) is set to 0.05 or further 0.08, and the effects of the present embodiment can thereby more certainly be obtained.

[0071] It is desirable that the optical system OL according to the present embodiment satisfy the following conditional expression (7).

$$0.10 < fF1/(-fR) < 8.00 \tag{7}$$

[0072] where fR: the focal length of the rear group GR.

[0073] The conditional expression (7) defines an appropriate relationship between the focal length of the first focusing lens group **GF1** and the focal length of the rear group GR. By satisfying the conditional expression (7), various aberrations such as the coma aberration can properly be corrected.

[0074] Because when the corresponding value of the conditional expression (7) exceeds the upper limit value, the refractive power of the rear group GR becomes too strong, it becomes difficult to correct the coma aberration and the curvature of field. The upper limit value of the conditional expression (7) is set to 6.00 or further 5.00, and the effects of the present embodiment can thereby more certainly be obtained.

[0075] Because when the corresponding value of the conditional expression (7) becomes below the lower limit value, the refractive power of the first focusing lens group **GF1** becomes too strong, it becomes difficult to correct the spherical aberration and the coma aberration in focusing on a short distance object. The lower limit value of the conditional expression (7) is set to 0.20 or further 0.30, and the effects of the present embodiment can thereby more certainly be obtained.

[0076] It is desirable that the optical system OL according to the present embodiment satisfy the following conditional expression (8).

$$0.10 < fA/(-fR) < 4.00 \tag{8}$$

[0077] where fR: the focal length of the rear group GR.

[0078] The conditional expression (8) defines an appropriate relationship between the focal length of the front group GA and the focal length of the rear group GR. By satisfying the conditional expression (8), various aberrations such as the coma aberration and the curvature of field can properly be corrected.

[0079] Because when the corresponding value of the conditional expression (8) exceeds the upper limit value, the refractive power of the rear group GR becomes too strong, it becomes difficult to correct the coma aberration and the curvature of field. The upper limit value of the conditional expression (8) is set to 3.00 or further 2.50, and the effects of the present embodiment can thereby more certainly be obtained.

[0080] Because when the corresponding value of the conditional expression (8) becomes below the lower limit value, the refractive power of the front group GA becomes too strong, it becomes difficult to correct the spherical aberration, the coma aberration, and the curvature of field. The lower limit value of the conditional expression (8) is set to 0.20 or further 0.30, and the effects of the present embodiment can thereby more certainly be obtained.

[0081] It is desirable that the optical system OL according to the present embodiment satisfy the following conditional expression (9).

$$1.00 < f/Bf < 8.00 \tag{9}$$

[0082] where f: the focal length of the optical system OL.

[0083] The conditional expression (9) defines an appropriate relationship between the focal length of the optical system OL and the back focal length of the optical system OL. By satisfying the conditional expression (9), it becomes possible to obtain an optical system having bright and favorable optical performance while having a small size. The upper limit value of the conditional expression (9) is set to 6.00 or further 4.50, and the effects of the present embodiment can thereby more certainly be obtained. Further, the lower limit value of the conditional expression (9) is set to 1.50 or further 2.50, and the effects of the present embodiment can thereby more certainly be obtained.

[0084] It is desirable that the optical system OL according to the present embodiment satisfy the following conditional expression (10).

$$0.50 < TL/f < 7.00 \tag{10}$$

[0085] where

[0086] f: the focal length of the optical system OL, and

[0087] TL: an entire length of the optical system OL.

[0088] The conditional expression (10) defines an appropriate relationship between the entire length of the optical system OL and the focal length of the optical system OL. Note that in the present embodiment, the entire length of the optical system OL is set as the distance, on the optical axis, from the lens surface of the optical system OL, which is closest to the object, to the image surface I (where the distance, on the optical axis, from the lens surface of the optical system OL, which is closest to the image surface, to the image surface I is the air equivalent distance). By satisfying the conditional expression (10), it becomes possible to obtain an optical system having bright and favorable optical performance while having a small size. The upper limit value of the conditional expression (10) is set to 6.00 or further 5.00, and the effects of the present embodiment can thereby more certainly be obtained. Further, the lower limit value of the conditional expression (10) is set to 1.00 or further 1.50, and the effects of the present embodiment can thereby more certainly be obtained.

[0089] It is desirable that the optical system OL according to the present embodiment satisfy the following conditional expression (11).

$$0.10 < fe/-fR < 0.90 \tag{11}$$

[0090] where

[0091] fe: the focal length of a negative lens which is arranged in a position of the rear group GR which is closest to the image surface, and

[0092] fR: the focal length of the rear group GR.

[0093] The conditional expression (11) defines an appropriate relationship between the focal length of the negative lens, which is arranged on the position of the rear group GR which is closest to the image surface, and the focal length of the rear group GR. By satisfying the conditional expression (11), various aberrations such as the curvature of field can properly be corrected.

[0094] Because when the corresponding value of the conditional expression (11) exceeds the upper limit value, the refractive power of the rear group GR becomes too strong, it becomes difficult to correct the coma aberration and the curvature of field. The upper limit value of the conditional expression (11) is set to 0.85 or further 0.75, and the effects of the present embodiment can thereby more certainly be obtained.

[0095] Because when the corresponding value of the conditional expression (11) becomes below the lower limit value, refractive power of the negative lens, which is arranged on the position of the rear group GR which is closest to the image surface, becomes too strong, it becomes difficult to correct the curvature of field. The lower limit value of the conditional expression (11) is set to 0.15 or further 0.20, and the effects of the present embodiment can thereby more certainly be obtained.

[0096] It is desirable that the optical system OL according to the present embodiment further have the aperture stop S which is arranged between the front group GA and the intermediate group GM. Accordingly, it becomes possible to correct the spherical aberration, the coma aberration, and the curvature of field in focusing on a short distance object.

[0097] In the optical system OL according to the present embodiment, it is desirable that the front group GA have positive refractive power. Accordingly, it becomes possible to correct the spherical aberration, the coma aberration, and the curvature of field.

[0098] In the optical system OL according to the present embodiment, it is desirable that the rear group GR have negative refractive power. Accordingly, it becomes possible to correct the coma aberration and the curvature of field.

[0099] Next, a method for manufacturing the optical system OL according to the present embodiment will be outlined with reference to FIG. **18**. First, in order from the object side along the optical axis, the front group GA, the intermediate group GM, and the rear group GR are arranged (step ST**1**). Next, in the intermediate group GM, in order from the object side along the optical axis, the first focusing lens group **GF1** having the positive refractive power and the second focusing lens group **GF2** having the positive refractive power are arranged (step ST**2**). Next, a configuration is made such that in focusing, the first focusing lens group **GF1** and the second focusing lens group **GF2** move along the optical axis differently with different loci from each other. The front group GA and the rear group GR are fixed with respect to the image surface I (step ST**3**). Further, the negative lens is provided closest to the image surface in the rear group GR (step ST**4**). Furthermore, each of the lenses is arranged in a lens barrel such that at least the above conditional expression (1) and conditional expression (2) are satisfied (step ST**5**). In such a method for manufacturing the optical system, it becomes possible to manufacture an optical system having bright and favorable optical performance while having a small size.

EXAMPLES

[0100] In the following, the optical systems OL according to examples of the present embodiment will be described based on the drawings. FIG. **1**, FIG. **3**, FIG. **5**, FIG. **7**, FIG. **9**, FIG. **11**, FIG. **13**, and FIG. **15** are cross-sectional diagrams which respectively illustrate configurations and refractive power distribution of the optical systems OL {OL(**1**) to OL(**8**)} according to first to eighth examples. In the cross-sectional diagrams of the optical systems OL(**1**) to OL(**8**) according to the first to eighth examples, a movement direction of each of the lens groups along the optical axis in focusing from infinity to a short distance object is indicated by an arrow.

[0101] In FIG. **1**, FIG. **3**, FIG. **5**, FIG. **7**, FIG. **9**, FIG. **11**, FIG. **13**, and FIG. **15**, each of the lens groups is denoted by a combination of a reference character G and a numeral, and each of the lenses is denoted by a combination of a reference character L and a numeral. In this case, in order to prevent a situation where kinds and the numbers of reference characters and numerals are increased and cause complication, lens groups and so forth are denoted by using independent combinations of reference characters and numerals for each of the examples. Thus, even when the same combinations of reference characters and numerals are used among the examples, this does not mean the same configuration.

[0102] Although table 1 to table 8 are illustrated in the following, among those, the table 1, the table 2, the table 3, the table 4, the table 5, the table 6, the table 7, and the table 8 are tables which represent respective data of the first example, the second example, the third example, the fourth example, the fifth example, the sixth example, the seventh example, and the eighth example. In each of the examples, as targets of calculation of aberration characteristics, a d-line (wavelength λ=587.6 nm) and a g-line (wavelength λ=435.8 nm) are selected.

[0103] In a table of [general data], f denotes a focal length of a whole lens system, FNO denotes an F-number, and ω denotes half angle of view (its unit is "°" (degree)), and Y denotes an image height. A reference character TL denotes a distance in which Bf (back focal length) is added to a distance, on the optical axis, from a lens surface of the optical system, which is closest to the object, to a lens surface, which is closest to the image surface side, upon focusing on infinity, and Bf denotes a distance (air equivalent distance), on the optical axis, from the lens surface of the optical system, which is closest to the image surface, to an image surface upon focusing on infinity.

[0104] Further, in the table of [general data], fA demotes the focal length of a front group. A reference character fR denotes the focal length of a rear group. A reference character fF1 denotes the focal length of a first focusing lens group. A reference character fF2 denotes the focal length of a second focusing lens group. A reference character fSa denotes the combined focal length, upon focusing on infinity, of a lens, which is arranged on the object side relative to an aperture stop, in the optical system. A reference character fSr denotes the combined focal length, upon focusing on infinity, of a lens, which is arranged on the image surface side relative to the aperture stop, in the optical system. A reference character fe denotes the focal length of a negative lens which is arranged in a position of the rear group which is closest to the image surface.

[0105] In a table of [lens data], a surface number denotes order of optical surfaces from the object side along a direction in which a beam of light progresses, R denotes a radius of curvature of each of the optical surfaces (a positive value is given to a surface whose center of curvature is positioned on the image side), D denotes a surface distance as a distance on the optical axis from each of the optical surfaces to the next optical surface (or the image surface), nd denotes a refractive index of a material of an optical member with respect to the d-line, and νd denotes the Abbe number of the material of the optical member with respect to the d-line as a reference. A radius of curvature of "∞" denotes a flat surface or an opening, and (aperture stop S) denotes the aperture stop S. A refractive index nd of air=1.00000 is not indicated. In a case where the optical surface is an aspherical surface, "*" sign is given to the surface number, and a paraxial radius of curvature is indicated in a field of the radius of curvature R.

[0106] In a table of [aspherical surface data], a shape of an aspherical surface indicated in [lens data] is expressed by the following expression (A). A term X(y) represents a distance (sag quantity), along an optical axis direction, from a tangential plane at an apex of the aspherical surface to a position on the aspherical surface at a height y, R denotes a radius of curvature (paraxial radius of curvature) of a reference spherical surface, κ denotes a conic constant, and Ai denotes an aspherical coefficient at the i-th order. A term "E-n" denotes "×10-n". For example, 1.234E-05=1.234×10-5. Note that an aspherical coefficient A2 at the second order is zero and is not indicated.

$$X(y) = (y^2/R)/\{1 + (1 - \kappa \times y^2/R^2)^{1/2}\} + A4 \times y^4 + A6 \times y^6 + A8 \times y^8 + A10 \times y^{10} \tag{A}$$

[0107] A table of [variable distance data] indicates each surface distance at a surface number i for which the surface distance is (Di) in the table of [lens data]. Further, the table of [variable distance data] indicates each surface distance upon focusing on infinity and each surface distance upon focusing on a short distance object. In the table of [variable distance data], f denotes the focal length of the whole lens system, and β denotes a photographing magnification. Further, D0 denotes a distance from an object to an optical surface in the optical system, which is closest to the object.

[0108] A table of [lens group data] indicates a first surface (a surface closest to the object) and a focal length of each of the lens groups.

[0109] In the following, in all of data values, "mm" is in general used for the focal lengths f, the radii of curvature R, the surface distances D, other lengths, and so forth, which appear herein, unless otherwise mentioned; however, this is not restrictive because the optical system can obtain equivalent optical performance even when the optical system is proportionally enlarged or proportionally shrunk.

[0110] The above descriptions about the tables are common to all of the examples, and the descriptions will not be repeated in the following.

First Example

[0111] The first example will be described by using FIG. **1**, FIG. **2**, and the table 1. FIG. **1** is a diagram illustrating a lens configuration of the optical system according to the first example. The optical system OL(**1**) according to the first example is formed from a first lens group G**1** having positive refractive power, a second lens group G**2** having positive refractive power, a third lens group G**3** having positive refractive power, and a fourth lens group G**4** having negative refractive power, which are arranged in order from the object side along the optical axis. In focusing from an object at infinity to an object at a short distance, the second lens group G**2** and the third lens group G**3** move to the object side along the optical axis in different loci (different in movement amounts), and intervals between the neighboring lens groups are thereby changed. Note that in focusing, positions of the first lens group G**1** and the fourth lens group G**4** are fixed with respect to the image surface I. A reference character (+) or (−) given to each lens group character indicates refractive power of each lens group, and the same applies to all of the following examples.

[0112] The aperture stop S is disposed between the first lens group G**1** and the second lens group G**2**. In focusing, a position of the aperture stop S is fixed with respect to the image surface I. In the present example, the first lens group G**1** constitutes the front group GA, the second lens group G**2** and the third lens group G**3** constitute the intermediate group GM, and the fourth lens group G**4** constitutes the rear group GR. Further, the second lens group G**2** corresponds to the first focusing lens group GF**1**, and the third lens group G**3** corresponds to the second focusing lens group GF**2**.

[0113] The first lens group G**1** is formed from a biconcave negative lens L**11** and a cemented positive lens in which a biconvex positive lens L**12** and a negative meniscus lens L**13** having a concave surface facing the object side are joined together, and the above lenses are arranged in order from the object side along the optical axis.

[0114] The second lens group G**2** is formed from a cemented negative lens, in which a biconcave negative lens L**21** and a positive meniscus lens L**22** having a convex surface facing the object side are joined together, and a biconvex positive lens L**23**, and the above lenses are arranged in order from the object side along the optical axis. The positive lens L**23** is a hybrid type lens which is configured such that a resin layer is provided on a surface of a glass-made lens main body on an image surface side. The surface of the resin layer on the image surface side is an aspherical surface, and the positive lens L**23** is a composite type aspherical lens. In [lens data] which will be described later, a surface number **10** denotes a surface of the lens main body on the object side, a surface number **11** denotes a surface of the lens main body on the image surface side and a surface of the resin layer on the object side (the surface on which both of those are joined together), and a surface number **12** denotes a surface of the resin layer on the image surface side.

[0115] The third lens group G**3** is formed from a biconvex positive lens L**31**. The positive lens L**31** is a hybrid type lens which is configured such that a resin layer is provided on a surface of a glass-made lens main body on the image surface side. The surface of the resin layer on the image surface side is an aspherical surface, and the positive lens L**31** is a composite type aspherical lens. In [lens data] which will be described later, a surface number **13** denotes a surface of the lens main body on the object side, a surface number **14** denotes a surface of the lens main body on the image surface side and a surface of the resin layer on the object side (the surface on which both of those are joined together), and a surface number **15** denotes a surface of the resin layer on the image surface side.

[0116] The fourth lens group G**4** is formed from a cemented positive lens in which a biconcave negative lens L**41** and a biconvex positive lens L**42** are joined together, a biconcave negative lens L**43**, and a plano-concave negative lens L**44** having a flat surface facing the image surface side, and the above lenses are arranged in order from the object side along the optical axis. The image surface I is arranged on the image side of the fourth lens group G**4**.

[0117] The following table 1 raises values of data of the optical system according to the first example.

TABLE 1

[General Data]

f = 36.050	FNO = 1.442
ω = 31.814	Y = 20.374
TL = 83.685	Bf = 12.113
FA = 154.383	fR = −70.566
fF1 = 150.000	fF2 = 42.786
fSa = 154.383	fSr = 41.385
fe = −49.090	

[Lens Data]

Surface Number	R	D	nd	νd
1	−84.278	1.000	1.48749	70.31
2	34.272	0.582		
3	42.331	6.737	1.83481	42.73
4	−39.159	0.900	1.76182	26.58
5	−167.335	1.600		
6	∞	(D6)		(Aperture Stop S)
7	−23.995	0.900	1.64769	33.73
8	28.408	5.263	1.83481	42.73
9	214.240	0.100		
10	69.377	5.846	1.83481	42.73
11	−52.510	0.100	1.56093	36.64
12*	−50.272	(D12)		
13	133.009	7.274	1.77250	49.62
14	−47.184	0.100	1.56093	36.64
15*	−41.494	(D15)		

TABLE 1-continued

Surface Number	R	D	nd	νd
16	−101.299	1.000	1.68893	31.16
17	37.985	11.824	1.83481	42.73
18	−43.191	0.100		
19	−79.644	1.000	1.78472	25.64
20	863.090	6.024		
21	−30.438	1.300	1.62004	36.40
22	∞	Bf		

[Aspherical Surface Data]

12th Surface
κ = 1.0000, A4 = 9.82707E−06, A6 = 8.10431E−09,
A8 = −4.53816E−11, A10 = 8.08855E−14
15th Surface
κ = 1.0000, A4 = 7.20448E−06, A6 = 3.36893E−10,
A8 = 3.34430E−11, A10 = −3.62441E−14

[Variable Distance Data]

	Upon focusing on infinity f = 36.050	Upon focusing on a short-distance object β = −0.03333
D0	∞	1073.885
D6	13.904	12.690
D12	4.519	4.847
D15	1.500	2.386
Bf	12.113	12.113

[Lens Group Data]

Group	First surface	Focal length
G1	1	154.383
G2	7	150.000
G3	13	42.786
G4	16	−70.566

[0118] FIG. **2**(A) illustrates diagrams of various aberrations of the optical system according to the first example upon focusing on infinity. FIG. **2**(B) illustrates diagrams of various aberrations of the optical system according to the first example upon focusing on a short distance object. In each of the diagrams of aberrations upon focusing on infinity, FNO denotes an F-number, and Y denotes an image height. In each of the diagrams of aberrations upon focusing on a short distance object, NA denotes a numerical aperture, and Y denotes the image height. Note that a spherical aberration diagram indicates the value of the F-number or the numerical aperture which corresponds to the maximum aperture, an astigmatism diagram and a distortion diagram respectively indicate the maximum values of the image height, and a coma aberration diagram indicates the value of each image height. A reference character d denotes the d-line (wavelength λ=587.6 nm), and g denotes the g-line (wavelength λ=435.8 nm). In the astigmatism diagram, a solid line indicates a sagittal image surface, and a broken line indicates a meridional image surface. Note that also in diagrams of aberrations in each of the examples, which will be described in the following, similar reference characters to the present example will be used, and descriptions thereof will not be repeated.

[0119] Based on each of the diagrams of various aberrations, it may be understood that not only upon focusing on infinity but also focusing on a short distance object, the optical system according to the first example properly corrects various aberrations and exhibits excellent image formation performance.

Second Example

[0120] The second example will be described by using FIG. **3**, FIG. **4**, and the table 2. FIG. **3** is a diagram illustrating a lens configuration of the optical system according to the second example. The optical system OL(**2**) according to the second example is formed from a first lens group G**1** having positive refractive power, a second lens group G**2** having positive refractive power, a third lens group G**3** having positive refractive power, and a fourth lens group G**4** having negative refractive power, which are arranged in order from the object side along the optical axis. In focusing from an object at infinity to an object at a short distance, the second lens group G**2** and the third lens group G**3** move to the object side along the optical axis in different loci (different in movement amounts), and intervals between the neighboring lens groups are thereby changed. Note that in focusing, positions of the first lens group G**1** and the fourth lens group G**4** are fixed with respect to the image surface I.

[0121] The aperture stop S is disposed between the first lens group G**1** and the second lens group G**2**. In focusing, the position of the aperture stop S is fixed with respect to the image surface front group GA, the second lens group G**2** and the third lens group G**3** constitute the intermediate group GM, and the fourth lens group G**4** constitutes the rear group GR. Further, the second lens group G**2** corresponds to the first focusing lens group GF**1**, and the third lens group G**3** corresponds to the second focusing lens group GF**2**.

[0122] The first lens group G**1** is formed from a positive meniscus lens L**11** having a convex surface facing the object side, a positive meniscus lens L**12** having a convex surface facing the object side, and a negative meniscus lens L**13** having a convex surface facing the object side, and the above lenses are arranged in order from the object side along the optical axis. A lens surface of the positive meniscus lens L**12** on the object side is an aspherical surface.

[0123] The second lens group G**2** is formed from a cemented negative lens, in which a biconcave negative lens L**21** and a positive meniscus lens L**22** having a convex surface facing the object side are joined together, and a biconvex positive lens L**23**, and the above lenses are arranged in order from the object side along the optical axis. The positive lens L**23** is a hybrid type lens which is configured such that a resin layer is provided on a surface of a glass-made lens main body on the image surface side. The surface of the resin layer on the image surface side is an aspherical surface, and the positive lens L**23** is a composite type aspherical lens. In [lens data] which will be described later, a surface number **11** denotes a surface of the lens main body on the object side, a surface number **12** denotes a surface of the lens main body on the image surface side and a surface of the resin layer on the object side (the surface on which both of those are joined together), and a surface number **13** denotes a surface of the resin layer on the image surface side.

[0124] The third lens group G**3** is formed from a biconvex positive lens L**31**. The positive lens L**31** is a hybrid type lens which is configured such that a resin layer is provided on a surface of a glass-made lens main body on the image surface side. The surface of the resin layer on the image surface side is an aspherical surface, and the positive lens L**31** is a composite type aspherical lens. In [lens data] which will be described later, a surface number **14** denotes a surface of the lens main body on the object side, a surface number **15** denotes a surface of the lens main body on the image surface side and a surface of the resin layer on the object side (the surface on which both of those are joined together), and a surface number **16** denotes a surface of the resin layer on the image surface side.

[0125] The fourth lens group G**4** is formed from a cemented positive lens in which a positive meniscus lens L**41** having a concave surface facing the object side and a negative meniscus lens L**42** having a concave surface facing the object side are joined together, a biconcave negative lens L**43**, and a plano-concave negative lens L**44** having a flat surface facing the image surface side, and the above lenses are arranged in order from the object side along the optical axis. The image surface I is arranged on the image side of the fourth lens group G**4**.

[0126] The following table 2 raises values of data of the optical system according to the second example.

TABLE 2

[General Data]

f = 48.500	FNO = 1.442
ω = 24.256	Y = 21.413
TL = 92.309	Bf = 12.113
fA = 144.537	fR = −64.985
fF1 = 141.932	fF2 = 42.786
fSa = 144.537	fSr = 45.388
fe = −398.038	

[Lens Data]

Surface Number	R	D	nd	νd
1	44.354	3.671	1.83481	42.73
2	68.031	2.679		
3*	30.946	5.657	1.83481	42.73
4	119.179	0.686		
5	456.720	0.900	1.59270	35.27
6	23.170	5.704		
7	∞	(D7)		(Aperture Stop S)
8	−19.295	0.900	1.64769	33.72
9	24.301	6.226	1.83481	42.73
10	222.101	0.100		
11	51.221	7.224	1.77250	49.62
12	−44.866	0.100	1.56093	36.64
13*	−44.287	(D13)		
14	51.773	6.423	1.77250	49.62
15	−154.916	0.100	1.56093	36.64
16*	−74.031	(D16)		
17	−510.487	12.769	1.85026	32.35
18	−20.236	1.000	1.90265	35.73
19	−61.076	0.100		
20	−98.851	1.024	1.75520	27.57
21	48.753	4.694		
22	−235.917	1.300	1.59270	35.27
23	∞	Bf		

[Aspherical Surface Data]

3rd Surface

κ = 1.0000, A4 = 1.39886E−06, A6 = 7.46585E−09,
A8 = −1.84946E−11, A10 = 7.06419E−14

13th Surface

κ = 1.0000, A4 = 6.25043E−06, A6 = 7.63434E−09,
A8 = −2.42103E−12, A10 = 2.61079E−14

TABLE 2-continued

16th Surface
κ = 1.0000, A4 = 1.51632E−05, A6 = −2.12876E−09, A8 = 3.12457E−11, A10 = −4.64496E−14

[Variable Distance Data]

	Upon focusing on infinity f = 48.500	Upon focusing on a short-distance β = −0.03333
D0	∞	1427.370
D7	12.239	11.399
D13	5.200	4.948
D16	1.500	2.591
Bf	12.113	12.113

[Lens Group Data]

Group	First surface	Focal length
G1	1	144.537
G2	8	141.932
G3	14	42.786
G4	17	−64.985

[0127] FIG. **4**(A) illustrates diagrams of various aberrations of the optical system according to the second example upon focusing on infinity. FIG. **4**(B) illustrates diagrams of various aberrations of the optical system according to the second example upon focusing on a short distance object. Based on each of the diagrams of various aberrations, it may be understood that not only upon focusing on infinity but also focusing on a short distance object, the optical system according to the second example properly corrects various aberrations and exhibits excellent image formation performance.

Third Example

[0128] The third example will be described by using FIG. **5**, FIG. **6**, and the table 3. FIG. **5** is a diagram illustrating a lens configuration of the optical system according to the third example. The optical system OL(**3**) according to the third example is formed from a first lens group G**1** having positive refractive power, a second lens group G**2** having positive refractive power, a third lens group G**3** having positive refractive power, and a fourth lens group G**4** having negative refractive power, which are arranged in order from the object side along the optical axis. In focusing from an object at infinity to an object at a short distance, the second lens group G**2** and the third lens group G**3** move to the object side along the optical axis in different loci (different in movement amounts), and intervals between the neighboring lens groups are thereby changed. Note that in focusing, positions of the first lens group G**1** and the fourth lens group G**4** are fixed with respect to the image surface I.

[0129] The aperture stop S is disposed between the first lens group G**1** and the second lens group G**2**. In focusing, the position of the aperture stop S is fixed with respect to the image surface I. In the present example, the first lens group G**1** constitutes the front group GA, the second lens group G**2** and the third lens group G**3** constitute the intermediate group GM, and the fourth lens group G**4** constitutes the rear group GR. Further, the second lens group G**2** corresponds to the first focusing lens group GF**1**, and the third lens group G**3** corresponds to the second focusing lens group GF**2**.

[0130] The first lens group G**1** is formed from a plano-concave negative lens L**11** having a flat surface facing the object side and a cemented positive lens in which a biconvex positive lens L**12** and a biconcave negative lens L**13** are joined together, and the above lenses are arranged in order from the object side along the optical axis.

[0131] The second lens group G**2** is formed from a cemented negative lens, in which a biconcave negative lens L**21** and a positive meniscus lens L**22** having a convex surface facing the object side are joined together, and a biconvex positive lens L**23**, and the above lenses are arranged in order from the object side along the optical axis. The positive lens L**23** is a hybrid type lens which is configured such that a resin layer is provided on a surface of a glass-made lens main body on the image surface side. The surface of the resin layer on the image surface side is an aspherical surface, and the positive lens L**23** is a composite type aspherical lens. In [lens data] which will be described later, a surface number **10** denotes a surface of the lens main body on the object side, a surface number **11** denotes a surface of the lens main body on the image surface side and a surface of the resin layer on the object side (the surface on which both of those are joined together), and a surface number **12** denotes a surface of the resin layer on the image surface side.

[0132] The third lens group G**3** is formed from a biconvex positive lens L**31**. The positive lens L**31** is a hybrid type lens which is configured such that a resin layer is provided on a surface of a glass-made lens main body on the image surface side. The surface of the resin layer on the image surface side is an aspherical surface, and the positive lens L**31** is a composite type aspherical lens. In [lens data] which will be described later, a surface number **13** denotes a surface of the lens main body on the object side, a surface number **14** denotes a surface of the lens main body on the image surface side and a surface of the resin layer on the object side (the surface on which both of those are joined together), and a surface number **15** denotes a surface of the resin layer on the image surface side.

[0133] The fourth lens group G**4** is formed from a cemented positive lens in which a biconcave negative lens L**41** and a biconvex positive lens L**42** are joined together, a negative meniscus lens L**43** having a concave surface facing the object side, and a plano-concave negative lens L**44** having a flat surface facing the image surface side, and the above lenses are arranged in order from the object side along the optical axis. The image surface I is arranged on the image side of the fourth lens group G**4**.

[0134] The following table 3 raises values of data of the optical system according to the third example.

TABLE 3

[General Data]

f = 36.050	FNO = 1.442
ω = 31.808	Y = 20.358
TL = 80.563	Bf = 12.113
fA = 175.868	fR = −103.535
fF1 = 100.040	fF2 = 50.621
fSa = 175.868	fSr = 38.887
fe = −55.498	

TABLE 3-continued

[Lens Data]

Surface Number	R	D	nd	νd
1	∞	1.000	1.48749	70.32
2	27.539	0.516		
3	31.701	6.527	1.83481	42.73
4	−58.413	0.900	1.72825	28.38
5	142.453	2.116		
6	∞	(D6)		(Aperture Stop S)
7	−23.996	0.900	1.59270	35.27
8	27.203	5.321	1.83481	42.73
9	403.040	0.124		
10	75.848	5.128	1.83481	42.73
11	−58.068	0.100	1.56093	36.64
12*	−54.564	(D12)		
13	1598.814	5.843	1.75500	52.34
14	−40.976	0.100	1.56093	36.64
15*	−38.468	(D15)		
16	−119.723	1.000	1.72825	28.38
17	34.445	12.585	1.90265	35.73
18	−36.878	0.100		
19	−43.561	2.607	1.84666	23.80
20	−236.442	4.820		
21	−32.894	1.300	1.59270	35.27
22	∞	Bf		

[Aspherical Surface Data]

12th Surface

κ = 1.0000, A4 = 1.47674E−05, A6 = −1.08656E−08,
A8 = 8.95106E−12, A10 = −3.68687E−15

15th Surface

κ = 1.0000, A4 = 4.77686E−06, A6 = 1.19495E−08,
A8 = 1.37062E−11, A10 = 3.29111E−14

[Variable Distance Data]

	Upon focusing on infinity f = 36.050	Upon focusing on a short-distance object β = −0.03333
D0	∞	1081.803
D6	12.622	10.849
D12	3.342	4.228
D15	1.500	2.387
Bf	12.113	12.113

[Lens Group Data]

Group	First surface	Focal length
G1	1	175.868
G2	7	100.040
G3	13	50.621
G4	16	−103.535

[0135] FIG. **6**(A) illustrates diagrams of various aberrations of the optical system according to the third example upon focusing on infinity. FIG. **6**(B) illustrates diagrams of various aberrations of the optical system according to the third example upon focusing on a short distance object. Based on each of the diagrams of various aberrations, it may be understood that not only upon focusing on infinity but also focusing on a short distance object, the optical system according to the third example properly corrects various aberrations and exhibits excellent image formation performance.

Fourth Example

[0136] The fourth example will be described by using FIG. **7**, FIG. **8**, and the table 4. FIG. **7** is a diagram illustrating a lens configuration of the optical system according to the fourth example. The optical system OL(**4**) according to the fourth example is formed from a first lens group G**1** having positive refractive power, a second lens group G**2** having positive refractive power, a third lens group G**3** having positive refractive power, and a fourth lens group G**4** having negative refractive power, which are arranged in order from the object side along the optical axis. In focusing from an object at infinity to an object at a short distance, the second lens group G**2** and the third lens group G**3** move to the object side along the optical axis in different loci (different in movement amounts), and intervals between the neighboring lens groups are thereby changed. Note that in focusing, positions of the first lens group G**1** and the fourth lens group G**4** are fixed with respect to the image surface I.

[0137] The aperture stop S is disposed between the first lens group G**1** and the second lens group G**2**. In focusing, the position of the aperture stop S is fixed with respect to the image surface front group GA, the second lens group G**2** and the third lens group G**3** constitute the intermediate group GM, and the fourth lens group G**4** constitutes the rear group GR. Further, the second lens group G**2** corresponds to the first focusing lens group GF**1**, and the third lens group G**3** corresponds to the second focusing lens group GF**2**.

[0138] The first lens group G**1** is formed from a negative meniscus lens L**11** having a convex surface facing the object side, a negative meniscus lens L**12** having a convex surface facing the object side, a cemented positive lens in which a biconvex positive lens L**13** and a biconcave negative lens L**14** are joined together, a cemented negative lens in which a biconcave negative lens L**15** and a biconvex positive lens L**16** are joined together, a biconvex positive lens L**17**, a biconvex positive lens L**18**, and a cemented negative lens in which a biconcave negative lens L**19** and a biconvex positive lens L**110** are joined together, and the above lenses are arranged in order from the object side along the optical axis. A lens surface of the negative meniscus lens L**12** on the image surface side is an aspherical surface.

[0139] The second lens group G**2** is formed from a biconcave negative lens L**21** and a biconvex positive lens L**22**, and the above lenses are arranged in order from the object side along the optical axis.

[0140] The third lens group G**3** is formed from a positive meniscus lens L**31** having a convex surface facing the object side and a positive meniscus lens L**32** having a convex surface facing the object side, and the above lenses are arranged in order from the object side along the optical axis. A lens surface of the positive meniscus lens L**31** on the image surface side is an aspherical surface. A lens surface of the positive meniscus lens L**32** on the image surface side is an aspherical surface.

[0141] The fourth lens group G**4** is formed from a positive meniscus lens L**41** having a concave surface facing the object side and a biconcave negative lens L**42**, and the above lenses are arranged in order from the object side along the optical axis. The image surface I is arranged on the image side of the fourth lens group G**4**.

[0142] The following table 4 raises values of data of the optical system according to the fourth example.

TABLE 4

[General Data]

f = 34.301	FNO = 1.230
ω = 32.681	Y = 21.600
TL = 145.455	Bf = 11.456
fA = 60.284	fR = −155.922
fF1 = 493.944	fF2 = 77.173
fSa = 60.284	fSr = 87.232
fe = −52.564	

[Lens Data]

Surface Number	R	D	nd	νd
1	96.047	2.000	1.48749	70.31
2	28.087	9.219		
3	66.416	1.800	1.58887	61.13
4*	42.041	2.388		
5	47.837	8.233	2.00100	29.12
6	−645.006	1.500	1.49782	82.57
7	35.910	11.438		
8	−33.782	1.500	1.85451	25.15
9	80.983	5.585	1.56732	42.58
10	−217.995	0.200		
11	237.343	8.059	2.00069	25.46
12	−51.294	0.200		
13	44.432	10.369	1.59349	67.00
14	−144.859	2.518		
15	−99.402	1.500	1.69895	30.13
16	27.200	14.331	1.59319	67.90
17	−86.856	2.000		
18	∞	(D18)		(Aperture Stop S)
19	−38.048	1.300	1.68376	37.64
20	178.836	0.200		
21	41.104	9.000	1.59349	67.00
22	−68.514	(D22)		
23	36.893	6.200	1.85108	40.12
24*	75.937	4.486		
25	157.349	2.500	1.77387	47.25
26*	161.771	(D26)		
27	−597.200	3.598	1.94595	17.98
28	−68.766	1.916		
29	−40.274	1.500	1.73037	32.23
30	834.207	Bf		

[Aspherical Surface Data]

4th Surface

κ = 1.0000, A4 = −1.39004E−06, A6 = −9.76153E−10,
A8 = −1.35116E−12, A10 = −7.50960E−16

24th Surface

κ = 1.0000, A4 = −4.67477E−06, A6 = −5.48120E−09,
A8 = 3.46635E−11, A10 = −1.11525E−14

26th Surface

κ = 1.0000, A4 = 2.09207E−05, A6 = 2.10855E−08,
A8 = −1. 68530E−11, A10 = −2.78769E−14

[Variable Distance Data]

	Upon focusing on infinity f = 34.301	Upon focusing on a short-distance B = −0.03333
D0	∞	993.600
D18	13.152	11.783
D22	2.047	2.000
D26	5.262	6.678
Bf	11.456	11.456

TABLE 4-continued

[Lens Group Data]

Group	First surface	Focal length
G1	1	60.284
G2	19	493.944
G3	23	77.173
G4	27	−155.922

[0143] FIG. **8**(A) illustrates diagrams of various aberrations of the optical system according to the fourth example upon focusing on infinity. FIG. **8**(B) illustrates diagrams of various aberrations of the optical system according to the fourth example upon focusing on a short distance object. Based on each of the diagrams of various aberrations, it may be understood that not only upon focusing on infinity but also focusing on a short distance object, the optical system according to the fourth example properly corrects various aberrations and exhibits excellent image formation performance.

Fifth Example

[0144] The fifth example will be described by using FIG. **9**, FIG. **10**, and the table 5. FIG. **9** is a diagram illustrating a lens configuration of the optical system according to the fifth example. The optical system OL(**5**) according to the fifth example is formed from a first lens group G**1** having positive refractive power, a second lens group G**2** having positive refractive power, a third lens group G**3** having positive refractive power, and a fourth lens group G**4** having negative refractive power, which are arranged in order from the object side along the optical axis. In focusing from an object at infinity to an object at a short distance, the second lens group G**2** and the third lens group G**3** move to the object side along the optical axis in different loci (different in movement amounts), and intervals between the neighboring lens groups are thereby changed. Note that in focusing, positions of the first lens group G**1** and the fourth lens group G**4** are fixed with respect to the image surface I.

[0145] The aperture stop S is disposed between the first lens group G**1** and the second lens group G**2**. In focusing, the position of the aperture stop S is fixed with respect to the image surface I. In the present example, the first lens group G**1** constitutes the front group GA, the second lens group G**2** and the third lens group G**3** constitute the intermediate group GM, and the fourth lens group G**4** constitutes the rear group GR. Further, the second lens group G**2** corresponds to the first focusing lens group GF**1**, and the third lens group G**3** corresponds to the second focusing lens group GF**2**.

[0146] The first lens group G**1** is formed from a negative meniscus lens L**11** having a convex surface facing the object side, a negative meniscus lens L**12** having a convex surface facing the object side, a cemented positive lens in which a biconvex positive lens L**13** and a biconcave negative lens L**14** are joined together, a cemented negative lens in which a biconcave negative lens L**15** and a biconvex positive lens L**16** are joined together, a biconvex positive lens L**17**, a biconvex positive lens L**18**, and a cemented negative lens in which a biconcave negative lens L**19** and a biconvex positive lens L**110** are joined together, and the above lenses are arranged in order from the object side along the optical axis.

A lens surface of the negative meniscus lens L**12** on the image surface side is an aspherical surface.

[0147] The second lens group G**2** is formed from a biconcave negative lens L**21** and a biconvex positive lens L**22**, and the above lenses are arranged in order from the object side along the optical axis.

[0148] The third lens group G**3** is formed from a cemented positive lens, in which a biconvex positive lens L**31** and a biconcave negative lens L**32** are joined together, and a negative meniscus lens L**33** having a concave surface facing the object side, and the above lenses are arranged in order from the object side along the optical axis. Both lens surfaces of the negative meniscus lens L**33** are aspherical surfaces.

[0149] The fourth lens group G**4** is formed from a positive meniscus lens L**41** having a concave surface facing the object side and a biconcave negative lens L**42**, and the above lenses are arranged in order from the object side along the optical axis. The image surface I is arranged on the image side of the fourth lens group G**4**.

[0150] The following table 5 raises values of data of the optical system according to the fifth example.

TABLE 5

[General Data]

f = 34.300	FNO = 1.230
ω = 32.676	Y = 21.600
TL = 145.455	Bf = 11.455
fA = 65.214	fR = −165.983
fF1 = 629.134	fF2 = 70.033
fSa = 65.214	fSr = 80.285
fe = −56.319	

[Lens Data]

Surface Number	R	D	nd	νd
1	72.093	2.000	1.48749	70.31
2	27.081	11.466		
3	105.428	1.800	1.51680	64.13
4*	49.653	1.202		
5	47.334	7.850	2.00100	29.12
6	−2063.273	1.500	1.49782	82.57
7	34.755	11.769		
8	−32.107	1.500	1.85451	25.15
9	82.520	5.950	1.67003	47.14
10	−198.954	0.200		
11	391.739	7.906	2.00069	25.46
12	−48.789	0.200		
13	41.194	11.022	1.59349	67.00
14	−135.101	1.669		
15	−112.838	1.500	1.73037	32.23
16	27.200	13.277	1.59319	67.90
17	−122.895	2.000		
18	∞	(D18)		(Aperture Stop S)
19	−42.056	1.300	1.68376	37.64
20	240.838	0.200		
21	38.726	7.500	1.59319	67.90
22	−118.915	(D22)		
23	42.490	7.198	1.83481	42.73
24	−124.265	1.500	1.68376	37.64
25	96.988	5.998		
26*	−257.390	2.500	1.77387	47.25
27*	−264.366	(D27)		
28	−531.885	3.492	1.94595	17.98
29	−71.866	1.741		
30	−43.260	1.500	1.73037	32.23
31	848.999	Bf		

TABLE 5-continued

[Aspherical Surface Data]

4th Surface

κ = 1.0000, A4 = −1.34774E−06, A6 = −9.46928E−10,
A8 = −1.46439E−12, A10 = −3.40961E−16

26th Surface

κ = 1.0000, A4 = −7.46350E−06, A6 = 6.20342E−08,
A8 = −1.63956E−10, A10 = 4.03734E−14

27th Surface

κ = 1.0000, A4 = 9.35182E−06, A6 = 7.30804E−08,
A8 = −1.33669E−10, A10 = 1.93285E−14

[Variable Distance Data]

	Upon focusing on infinity f=34.300	Upon focusing on a short-distance β = −0.03333
D0	∞	994.412
D18	12.611	11.246
D22	2.244	2.268
D27	3.404	4.744
Bf	11.455	11.455

[Lens Group Data]

Group	First surface	Focal length
G1	1	65.214
G2	19	629.134
G3	23	70.033
G4	27	−165.983

[0151] FIG. **10**(A) illustrates diagrams of various aberrations of the optical system according to the fifth example upon focusing on infinity. FIG. **10**(B) illustrates diagrams of various aberrations of the optical system according to the fifth example upon focusing on a short distance object. Based on each of the diagrams of various aberrations, it may be understood that not only upon focusing on infinity but also focusing on a short distance object, the optical system according to the fifth example properly corrects various aberrations and exhibits excellent image formation performance.

Sixth Example

[0152] The sixth example will be described by using FIG. **11**, FIG. **12**, and the table 6. FIG. **11** is a diagram illustrating a lens configuration of the optical system according to the sixth example. The optical system OL(**6**) according to the sixth example is formed from a first lens group G**1** having positive refractive power, a second lens group G**2** having positive refractive power, a third lens group G**3** having positive refractive power, and a fourth lens group G**4** having negative refractive power, which are arranged in order from the object side along the optical axis. In focusing from an object at infinity to an object at a short distance, the second lens group G**2** and the third lens group G**3** move to the object side along the optical axis in different loci (different in movement amounts), and intervals between the neighboring lens groups are thereby changed. Note that in focusing, positions of the first lens group G**1** and the fourth lens group G**4** are fixed with respect to the image surface I.

[0153] The aperture stop S is disposed between the first lens group G**1** and the second lens group G**2**. In focusing, the position of the aperture stop S is fixed with respect to the image surface I. In the present example, the first lens group G1 constitutes the front group GA, the second lens group G2 and the third lens group G3 constitute the intermediate group GM, and the fourth lens group G4 constitutes the rear group GR. Further, the second lens group G2 corresponds to the first focusing lens group GF1, and the third lens group G3 corresponds to the second focusing lens group GF2.

[0154] The first lens group G1 is formed from a negative meniscus lens L11 having a convex surface facing the object side, a cemented positive lens in which a biconvex positive lens L12 and a biconcave negative lens L13 are joined together, a cemented negative lens in which a biconcave negative lens L14 and a positive meniscus lens L15 having a convex surface facing the object side are joined together, a cemented positive lens in which a biconvex positive lens L16 and a negative meniscus lens L17 having a concave surface facing the object side are joined together, a positive meniscus lens L18 having a convex surface facing the object side, and a cemented negative lens in which a biconvex positive lens L19 and a biconcave negative lens L110 are joined together, and the above lenses are arranged in order from the object side along the optical axis.

[0155] The second lens group G2 is formed from a negative meniscus lens L21 having a concave surface facing the object side, a biconvex positive lens L22, and a negative meniscus lens L23 having a concave surface facing the object side, and the above lenses are arranged in order from the object side along the optical axis. Both lens surfaces of the negative meniscus lens L23 are aspherical surfaces.

[0156] The third lens group G3 is formed from a positive meniscus lens L31 having a concave surface facing the object side and a negative meniscus lens L32 having a concave surface facing the object side, and the above lenses are arranged in order from the object side along the optical axis. A lens surface of the positive meniscus lens L31 on the image surface side is an aspherical surface. A lens surface of the negative meniscus lens L32 on the object side is an aspherical surface.

[0157] The fourth lens group G4 is formed from a cemented negative lens in which a positive meniscus lens L41 having a concave surface facing the object side and a biconcave negative lens L42 are joined together, and the above lenses are arranged in order from the object side along the optical axis. The image surface I is arranged on the image side of the fourth lens group G4.

[0158] The following table 6 raises values of data of the optical system according to the sixth example.

TABLE 6

[General Data]

f = 34.300	FNO = 1.228
ω = 32.697	Y = 21.600
TL = 155.455	Bf = 11.455
fA = 75.723	fR = −60.553
fF1 = 69.782	fF2 = 58.312
fSa = 75.723	fSr = 61.522
fe = −26.934	

TABLE 6-continued

[Lens Data]

Surface Number	R	D	nd	νd
1	81.239	2.000	1.59349	67.00
2	29.403	11.650		
3	97.417	9.313	1.90265	35.77
4	−66.592	1.500	1.51742	52.20
5	37.688	11.679		
6	−36.576	3.997	1.73037	32.23
7	57.862	5.275	1.94595	17.98
8	437.731	0.200		
9	137.189	14.813	1.84850	43.79
10	−31.982	1.500	1.85451	25.15
11	−58.341	0.200		
12	50.708	7.542	1.59319	67.90
13	173.475	0.200		
14	50.175	13.955	1.59319	67.90
15	−45.041	1.500	1.64769	33.73
16	49.712	5.575		
17	∞	(D17)		(Aperture Stop S)
18	−42.349	1.500	1.61266	44.46
19	−303.712	0.200		
20	30.793	9.330	1.59349	67.00
21	−73.903	0.200		
22*	−74.759	2.000	1.88202	37.23
23*	−78.949	(D23)		
24	−117.169	3.976	1.77387	47.25
25*	−26.746	0.564		
26*	−30.019	3.648	1.58887	61.13
27	−41.705	(D27)		
28	−65.973	6.366	1.94595	17.98
29	−27.107	1.500	1.77047	29.74
30	90.644	Bf		

[Aspherical Surface Data]

22nd Surface

κ = 1.0000, A4 = 1.73688E−05, A6 = 9.00046E−08,
A8 = −3.66508E−10, A10 = 3.45942E−13

23rd Surface

κ = 1.0000, A4 = 2.84915E−05, A6 = 9.29029E−08,
A8 = −3.03655E−10, A10 = 1.96904E−13

25th Surface

κ = 1.0000, A4 = 5.79685E−05, A6 = −1.66905E−07,
A8 = 4.04878E−10, A10 = −3.50430E−13

26th Surface

κ = 1.0000, A4 = 6.83994E−05, A6 = −2.43826E−07,
A8 = 5.82093E−10, A10 = −5.75702E−13

[Variable Distance Data]

	Upon focusing on infinity f = 34.300	Upon focusing on a short-distance object β = −0.03333
D0	∞	988.825
D17	13.387	12.265
D23	8.429	8.961
D27	2.000	2.591
Bf	11.455	11.455

[Lens Group Data]

Group	First surface	Focal length
G1	1	75.723
G2	18	69.782

TABLE 6-continued

G3	24	58.312
G4	28	−60.553

[0159] FIG. **12**(A) illustrates diagrams of various aberrations of the optical system according to the sixth example upon focusing on infinity. FIG. **12**(B) illustrates diagrams of various aberrations of the optical system according to the sixth example upon focusing on a short distance object. Based on each of the diagrams of various aberrations, it may be understood that not only upon focusing on infinity but also focusing on a short distance object, the optical system according to the sixth example properly corrects various aberrations and exhibits excellent image formation performance.

Seventh Example

[0160] The seventh example will be described by using FIG. **13**, FIG. **14**, and the table 7. FIG. **13** is a diagram illustrating a lens configuration of the optical system according to the seventh example. The optical system OL(**7**) according to the seventh example is formed from a first lens group G**1** having positive refractive power, a second lens group G**2** having positive refractive power, a third lens group G**3** having positive refractive power, and a fourth lens group G**4** having negative refractive power, which are arranged in order from the object side along the optical axis. In focusing from an object at infinity to an object at a short distance, the second lens group G**2** and the third lens group G**3** move to the object side along the optical axis in different loci (different in movement amounts), and intervals between the neighboring lens groups are thereby changed. Note that in focusing, positions of the first lens group G**1** and the fourth lens group G**4** are fixed with respect to the image surface I.

[0161] The aperture stop S is disposed between the first lens group G**1** and the second lens group G**2**. In focusing, the position of the aperture stop S is fixed with respect to the image surface I. In the present example, the first lens group G**1** constitutes the front group GA, the second lens group G**2** and the third lens group G**3** constitute the intermediate group GM, and the fourth lens group G**4** constitutes the rear group GR. Further, the second lens group G**2** corresponds to the first focusing lens group GF**1**, and the third lens group G**3** corresponds to the second focusing lens group GF**2**.

[0162] The first lens group G**1** is formed from a negative meniscus lens L**11** having a convex surface facing the object side, a cemented positive lens in which a negative meniscus lens L**12** having a convex surface facing the object side and a positive meniscus lens L**13** having a convex surface facing the object side are joined together, a cemented negative lens in which a biconvex positive lens L**14** and a biconcave negative lens L**15** are joined together, a biconcave negative lens L**16**, a biconvex positive lens L**17**, a biconvex positive lens L**18**, and a cemented negative lens in which a biconcave negative lens L**19** and a biconvex positive lens L**110** are joined together, and the above lenses are arranged in order from the object side along the optical axis.

[0163] The second lens group G**2** is formed from a negative meniscus lens L**21** having a concave surface facing the object side and a biconvex positive lens L**22**, and the above lenses are arranged in order from the object side along the optical axis.

[0164] The third lens group G**3** is formed from a biconcave negative lens L**31** and a biconvex positive lens L**32**, and the above lenses are arranged in order from the object side along the optical axis. A lens surface of the negative lens L**31** on the image surface side is an aspherical surface. Both lens surfaces of the positive lens L**32** are aspherical surfaces.

[0165] The fourth lens group G**4** is formed from a biconvex positive lens L**41** and a biconcave negative lens L**42**, and the above lenses are arranged in order from the object side along the optical axis. The image surface I is arranged on the image side of the fourth lens group G**4**.

[0166] The following table 7 raises values of data of the optical system according to the seventh example.

TABLE 7

[General Data]

f = 34.300	FNO = 1.230
ω = 32.684	Y = 21.600
TL = 157.455	Bf = 11.455
fA = 70.486	fR = −192.806
fF1 = 74.747	fF2 = 247.083
fSa = 70.486	fSr = 72.472
fe = −39.734	

[Lens Data]

Surface Number	R	D	nd	νd
1	66.961	2.000	1.81600	46.59
2	32.457	11.809		
3	128.665	1.800	1.59319	67.90
4	40.741	9.802	2.00069	25.46
5	215.641	0.200		
6	110.947	7.041	1.81600	46.59
7	−112.594	1.500	1.51680	64.14
8	28.007	12.084		
9	−40.962	8.018	1.73037	32.23
10	857.978	0.200		
11	70.201	9.539	1.81600	46.59
12	−61.720	0.200		
13	54.810	7.279	1.59349	67.00
14	−212.179	2.494		
15	−66.201	1.500	1.73037	32.23
16	27.501	13.807	1.59319	67.90
17	−57.491	2.000		
18	∞	(D18)		(Aperture Stop S)
19	−41.015	1.300	1.56732	42.58
20	−310.485	0.200		
21	38.747	7.973	1.77250	49.62
22	−146.553	(D22)		
23	−42.724	1.500	1.62004	36.40
24*	60.145	0.200		
25*	58.069	3.682	1.85108	40.12
26*	−62.761	(D26)		
27	154.307	8.500	1.94595	17.98
28	−76.392	1.740		
29	−47.089	3.595	1.75520	27.57
30	85.433	Bf		

[Aspherical Surface Data]

24th Surface

κ = 1.0000, A4 = −1.09574E−04, A6 = 3.34832E−07,
A8 = −5.81576E−10, A10 = 4.32381E−13

25th Surface

κ = 1.0000, A4 = −7.33927E−05, A6 = 3.59893E−07,
A8 = −6.97315E−10, A10 = 4.91900E−13

TABLE 7-continued

26th Surface
κ = 1.0000, A4 = 1.43166E−05, A6 = 1.17989E−07, A8 = −2.22684E−10, A10 = 1.31507E−13

[Variable Distance Data]

	Upon focusing on infinity f = 34.300	Upon focusing on a short-distance β = −0.03333
D0	∞	987.480
D18	16.159	14.666
D22	7.879	7.859
D26	2.000	3.512
Bf	11.455	11.455

[Lens Group Data]

Group	First surface	Focal length
G1	1	70.486
G2	19	74.747
G3	23	247.083
G4	27	−192.806

[0167] FIG. **14**(A) illustrates diagrams of various aberrations of the optical system according to the seventh example upon focusing on infinity. FIG. **14**(B) illustrates diagrams of various aberrations of the optical system according to the seventh example upon focusing on a short distance object. Based on each of the diagrams of various aberrations, it may be understood that not only upon focusing on infinity but also focusing on a short distance object, the optical system according to the seventh example properly corrects various aberrations and exhibits excellent image formation performance.

Eighth Example

[0168] The eighth example will be described by using FIG. **15**, FIG. **16**, and the table 8. FIG. **15** is a diagram illustrating a lens configuration of the optical system according to the eighth example. The optical system OL(**8**) according to the eighth example is formed from a first lens group G**1** having positive refractive power, a second lens group G**2** having positive refractive power, a third lens group G**3** having positive refractive power, and a fourth lens group G**4** having negative refractive power, which are arranged in order from the object side along the optical axis. In focusing from an object at infinity to an object at a short distance, the second lens group G**2** and the third lens group G**3** move to the object side along the optical axis in different loci (different in movement amounts), and intervals between the neighboring lens groups are thereby changed. Note that in focusing, positions of the first lens group G**1** and the fourth lens group G**4** are fixed with respect to the image surface I.

[0169] The aperture stop S is disposed between the first lens group G**1** and the second lens group G**2**. In focusing, a position of the aperture stop S is fixed with respect to the image surface I. In the present example, the first lens group G**1** constitutes the front group GA, the second lens group G**2** and the third lens group G**3** constitute the intermediate group GM, and the fourth lens group G**4** constitutes the rear group GR. Further, the second lens group G**2** corresponds to the first focusing lens group GF**1**, and the third lens group G**3** corresponds to the second focusing lens group GF**2**.

[0170] The first lens group G**1** is formed from a negative meniscus lens L**11** having a convex surface facing the object side, a negative meniscus lens L**12** having a convex surface facing the object side, a cemented positive lens in which a positive meniscus lens L**13** having a convex surface facing the object side and a negative meniscus lens L**14** having a convex surface facing the object side are joined together, a cemented negative lens in which a biconcave negative lens L**15** and a biconvex positive lens L**16** are joined together, a biconvex positive lens L**17**, a biconvex positive lens L**18**, and a cemented negative lens in which a biconcave negative lens L**19** and a biconvex positive lens L**110** are joined together, and the above lenses are arranged in order from the object side along the optical axis. A lens surface of the negative meniscus lens L**12** on the image surface side is an aspherical surface.

[0171] The second lens group G**2** is formed from a biconcave negative lens L**21** and a biconvex positive lens L**22**, and the above lenses are arranged in order from the object side along the optical axis.

[0172] The third lens group G**3** is formed from a positive meniscus lens L**31** having a convex surface facing the object side and a biconvex positive lens L**32**, and the above lenses are arranged in order from the object side along the optical axis. A lens surface of the positive meniscus lens L**31** on the image surface side is an aspherical surface. A lens surface of the positive lens L**32** on the image surface side is an aspherical surface.

[0173] The fourth lens group G**4** is formed from a positive meniscus lens L**41** having a concave surface facing the object side and a negative meniscus lens L**42** having a concave surface facing the object side, and the above lenses are arranged in order from the object side along the optical axis. The image surface I is arranged on the image side of the fourth lens group G**4**.

[0174] The following table 8 raises values of data of the optical system according to the eighth example.

TABLE 8

[General Data]

f = 35.000	FNO = 1.230
ω = 31.746	Y = 21.600
TL = 145.455	Bf = 10.955
fA = 55.625	fR = −115.422
fF1 = 489.379	fF2 = 77.454
fSa = 55.625	fSr = 106.986
fe = −55.441	

[Lens Data]

Surface Number	R	D	nd	νd
1	67.860	2.000	1.48749	70.31
2	28.552	8.759		
3	56.466	1.800	1.58887	61.13
4*	37.716	3.790		
5	51.569	7.504	2.00100	29.12
6	12706.656	1.500	1.49782	82.57
7	39.896	11.204		
8	−34.883	1.500	1.85451	25.15
9	63.438	8.797	1.56732	42.58
10	−166.403	0.200		
11	208.847	8.476	2.00069	25.46
12	−55.223	0.200		
13	42.842	9.992	1.59349	67.00
14	−402.195	2.085		

TABLE 8-continued

15	−164.696	1.500	1.69895	30.13
16	27.200	14.211	1.59319	67.90
17	−118.275	2.983		
18	∞	(D18)		(Aperture Stop S)
19	−41.627	1.300	1.68376	37.64
20	117.749	0.200		
21	37.122	8.000	1.59349	67.00
22	−76.861	(D22)		
23	32.715	5.200	1.85108	40.12
24*	46.365	4.147		
25	212.737	2.500	1.77387	47.25
26*	−1000.777	(D26)		
27	−811.142	3.025	1.94595	17.98
28	−93.510	2.770		
29	−37.711	1.500	1.73037	32.23
30	−558.335	Bf		

[Aspherical Surface Data]

4th Surface

κ = 1.0000, A4 = −1.76373E−06, A6 = −1.17943E−09,
A8 = −1.59414E−12, A10 = −1.08316E−15

24th Surface

κ = 1.0000, A4 = −3.14395E−06, A6 = −1.49476E−08,
A8 = −1.54681E−11, A10 = 1.13351E−13

26th Surface

κ = 1.0000, A4 = 1.94012E−05, A6 = 2.29617E−08,
A8 = 1.02524E−10, A10 = −2.34228E−13

[Variable Distance Data]

	Upon focusing on infinity f = 35.000	Upon focusing on a short-distance β = −0.03333
D0	∞	1010.855
D18	12.903	11.498
D22	2.081	1.999
D26	4.374	5.861
Bf	10.955	10.955

[Lens Group Data]

Group	First surface	Focal length
G1	1	55.625
G2	19	489.379
G3	23	77.454
G4	27	−115.422

[0175] FIG. **16**(A) illustrates diagrams of various aberrations of the optical system according to the eighth example upon focusing on infinity. FIG. **16**(B) illustrates diagrams of various aberrations of the optical system according to the eighth example upon focusing on a short distance object. Based on each of the diagrams of various aberrations, it may be understood that not only upon focusing on infinity but also focusing on a short distance object, the optical system according to the eighth example properly corrects various aberrations and exhibits excellent image formation performance.

[0176] Next, a table of [conditional expression corresponding values] will be illustrated in the following. This table indicates, in a summarized manner, values corresponding to the conditional expressions (1) to (11) for all of the examples (first to eighth examples).

$$0.01 < fF2/fF1 < 10.00 \quad \text{Conditional Expression (1)}$$

$$0.50 < Y/Bf < 5.00 \quad \text{Conditional Expression (2)}$$

$$0.05 < fSr/fSa < 4.00 \quad \text{Conditional Expression (3)}$$

$$0.05 < fF2/fA < 8.00 \quad \text{Conditional Expression (4)}$$

$$0.10 < (-fR)/fF2 < 8.00 \quad \text{Conditional Expression (5)}$$

$$0.02 < fA/fF1 < 4.00 \quad \text{Conditional Expression (6)}$$

$$0.10 < fF1/(-fR) < 8.00 \quad \text{Conditional Expression (7)}$$

$$0.10 < fA/(-fR) < 4.00 \quad \text{Conditional Expression (8)}$$

$$1.00 < f/Bf < 8.00 \quad \text{Conditional Expression (9)}$$

$$0.50 < TL/f < 7.00 \quad \text{Conditional Expression (10)}$$

$$0.10 < fe/fR < 0.90 \quad \text{Conditional Expression (11)}$$

[Conditional Expression Corresponding Value] (First to Fourth Example)

Conditional Expression	First example	Second example	Third example	Fourth example
(1)	0.285	0.301	0.506	0.156
(2)	1.682	1.768	1.681	1.894
(3)	0.268	0.314	0.221	1.447
(4)	0.277	0.296	0.288	1.280
(5)	1.649	1.519	2.045	2.020
(6)	1.029	1.018	1.758	0.122
(7)	2.126	2.184	0.966	3.168
(8)	2.188	2.224	1.699	0.387
(9)	2.976	4.004	2.976	2.994
(10)	2.321	1.903	2.235	4.241
(11)	0.696	6.125	0.536	0.337

[Conditional Expression Corresponding Value] (Fifth to Eighth Example)

Conditional Expression	Fifth example	Sixth example	Seventh example	Eighth example
(1)	0.111	0.836	3.306	0.158
(2)	1.894	1.894	1.894	1.981
(3)	1.231	0.812	1.028	1.923
(4)	1.074	0.770	3.505	1.392
(5)	2.370	1.038	0.780	1.490
(6)	0.104	1.085	0.943	0.114
(7)	3.790	1.152	0.388	4.240
(8)	0.393	1.251	0.366	0.482
(9)	2.994	2.994	2.994	3.195
(10)	4.241	4.532	4.591	4.156
(11)	0.339	0.445	0.206	0.480

[0177] In each of the above examples, an optical system can be realized which has bright and favorable optical performance while having a small size.

[0178] Each of the above examples represents one specific example of the invention of the present application, and the invention of the present application is not limited to those.

[0179] It is possible to appropriately employ the following contents in a range in which optical performance of the optical systems of the present embodiment is not impaired.

[0180] Four-group configurations are described as the examples of the optical systems of the present embodiment; however, the present application is not limited to those, and optical systems in other group configurations (for example, five groups, six groups, seven groups and so forth) can be formed. Specifically, a configuration is possible in which a lens or a lens group is added to a position, which is closest to the object or closest to the image surface, in each of the optical systems of the present embodiment. A configuration is possible in which a lens or a lens group is added between the first focusing lens group and the second focusing lens group in the intermediate group in each of the optical systems of the present embodiment. Note that a lens group denotes a portion having at least one lens that is separated by an air distance which changes in focusing.

[0181] A lens group or a partial lens group is moved so as to have a component in a vertical direction to the optical axis or is rotationally moved (swung) in an in-plane direction including the optical axis, and a vibration-proof lens group may thereby be provided which corrects an image blur caused due to camera shake.

[0182] A lens surface may be formed with a spherical surface or a flat surface or may be formed with an aspherical surface. A case where the lens surface is a spherical surface or a flat surface is preferable because processing, assembly, and adjustment of a lens become easy and degradation of optical performance due to errors in processing, assembly, and adjustment can be prevented. Further, the above case is preferable because degradation of representation performance is small even in a case where the image surface is deviated.

[0183] In a case where the lens surface is an aspherical surface, the aspherical surface may be any of an aspherical surface by a grinding process, a glass-molding aspherical surface in which glass is formed into an aspherical shape by a mold, and a composite type aspherical surface in which a resin is formed into an aspherical shape on a surface of glass. Further, the lens surface may be formed as a diffraction surface, and a lens may be formed as a gradient-index lens (GRIN lens) or a plastic lens.

[0184] Although it is preferable that an aperture stop be arranged between the first lens group constituting the front group and the second lens group constituting the intermediate group, without providing a member as the aperture stop, its function may be provided by a frame of a lens instead. Further, the first focusing lens group may be arranged to be opposed to the image surface side of the aperture stop.

[0185] In order to reduce a flare or a ghost and to achieve optical performance with high contrast, each lens surface may be coated with an anti-reflection film which has a high transmittance in a wide wavelength range.

EXPLANATION OF NUMERALS AND CHARACTERS

[0186] G1 first lens group

[0187] G2 second lens group

[0188] G3 third lens group

[0189] G4 fourth lens group

[0190] I image surface

[0191] S aperture stop

1. An optical system essentially consisting of:

a front group; an intermediate group; and a rear group, which are arranged in order from an object side along an optical axis, wherein

the intermediate group essentially consists of a first focusing lens group having positive refractive power and a second focusing lens group having positive refractive power, which are arranged in order from the object along the optical axis,

in focusing, the first focusing lens group and the second focusing lens group move along the optical axis differently with different loci from each other, and the front group and the rear group are fixed with respect to an image surface,

the rear group comprises a negative lens which is arranged at a position closest to an image surface in the rear lens group, and

the following conditional expressions are satisfied:

$$0.01 < fF2 / fF1 < 10.00$$

$$0.50 < Y / Bf < 5.00$$

where

fF1: a focal length of the first focusing lens group,

fF2: a focal length of the second focusing lens group,

Y: an image height of the optical system, and

Bf: a back focal length of the optical system.

2. The optical system according to claim 1, wherein

an aperture stop is further provided, and

the following conditional expression is satisfied:

$$0.05 < fSr / fSa < 4.00$$

where fSr: a combined focal length, upon focusing on infinity, of a lens, which is arranged on the image surface side relative to the aperture stop, in the optical system, and

fSa: a combined focal length, upon focusing on infinity, of a lens, which is arranged on the object side relative to the aperture stop, in the optical system.

3. The optical system according to claim 1 or 2, wherein

the following conditional expression is satisfied:

$$0.05 < fF2 / fA < 8.00$$

where fA: a focal length of the front group.

4. The optical system according to any one of claims 1 to 3, wherein

the following conditional expression is satisfied:

$$0.10 < (-fR) / fF2 < 8.00$$

where fR: a focal length of the rear group.

5. The optical system according to any one of claims **1** to **4**, wherein

the following conditional expression is satisfied:

$$0.02 < fA / fF1 < 4.00$$

where fA: a focal length of the front group.

6. The optical system according to any one of claims **1** to **5**, wherein

the following conditional expression is satisfied:

$$0.10 < fF1 / (-fR) < 8.00$$

where fR: a focal length of the rear group.

7. The optical system according to any one of claims **1** to **6**, wherein

the following conditional expression is satisfied:

$$0.10 < fA / (-fR) < 4.00$$

where fR: a focal length of the rear group.

8. The optical system according to any one of claims **1** to **7**, wherein

the following conditional expression is satisfied:

$$1.00 < f / Bf < 8.00$$

where f: a focal length of the optical system.

9. The optical system according to any one of claims **1** to **8**, wherein

the following conditional expression is satisfied:

$$0.50 < TL / f < 7.00$$

where f: a focal length of the optical system, and

TL: an entire length of the optical system.

10. The optical system according to any one of claims **1** to **9**, wherein

the following conditional expression is satisfied:

$$0.10 < fe / fR < 0.90$$

where fe: a focal length of a negative lens which is arranged in a position of the rear group which is closest to the image surface, and

fR: a focal length of the rear group.

11. The optical system according to any one of claims **1** to **10**, further comprising

an aperture stop which is provided between the front group and the intermediate group.

12. The optical system according to any one of claims **1** to **11**, wherein

the front group has positive refractive power.

13. The optical system according to any one of claims **1** to **12**, wherein

the rear group has negative refractive power.

14. An optical apparatus comprising the optical system according to any one of claims **1** to **13**.

15. A method for manufacturing an optical system, which essentially consists of: a front group; an intermediate group; and a rear group, which are arranged in order from an object side along an optical axis, comprising a step for arranging the lens groups in a lens barrel so that;

the intermediate group essentially consists of a first focusing lens group having positive refractive power and a second focusing lens group having positive refractive power, which are arranged in order from the object along the optical axis,

in focusing, the first focusing lens group and the second focusing lens group move along the optical axis differently with different loci from each other, and the front group and the rear group are fixed with respect to an image surface,

the rear group comprises a negative lens which is arranged at a position closest to an image surface in the rear lens group, and

the following conditional expressions are satisfied:

$$0.01 < fF2 / fF1 < 10.00$$

$$0.50 < Y / Bf < 5.00$$

where

fF1: a focal length of the first focusing lens group,

fF2: a focal length of the second focusing lens group,

Y: an image height of the optical system, and

Bf: a back focal length of the optical system.

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