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Inventor(s) SASHIMA; Tomoyuki et al.

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

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.
[00001]$0.01 < fF2 / fF1 < 10.; 0.5 < Y / Bf < 5.$.
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).

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

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

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Background/Summary

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:
[00002]$0.01 < fF2 / fF1 < 10.0$ $0.5 < Y / Bf < 5.00$ [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:
[00003]$0.01 < fF2 / fF1 < 10.0$ $0.5 < Y / Bf < 5.00$ [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.

Description

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).

[00004] $0.01 < fF2 / fF1 < 10. \quad (1) \quad 0.5 < Y / Bf < 5. \quad (2)$

[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).
[00005] $0.05 < fSr / fSa < 4.00$ (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).
[00006] $0.05 < fF2 / fA < 8.00$ (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 GF**2** 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 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 (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).

[00007] $0.1 < -fR / fF2 < 8.$ (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 GF**2**. 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 GF**2** 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).

[00008] $0.02 < fA / fF1 < 4.$ (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 GF**1**. 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 GF**1** 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).

[00009] $0.10 < fF1 / (-fR) < 8.00 \quad (7)$

[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 GF**1** 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 GF**1** 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).

[00010] $0.1 < fA / (-fR) < 4.00 \quad (8)$

[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).

[00011] $1.00 < f / Bf < 8.00 \quad (9)$

[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).

[00012] $0.50 < TL / f < 7.00$ (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).

[00013] $0.1 < fe / -fR < 0.90$ (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 GF**1** having the positive refractive power and the second focusing lens group GF**2** having the positive refractive power are arranged (step ST**2**). Next, a configuration is made such that 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 (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 vd 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.

[00014]

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

[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-US-00001 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 vd 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) 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 Upon focusing on a on infinity short-distance object f = 36.050 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-US-00002 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 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 Upon focusing on infinity on a short-distance f = 48.500 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] First Focal Group surface 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-US-00003 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 [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 Upon focusing on infinity on a short-distance object f = 36.050 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] First Focal Group surface 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-US-00004 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 vd 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 Upon focusing on infinity on a short-distance f = 34.301 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 [Lens Group Data] First Focal Group surface 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-US-00005 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 [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 Upon focusing on infinity on a short-distance f=34.300 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] First Focal Group surface 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 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**.

[0154] 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 biconvex positive lens L**12** and a biconcave negative lens L**13** are joined together, a cemented negative lens in which a biconcave negative lens L**14** and a positive meniscus lens L**15** having a convex surface facing the object side are joined together, a cemented positive lens in which a biconvex positive lens L**16** and a negative meniscus lens L**17** having a concave surface facing the object side are joined together, a positive meniscus lens L**18** having a convex surface facing the object side, and a cemented negative lens in which a biconvex positive lens L**19** and a biconcave negative lens L**110** are joined together, and the above lenses are arranged in order from the object side along the optical axis.

[0155] The second lens group G**2** is formed from a negative meniscus lens L**21** having a concave surface facing the object side, a biconvex positive lens L**22**, and a negative meniscus lens L**23** 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**23** are aspherical surfaces.

[0156] The third lens group G**3** is formed from a positive meniscus lens L**31** having a concave surface facing the object side and a negative meniscus lens L**32** 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 L**31** on the image surface side is an aspherical surface. A lens surface of the negative meniscus lens L**32** on the object side is an aspherical surface.

[0157] The fourth lens group G**4** is formed from a cemented negative lens in which a positive meniscus lens L**41** having a concave surface facing the object side and a biconcave negative lens L**42** 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 G**4**.

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

TABLE-US-00006 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 [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 Upon focusing on infinity on a short-distance object f = 34.300 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] First Focal Group surface length G1 1 75.723 G2 18 69.782 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-US-00007 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 vd 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 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 Upon focusing on infinity on a short-distance f = 34.300 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] First Focal Group surface 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-US-00008 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 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 Upon focusing on infinity on a short-distance f = 35.000 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] First Focal Group surface 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).

[00015] $0.01 < fF2/fF1 < 10. \quad \text{ConditionalExpression}(1)$

$0.5 < Y/Bf < 5.00 \quad \text{ConditionalExpression}(2)$

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

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

$0.1 < (-fR) / fF2 < 8.00$ ConditionalExpression(5)

$0.02 < fA / fF1 < 4.$ ConditionalExpression(6)

$0.1 < fF1 / (-fR) < 8.00$ ConditionalExpression(7)

$0.1 < fA / (-fR) < 4.00$ ConditionalExpression(8)

$1. < f / Bf < 8.00$ ConditionalExpression(9) $0.5 < TL / f < 7.00$ ConditionalExpression(10)

$0.1 < fe / fR < 0.90$ ConditionalExpression(11)

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

TABLE-US-00009

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)

TABLE-US-00010

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] G**1** first lens group [0187] G**2** second lens group [0188] G**3** third lens group [0189] G**4** fourth lens group [0190] I image surface [0191] S aperture stop

Claims

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: $0.01 < fF2 / fF1 < 10.$ $0.5 < Y / Bf < 5.00$ 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: $0.10 < (-fR) / fF2 < 8.$ 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: $0.02 < fA / fF1 < 4.$ 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: $1. < f / Bf < 8.00$ 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: $0.5 < TL / f < 7.00$ 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: $0.01 < fF2 / fF1 < 10$. $0.5 < Y / Bf < 5.00$ 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.