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G02B 15/24 (2006.01)

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JP 2012027262 A **US 20210018721 A1**
US 20180074300 A1 **US 20140152887 A1**

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INT CL **G02B**
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Middlesex, UB11 1AF, United Kingdom

(54) Title of the Invention: **Zoom lens, and image pickup apparatus having the same**
Abstract Title: **A zoom lens and an image pickup apparatus with the zoom lens satisfying predetermined inequalities for focal length ratios and optical axis distance ratios.**

(57) A zoom lens includes multiple lens units with, from an object to an image side, first L1, second L2, third L3 and fourth L4 lens units having negative, positive, negative and positive refractive power respectively. A distance between adjacent lens units changes during zooming from a wide-angle to a telephoto end. The first lens unit includes three or more lenses and is fixed relative to an image plane during zooming. Predetermined inequalities specifying focal length ratios -f1/f2 of the first and second lens units respectively and -f1/f4 for the first and fourth lens units respectively are satisfied. A ratio of the optical axis distance LD1 between outermost lens surfaces of the first lens unit to the optical axis distance TTL from a lens, closest to the object, surface's object side to the image plane, at the wide-angle end is also satisfied.
Inequalities for ratios between an air conversion amount of a distance on the optical axis from a lens surface on the image side of the lens closest to the image plane at the wide-angle end to the image plane or back focus, to the focal length of the first lens unit or the distance TTL may be satisfied.

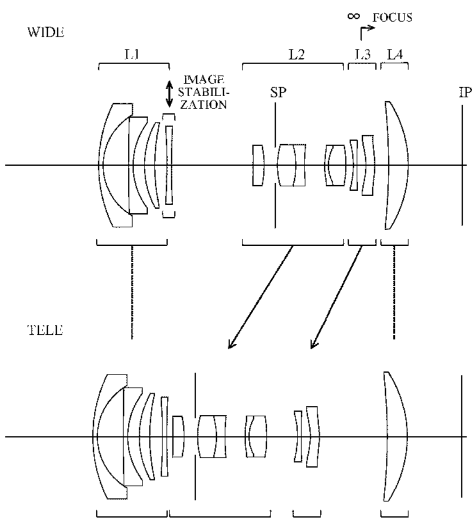


FIG. 1

GB 2625907 A

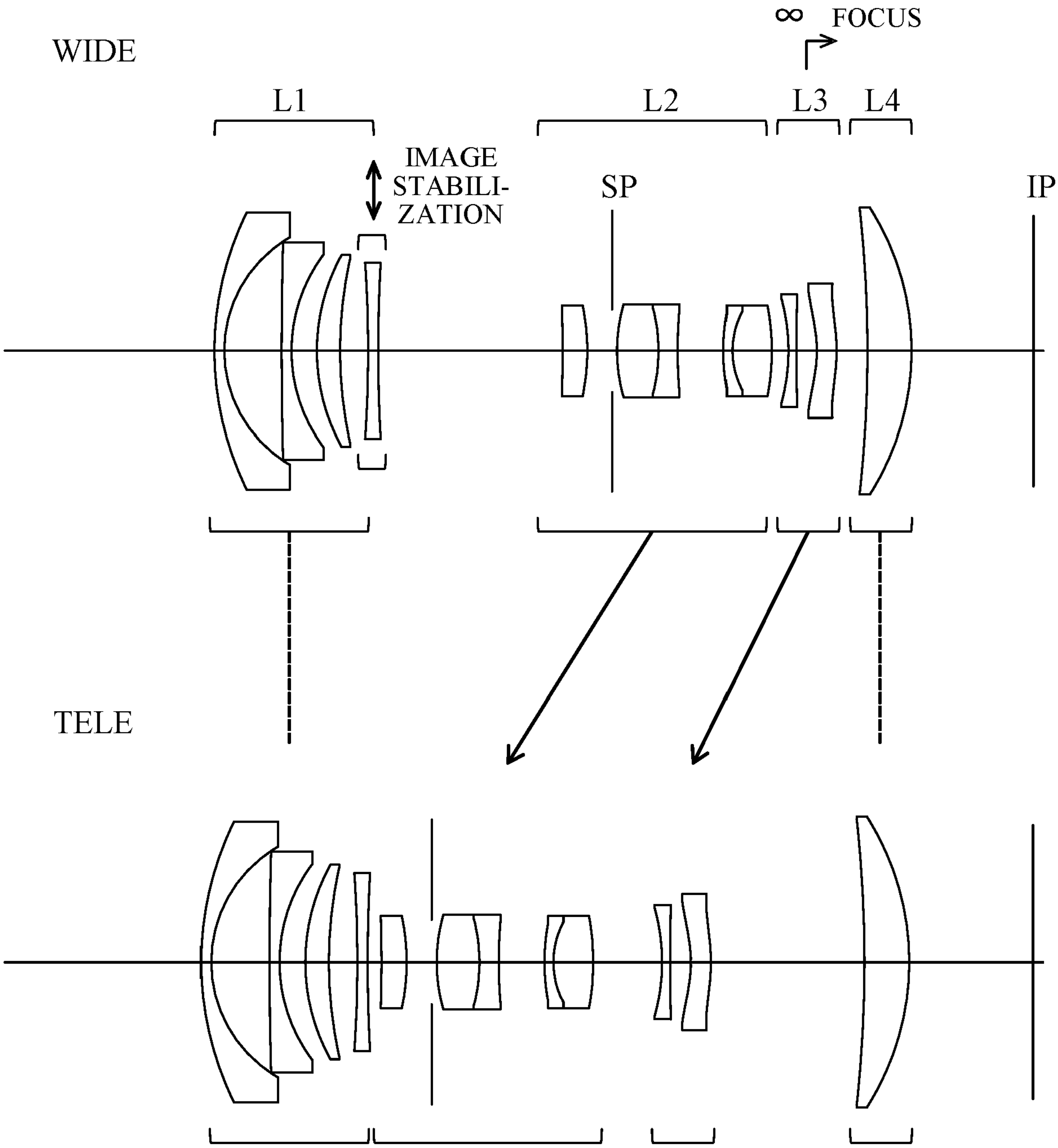
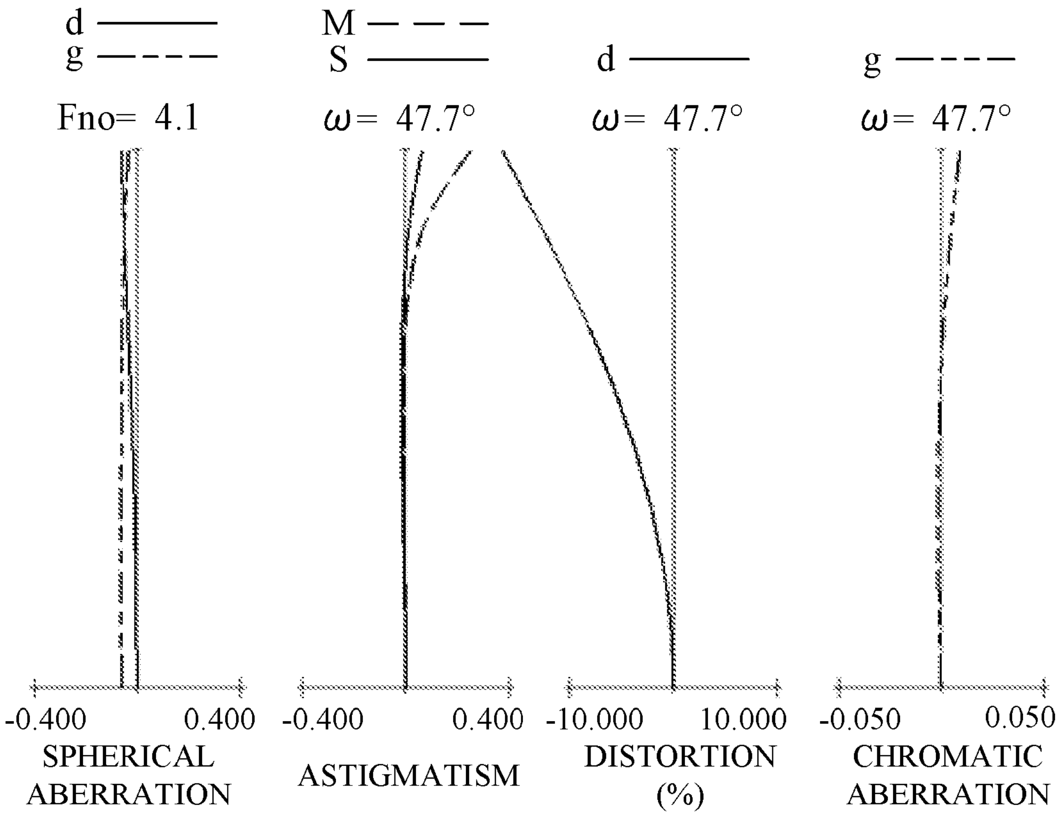


FIG. 1



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SPHERICAL ABERRATION
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ASTIGMATISM
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DISTORTION (%)
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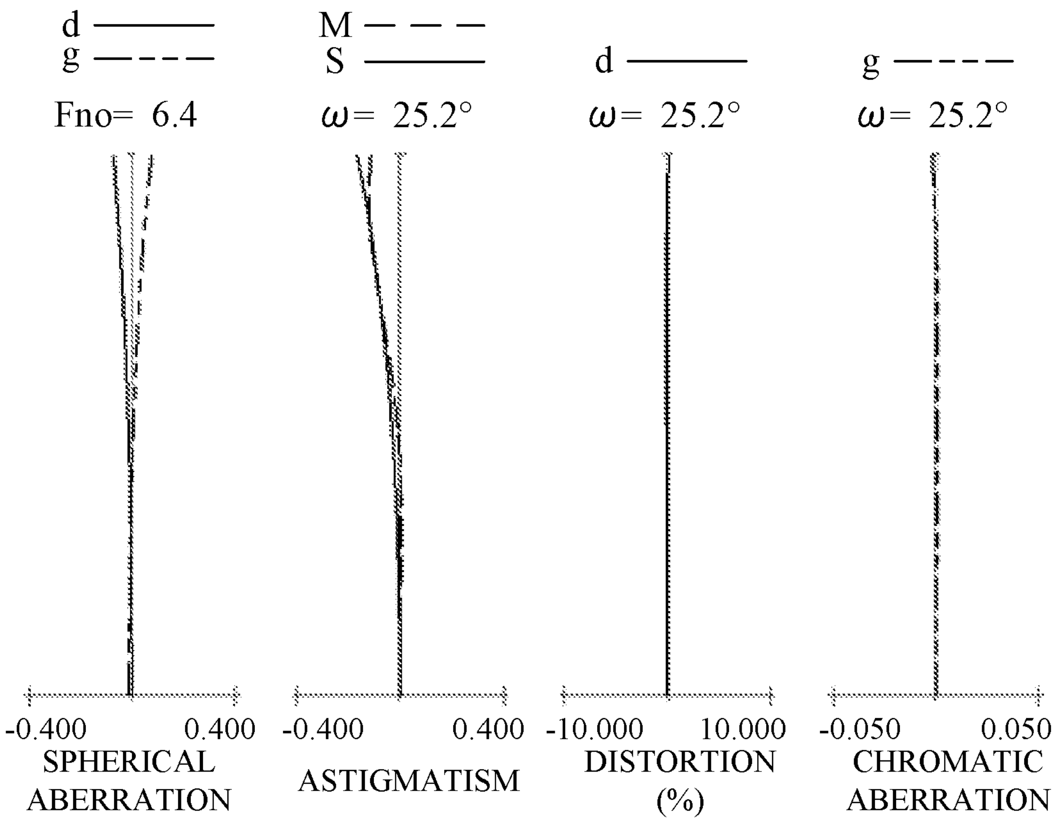
CHROMATIC ABERRATION

FIG. 2A



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ASTIGMATISM
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DISTORTION (%)
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0.050
CHROMATIC ABERRATION

FIG. 2B

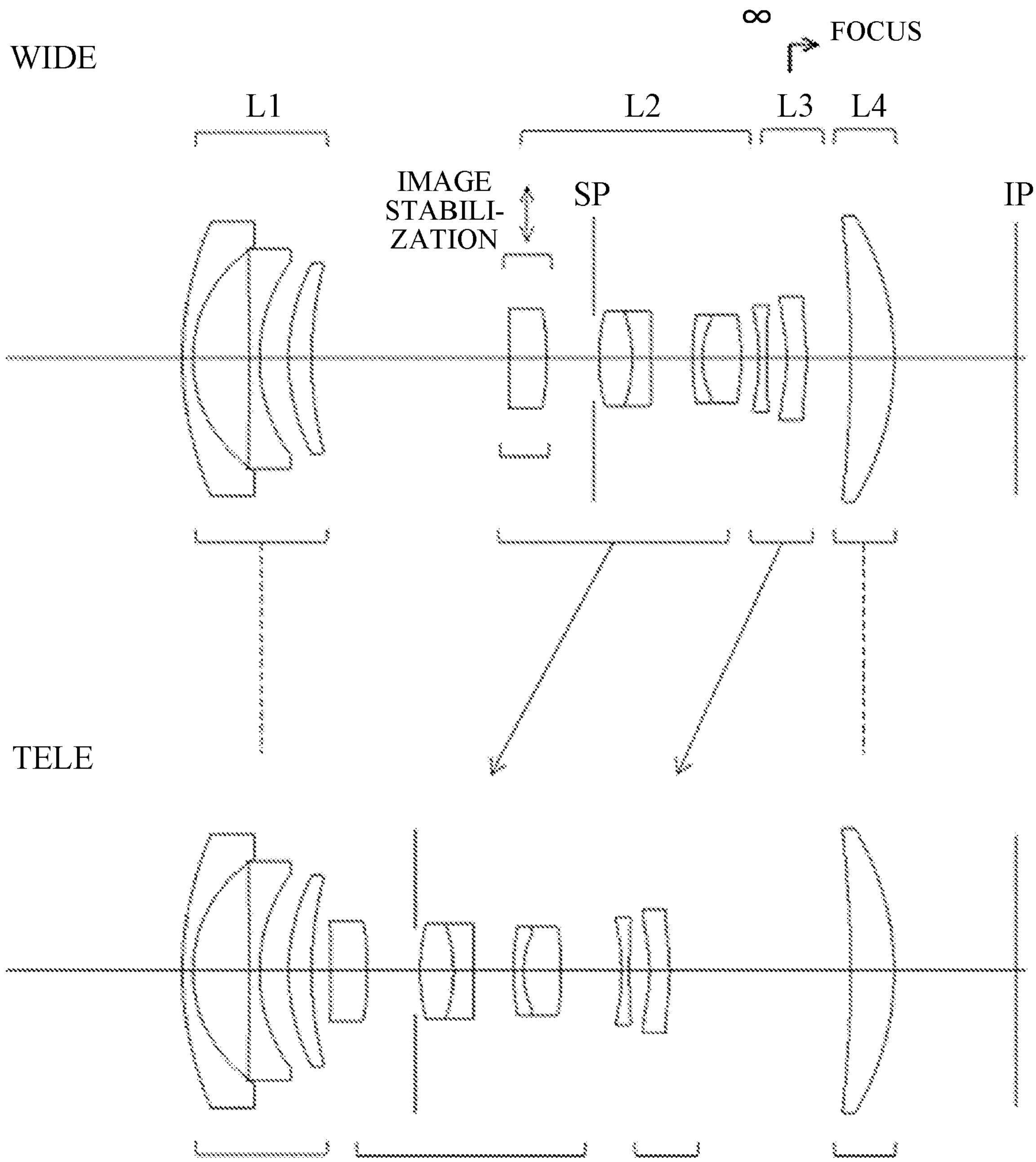
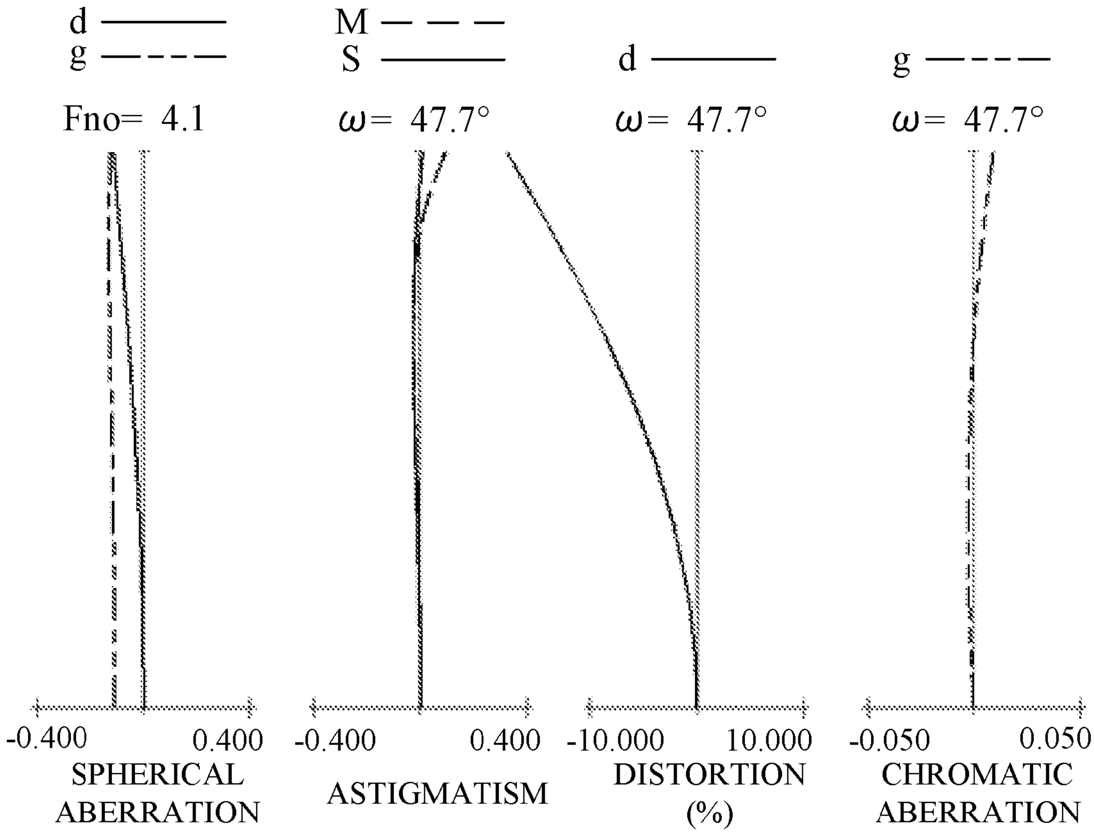


FIG. 3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SPHERICAL ABERRATION
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ASTIGMATISM
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DISTORTION (%)
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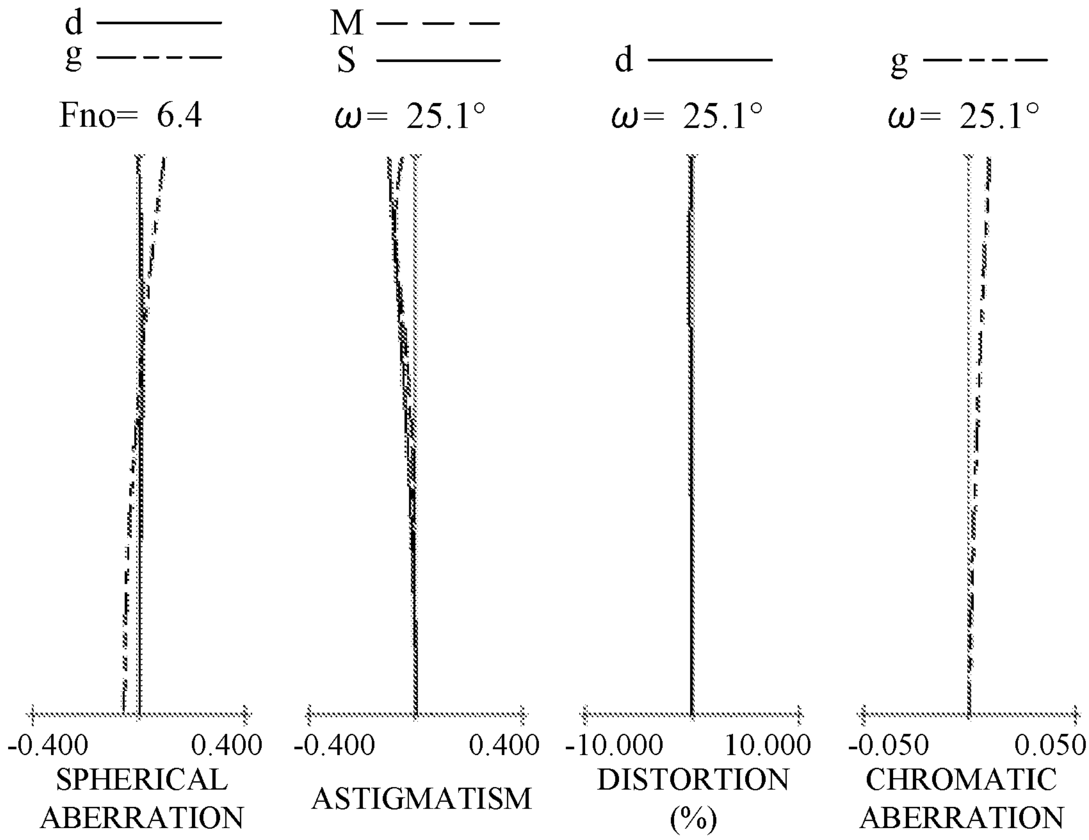
CHROMATIC ABERRATION

FIG. 4A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ASTIGMATISM
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DISTORTION (%)
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CHROMATIC ABERRATION

FIG. 4B

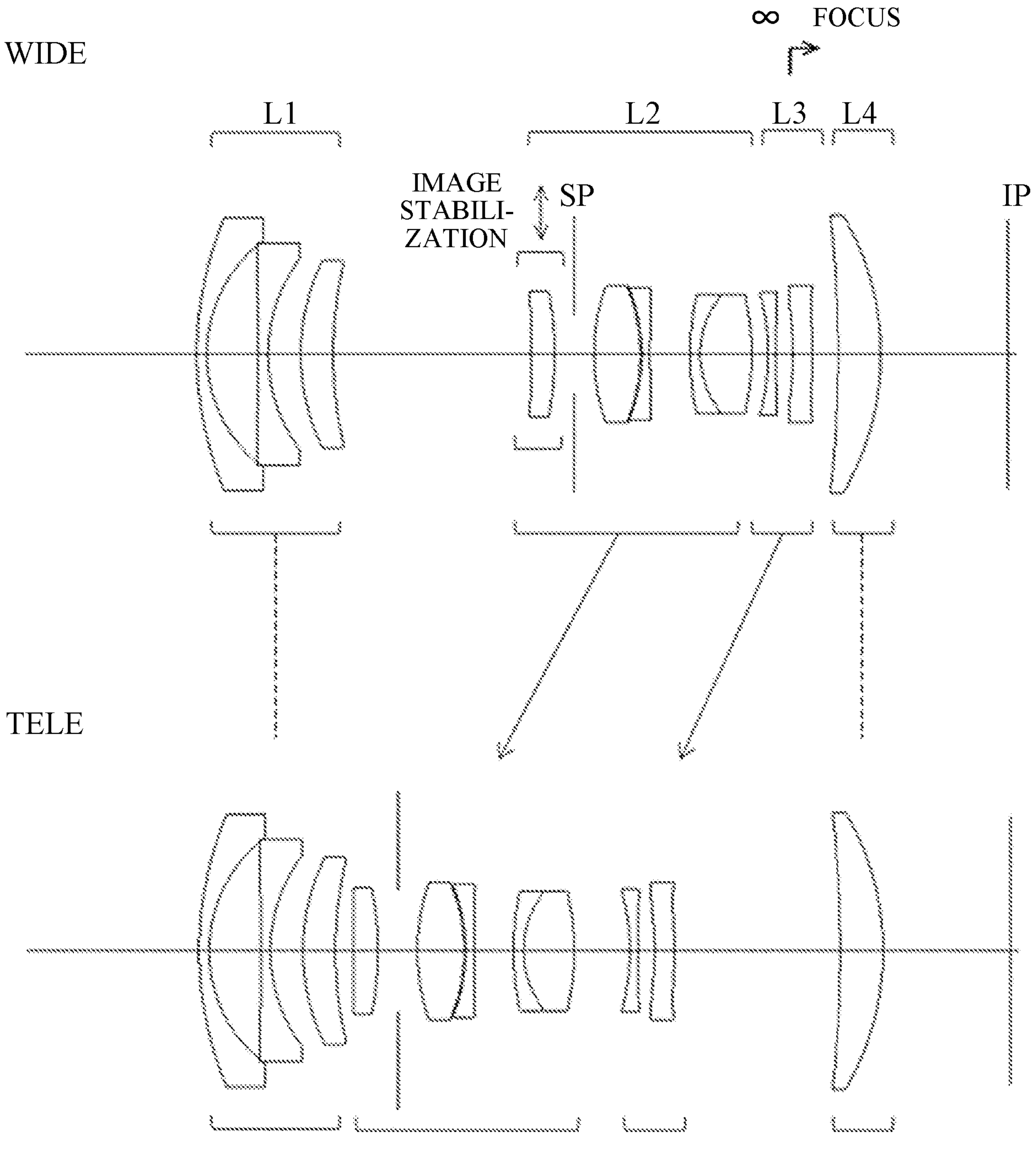
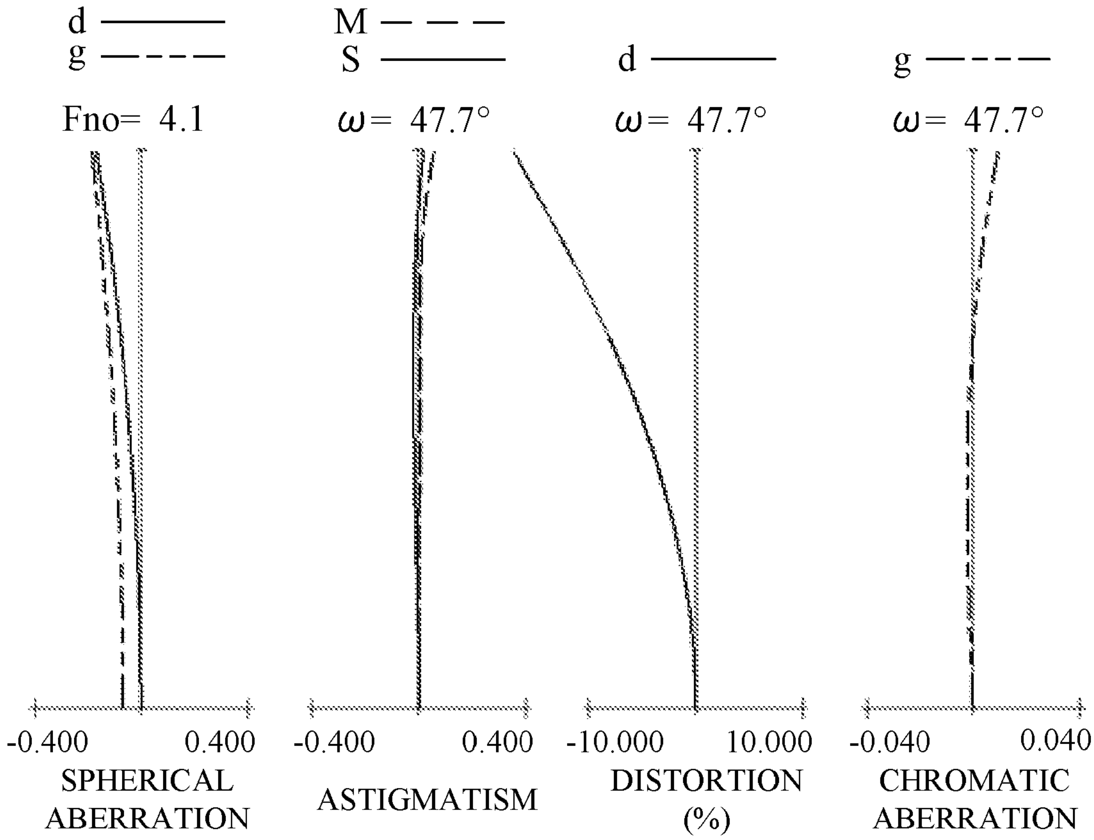


FIG. 5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SPHERICAL ABERRATION
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ASTIGMATISM
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DISTORTION (%)
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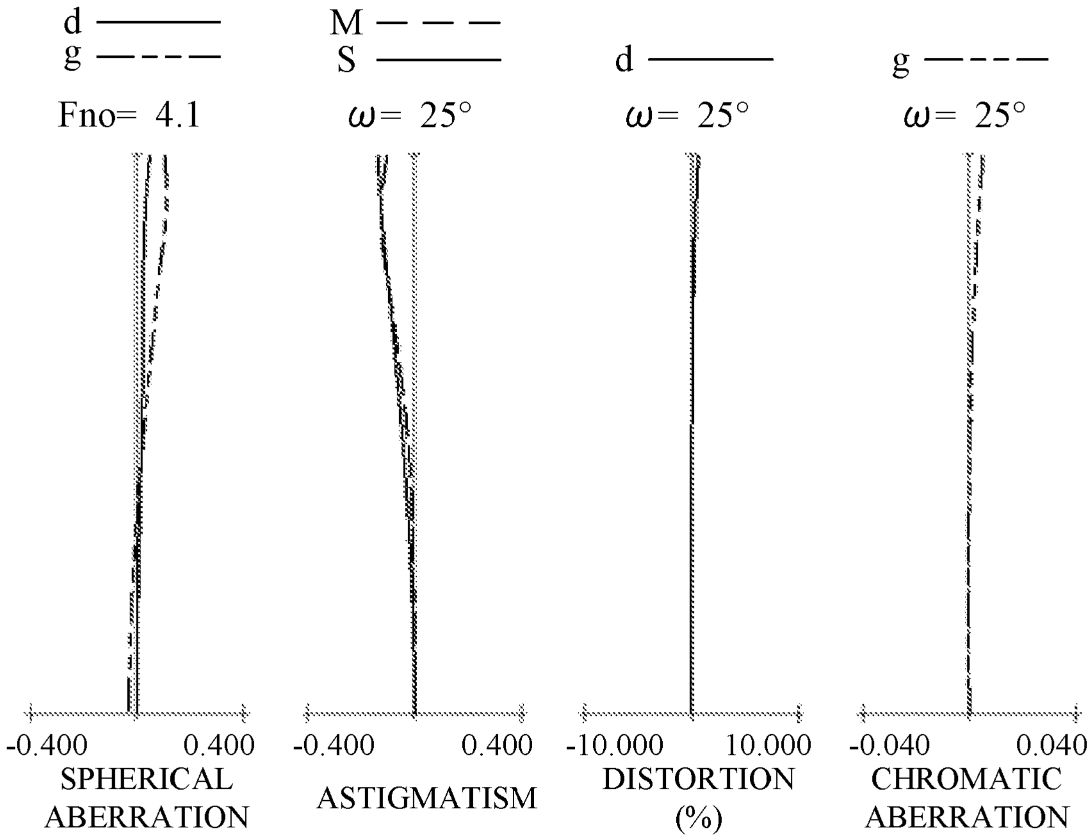
CHROMATIC ABERRATION

FIG. 6A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DISTORTION (%)
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CHROMATIC ABERRATION

FIG. 6B

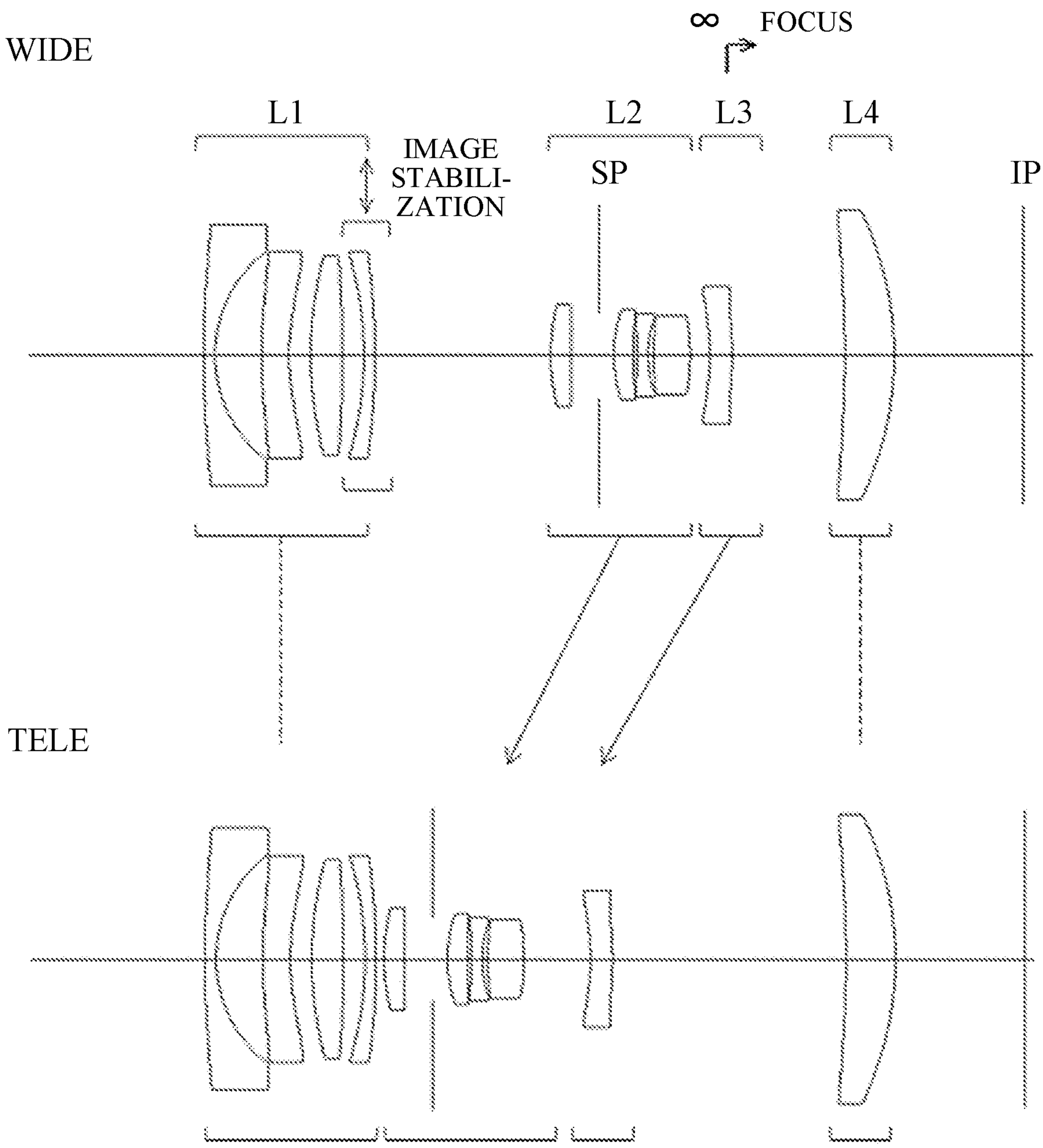
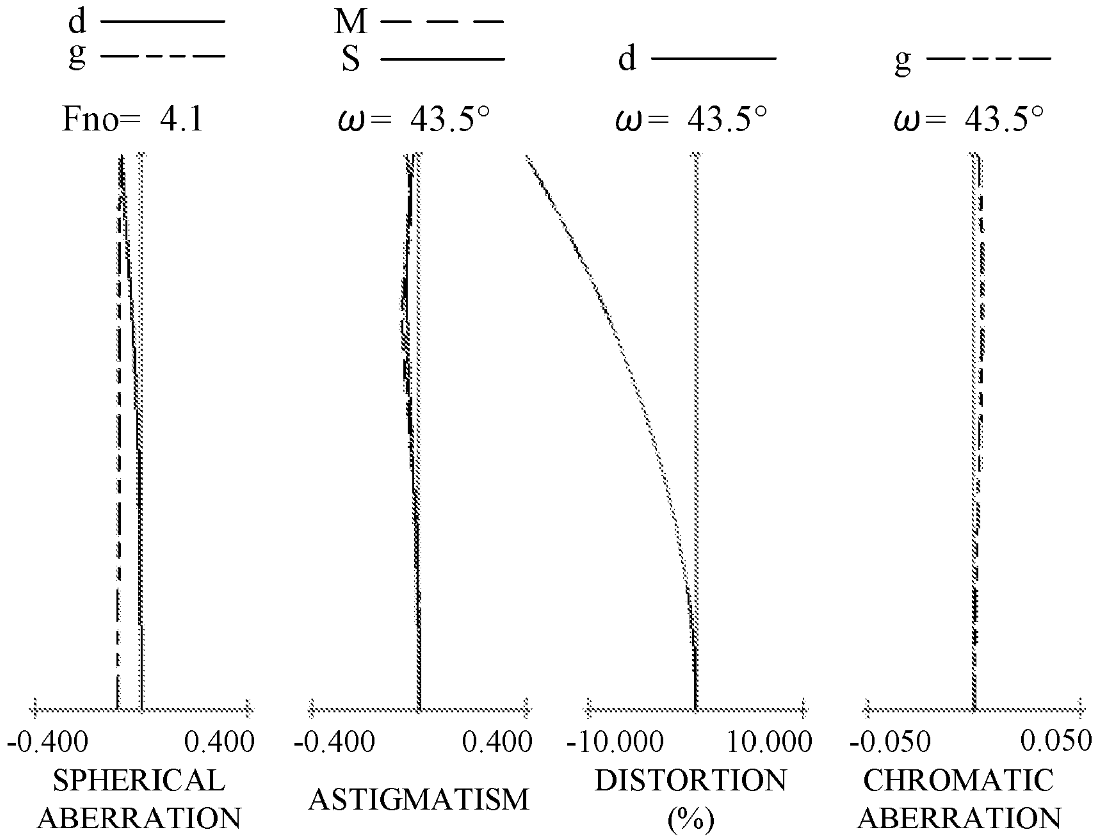


FIG. 7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SPHERICAL ABERRATION
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DISTORTION (%)
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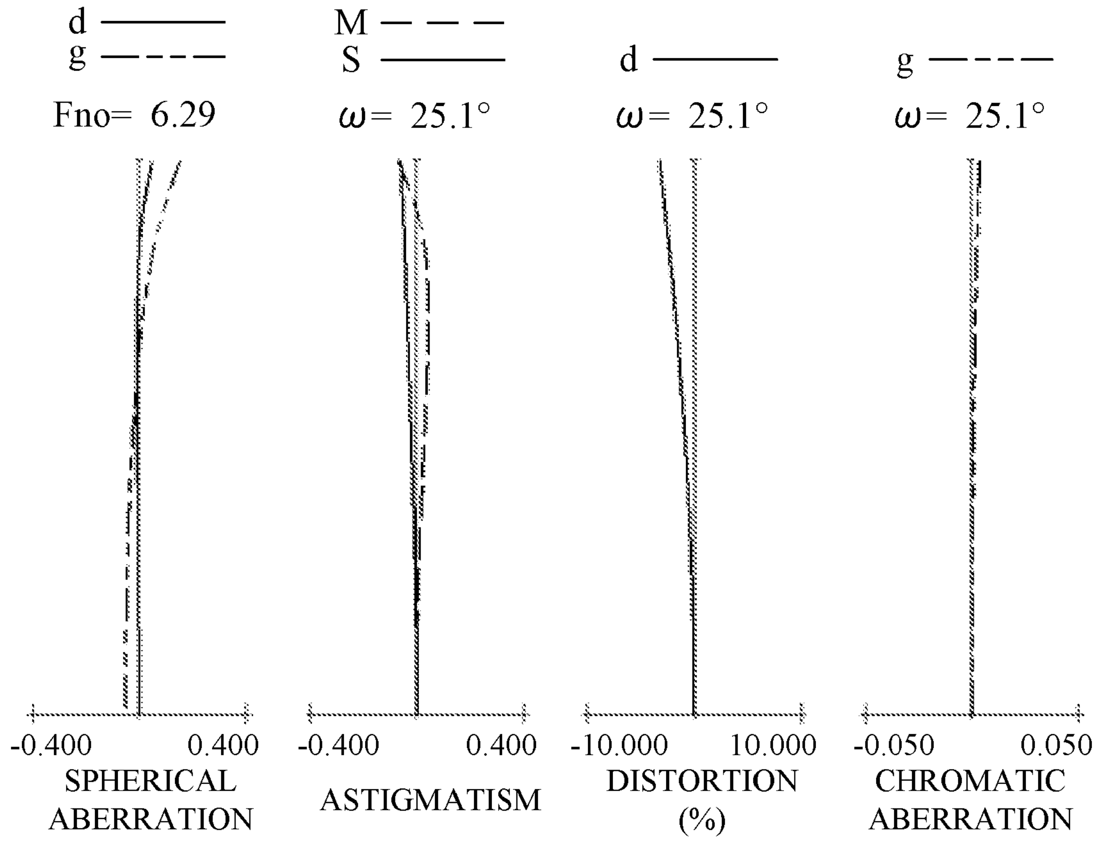
CHROMATIC ABERRATION

FIG. 8A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SPHERICAL ABERRATION
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ASTIGMATISM
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10.000
DISTORTION (%)
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CHROMATIC ABERRATION

FIG. 8B

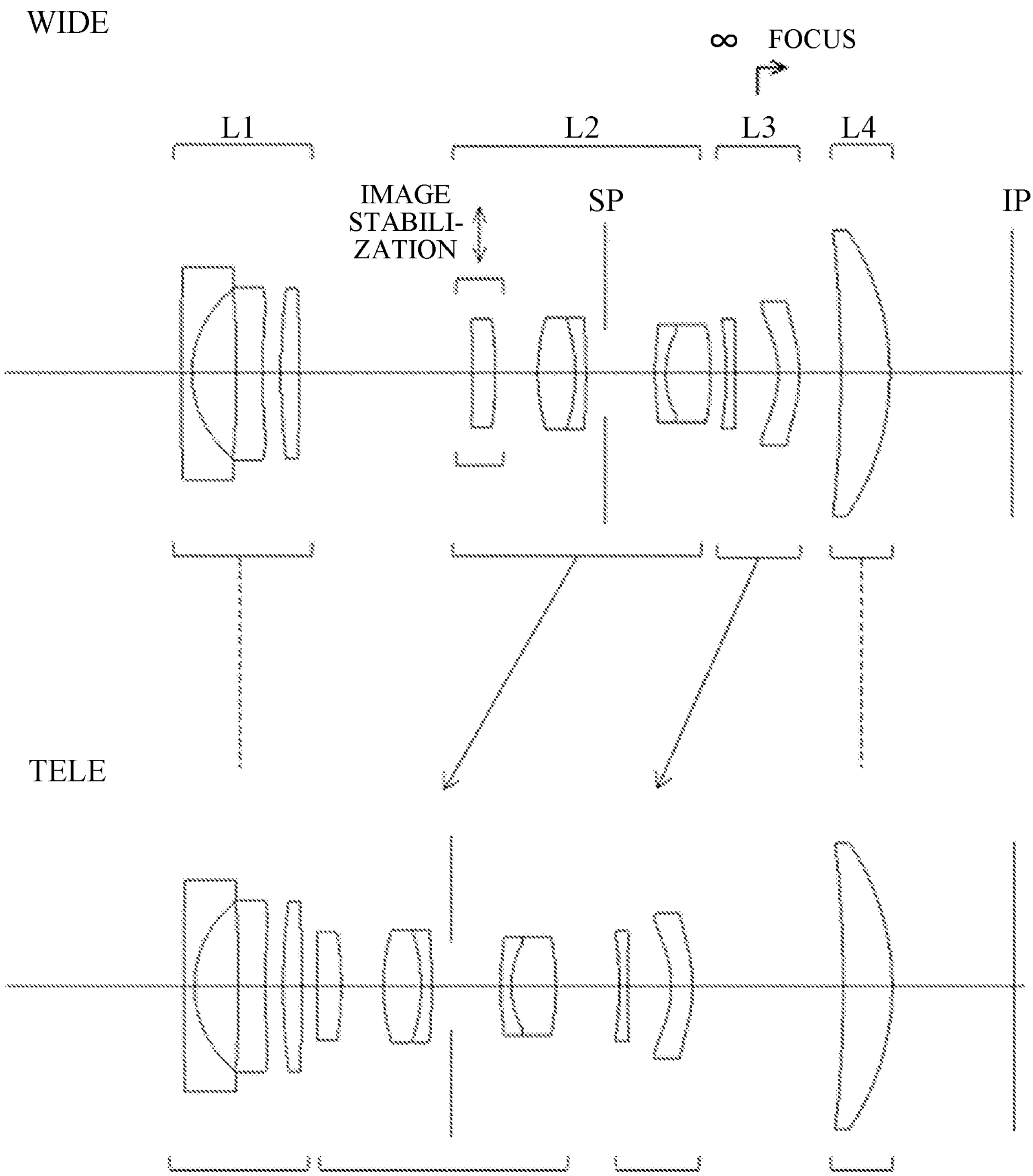

FIG. 9

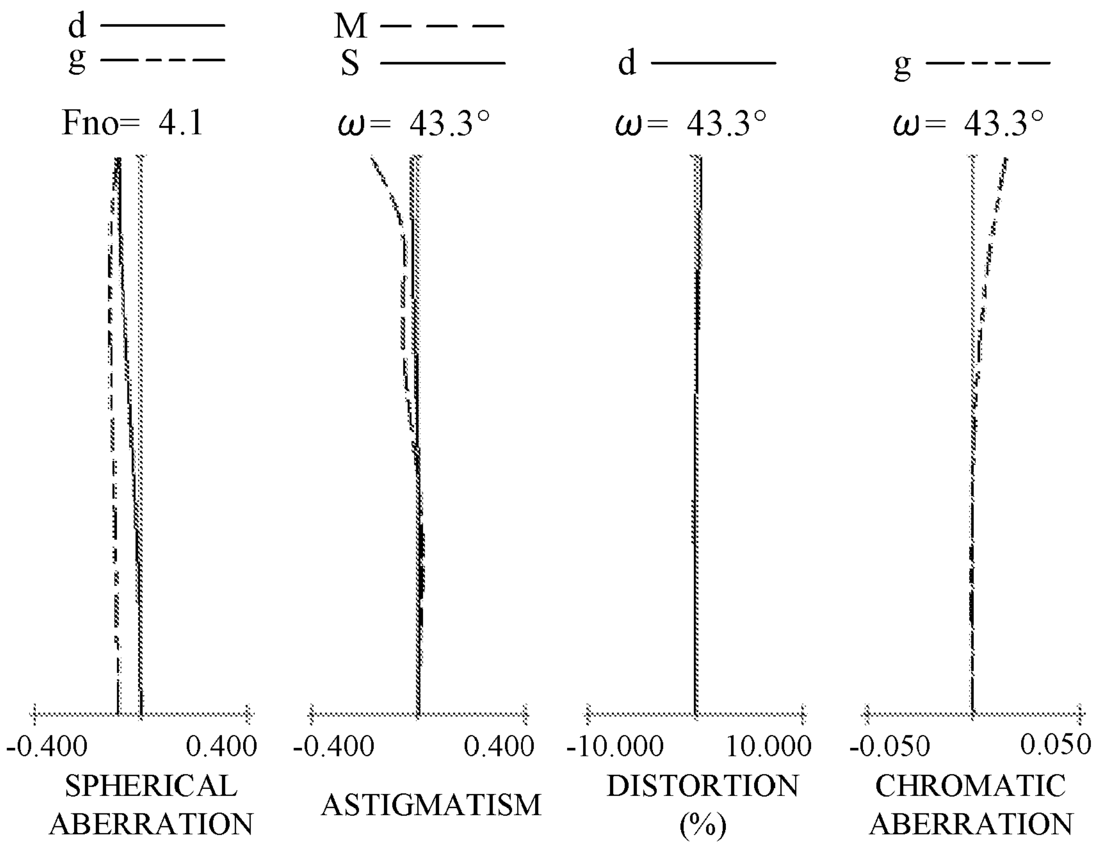

FIG. 10A

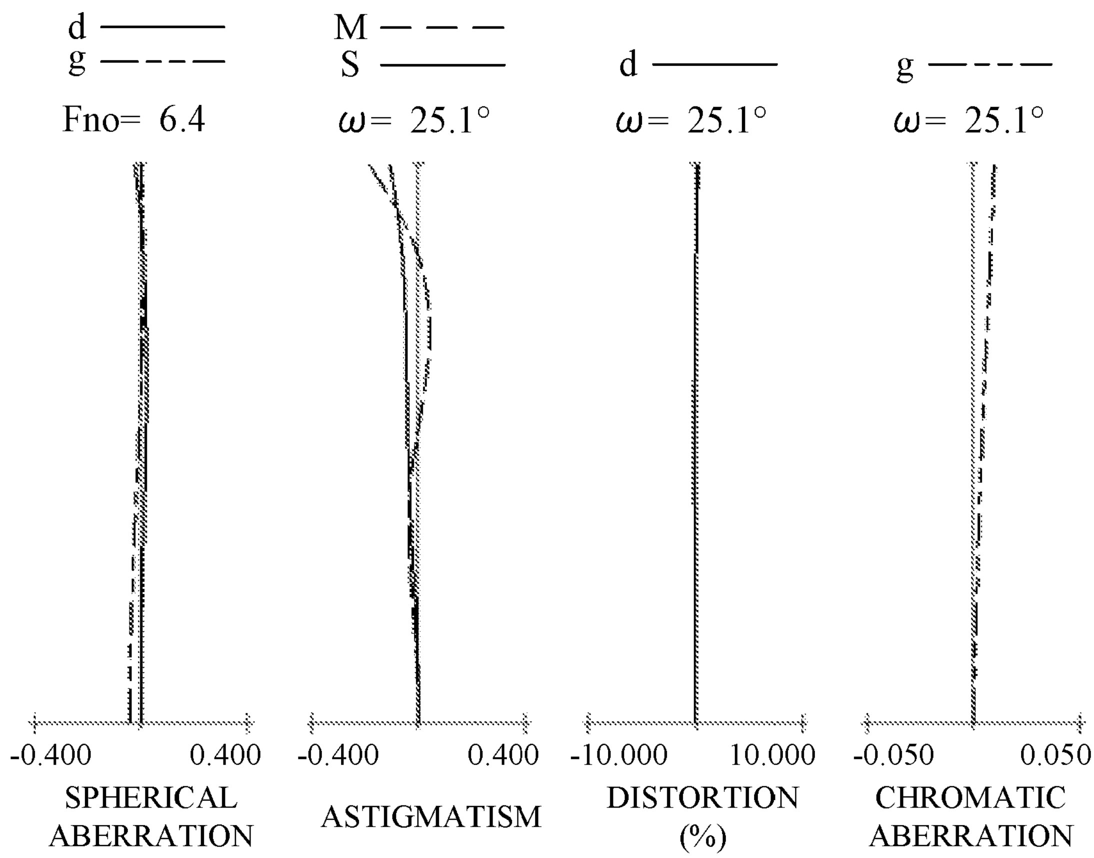

FIG. 10B

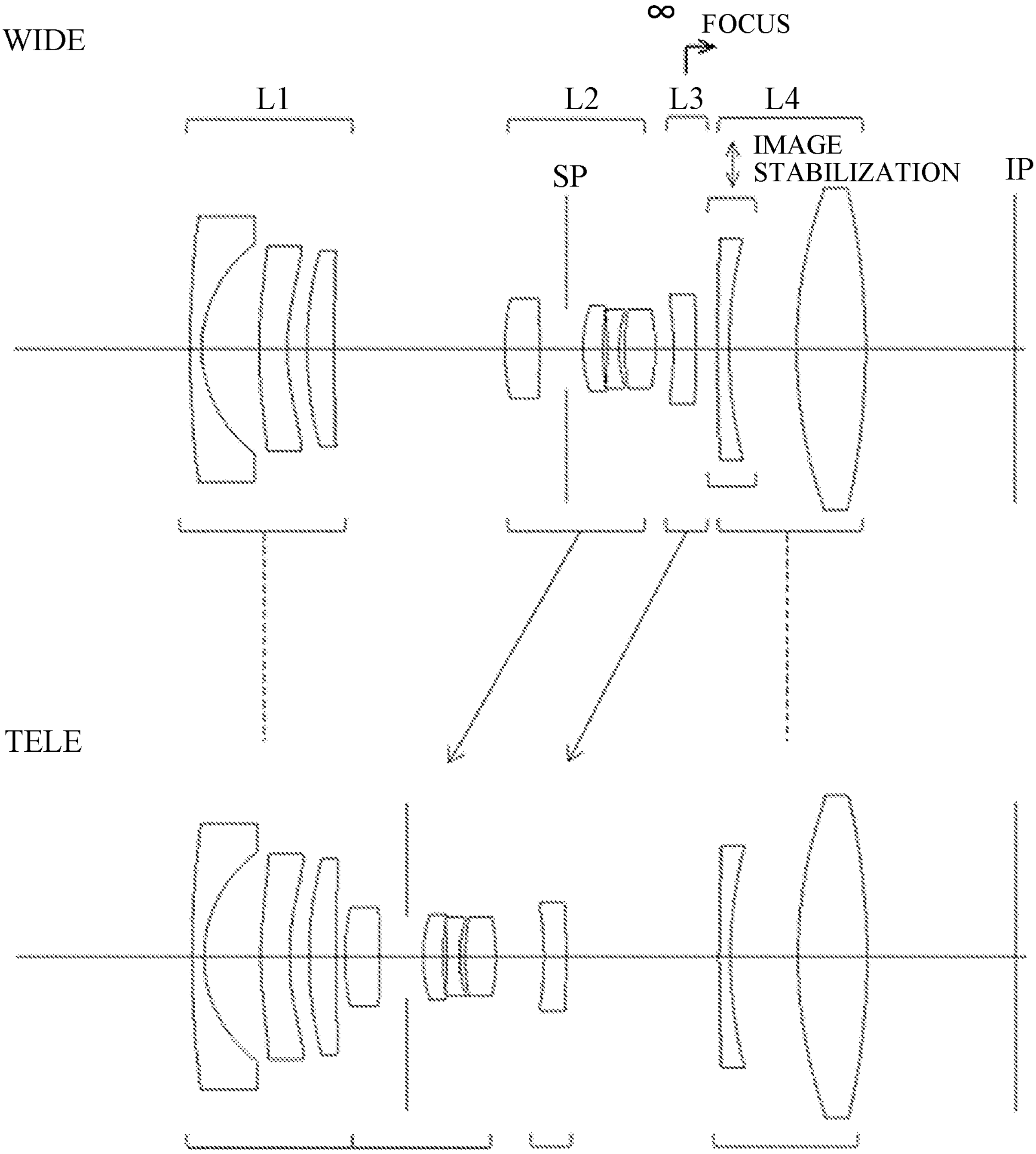

FIG. 11

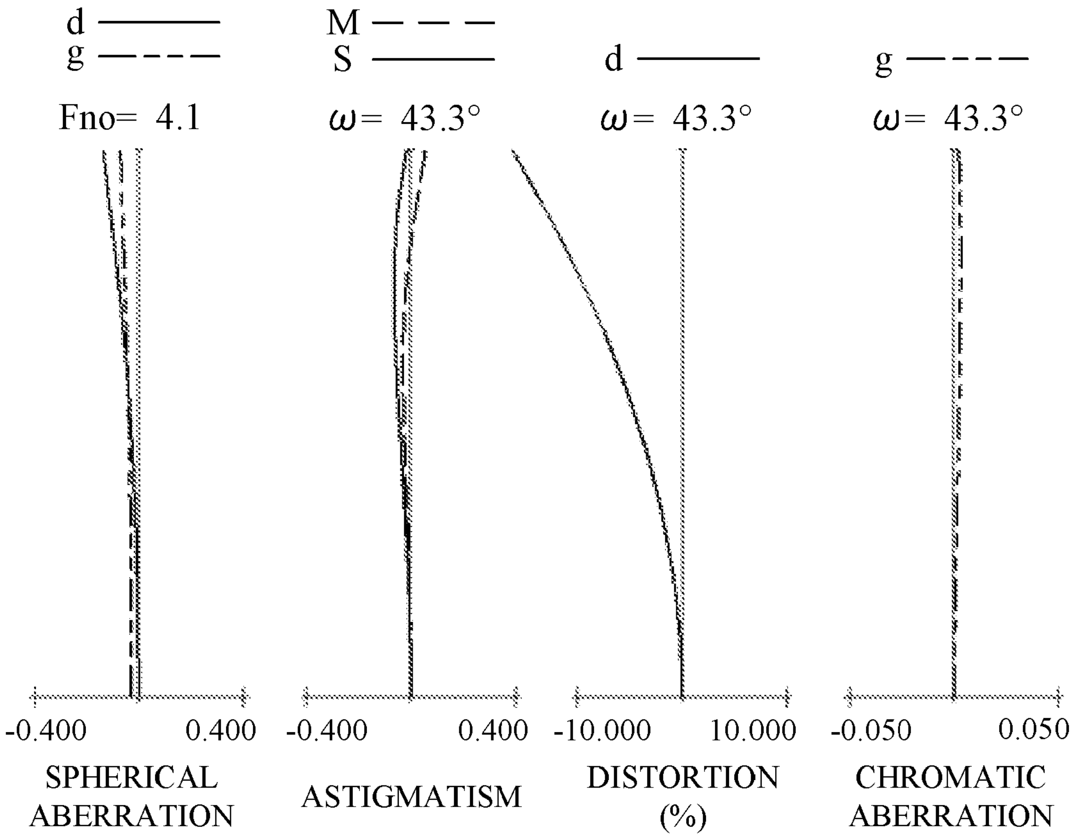

FIG. 12A

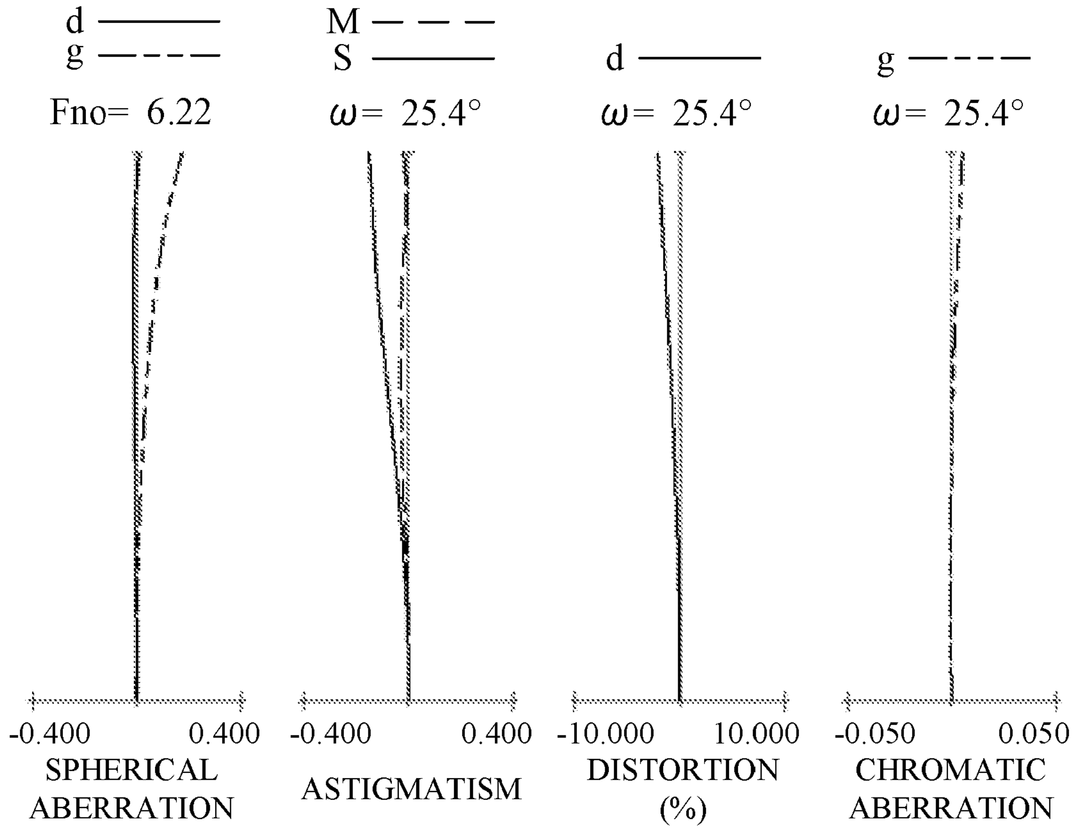

FIG. 12B

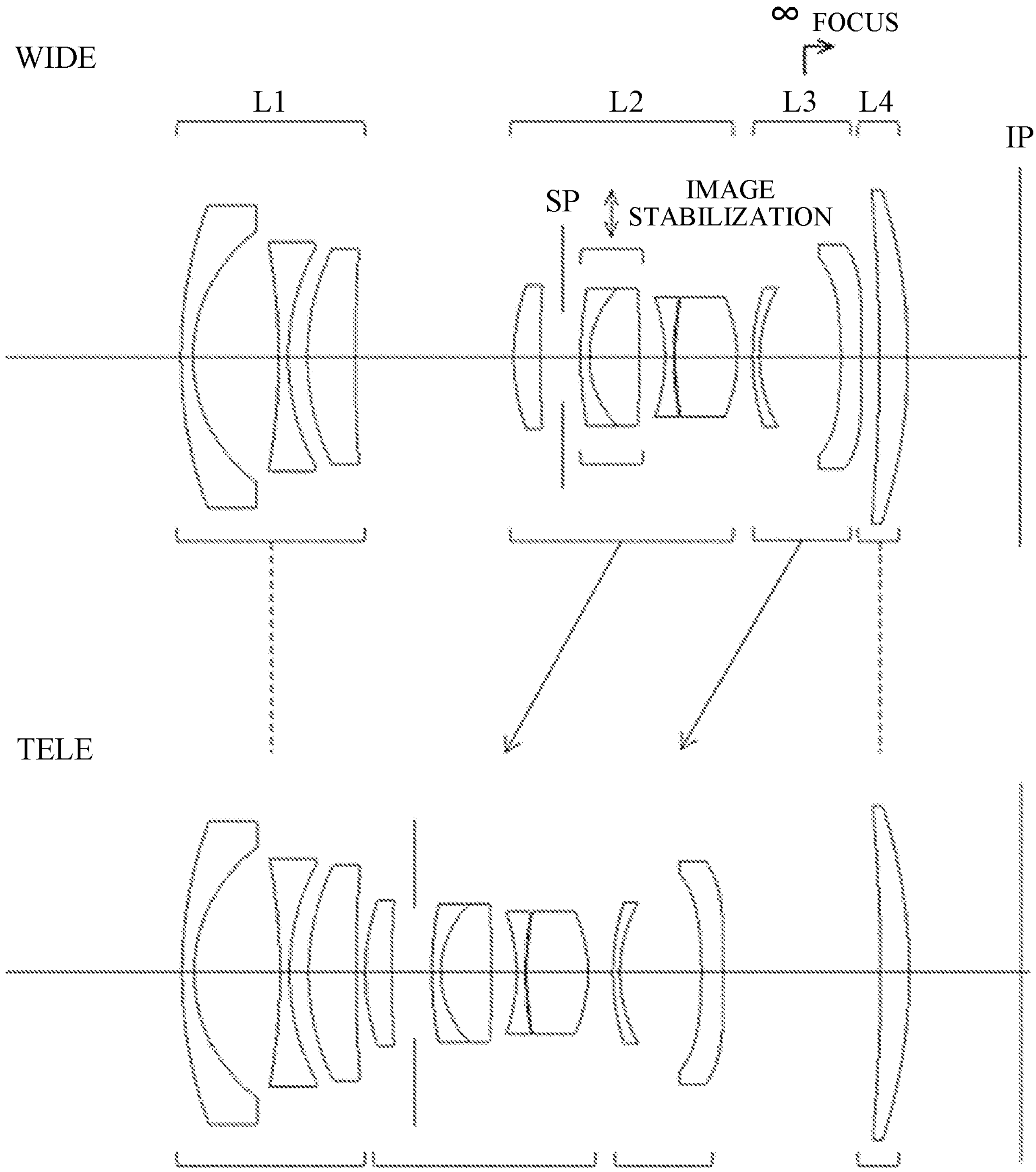

FIG. 13

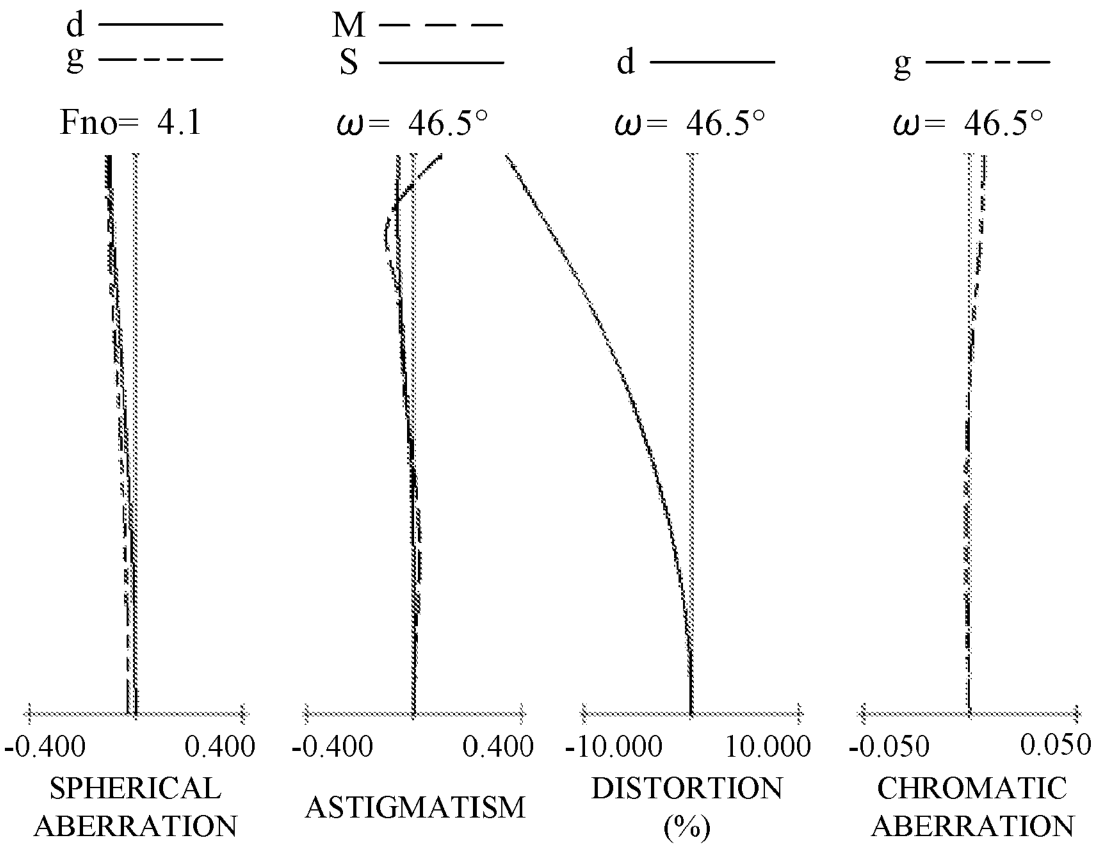

FIG. 14A

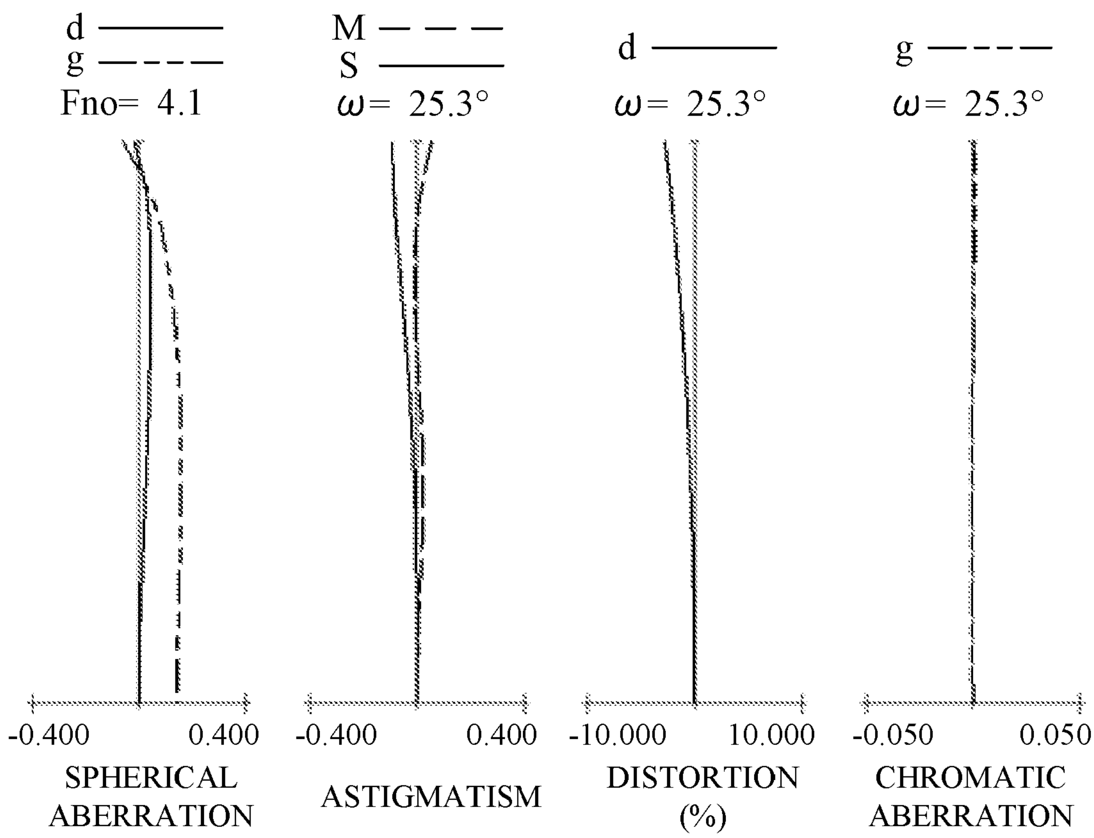

FIG. 14B

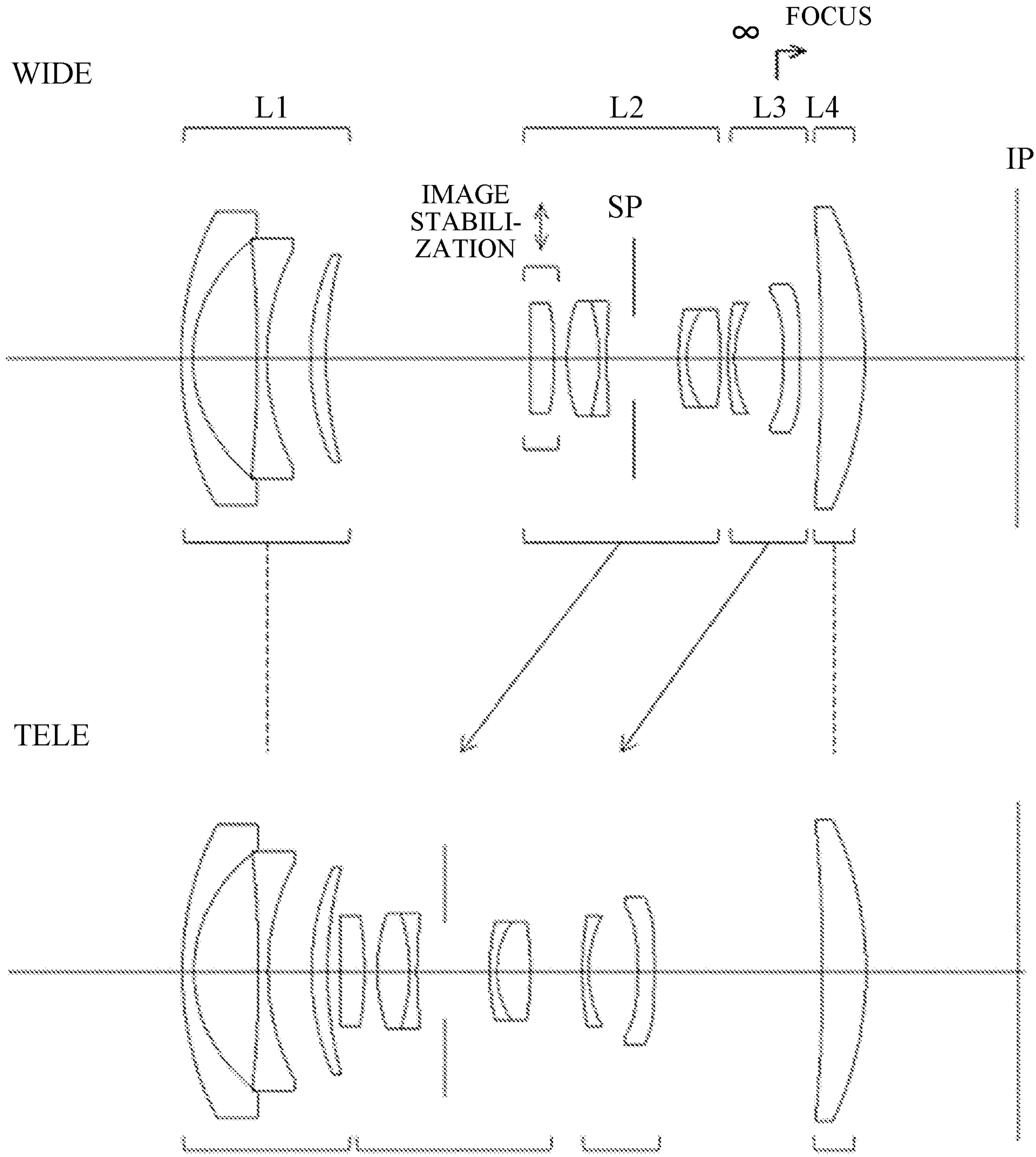

FIG. 15

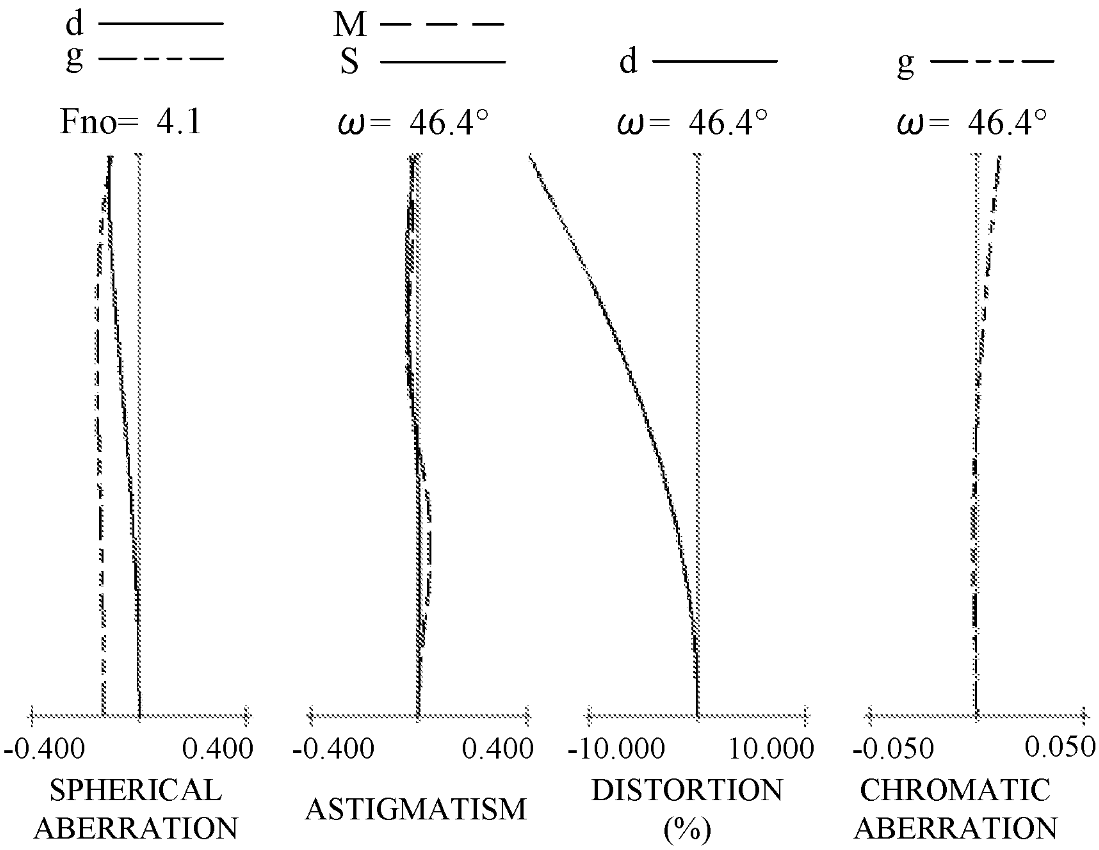

FIG. 16A

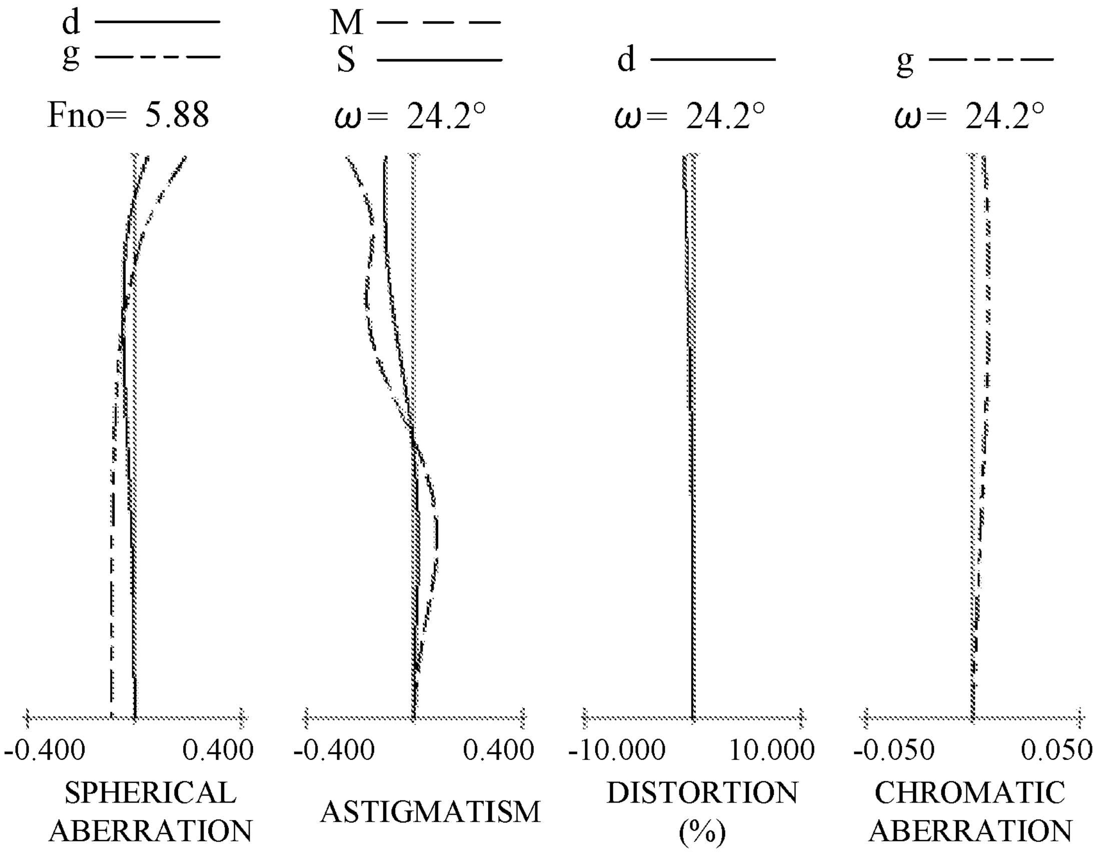

FIG. 16B

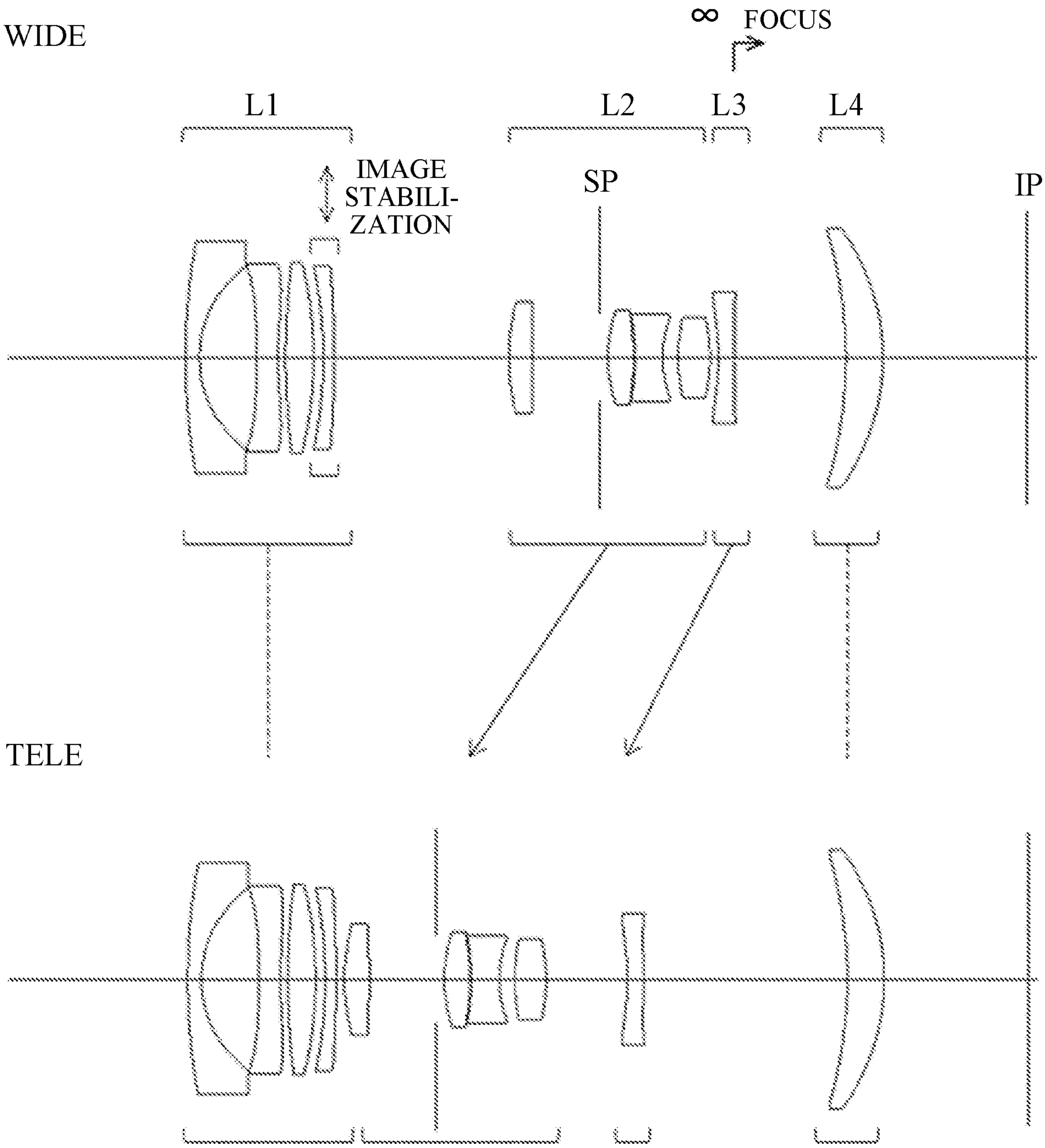

FIG. 17

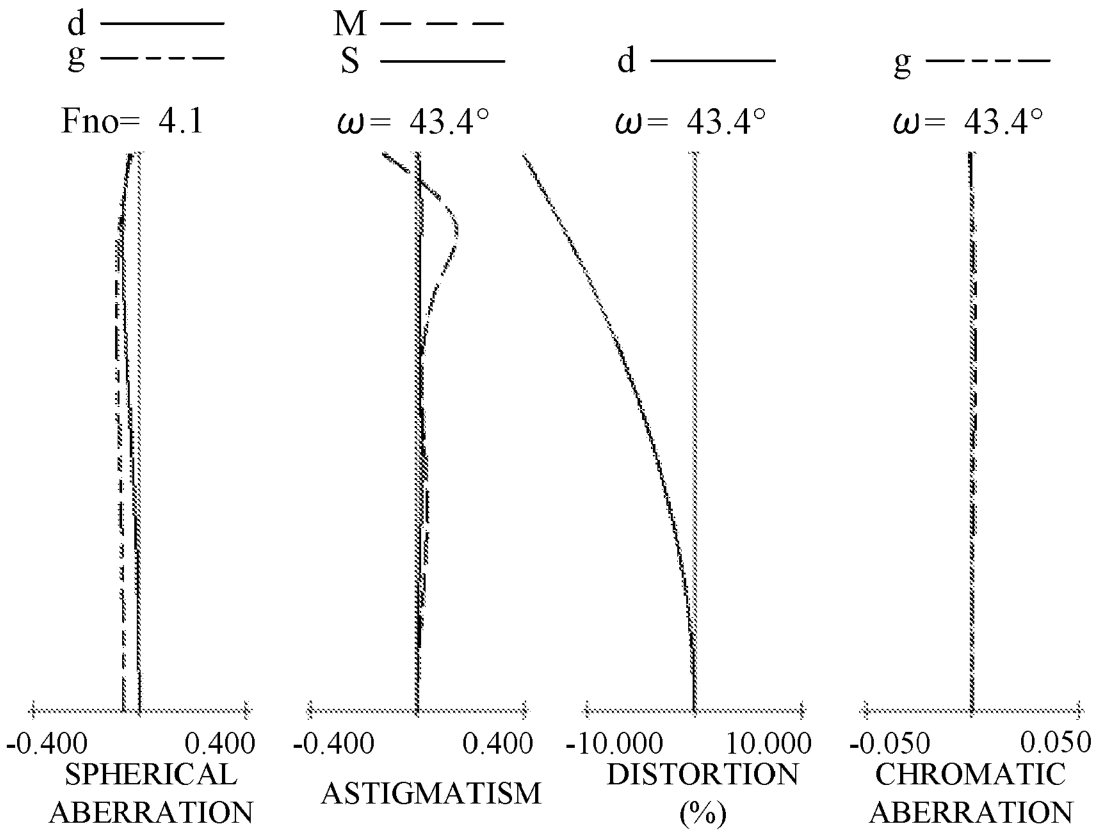

FIG. 18A

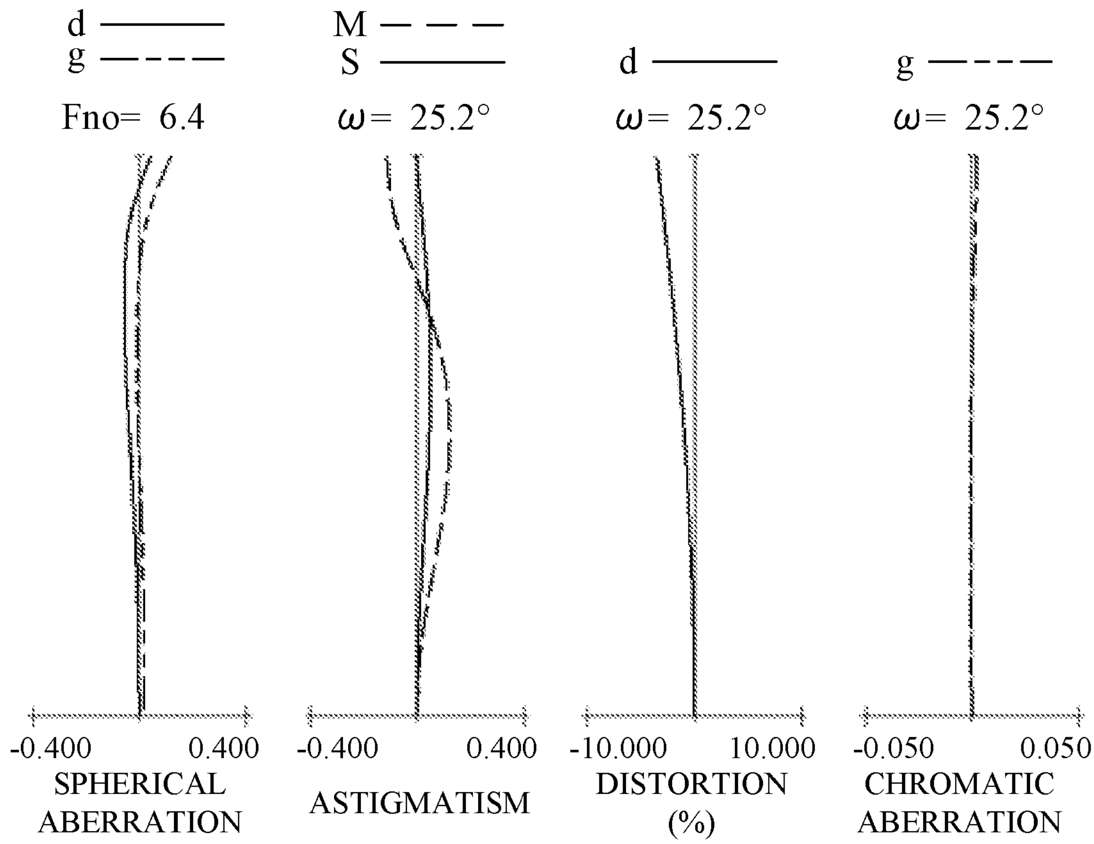

FIG. 18B

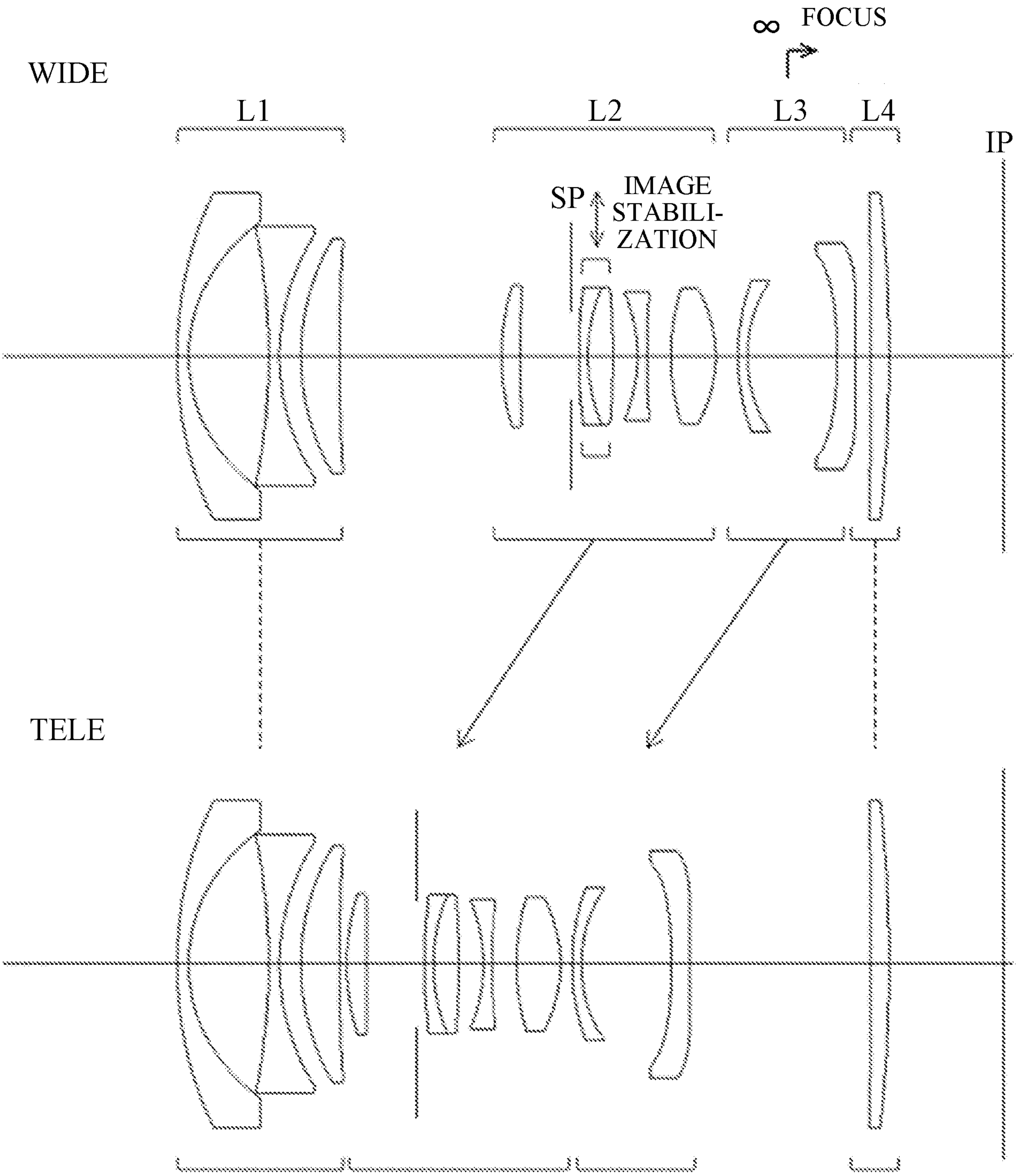

FIG. 19

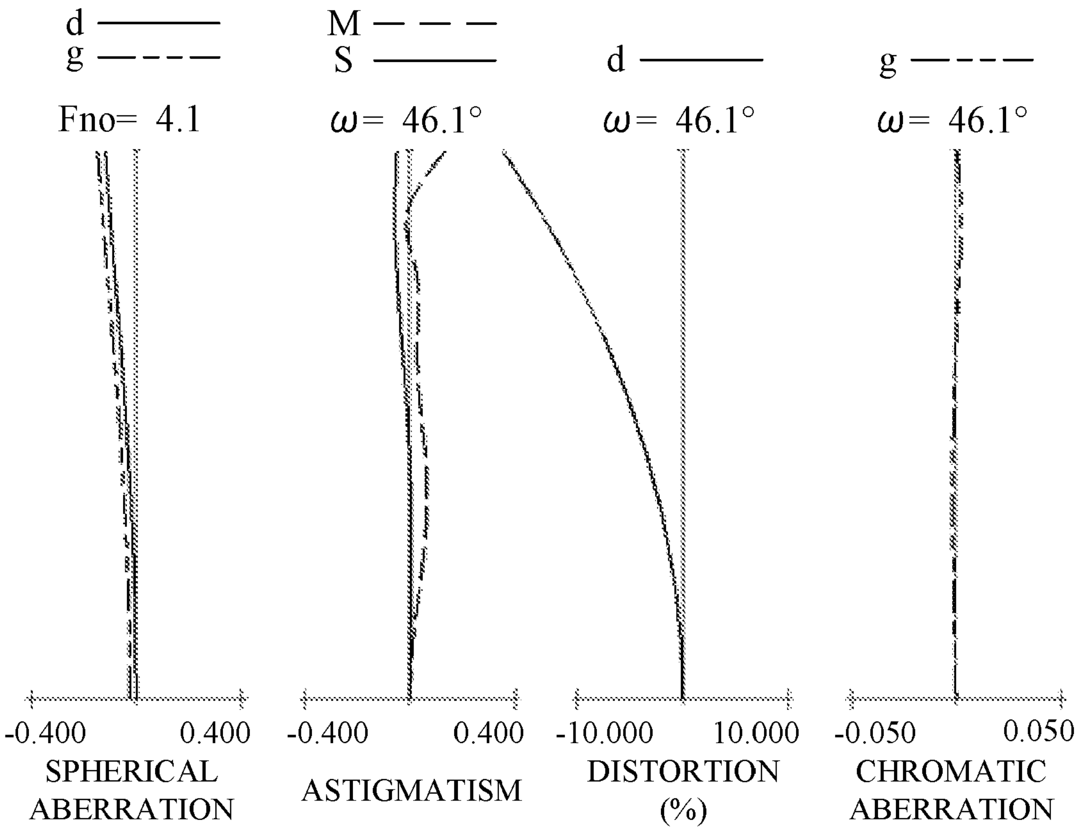

FIG. 20A

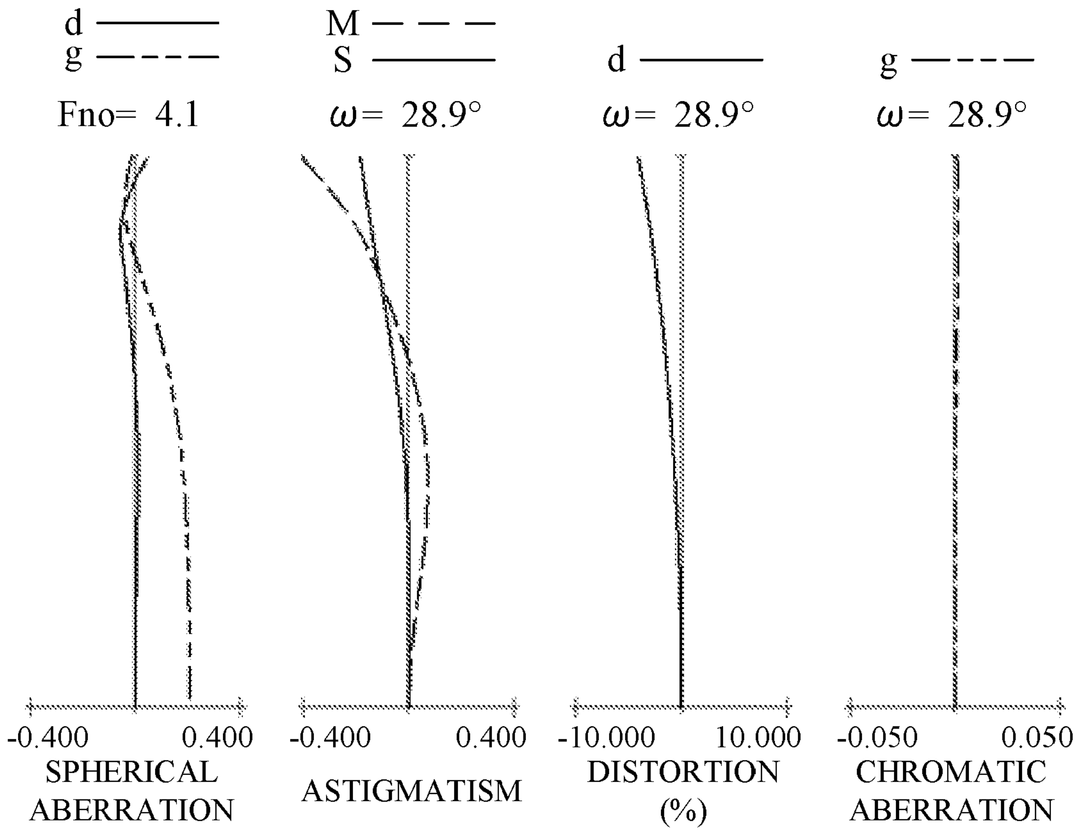

FIG. 20B

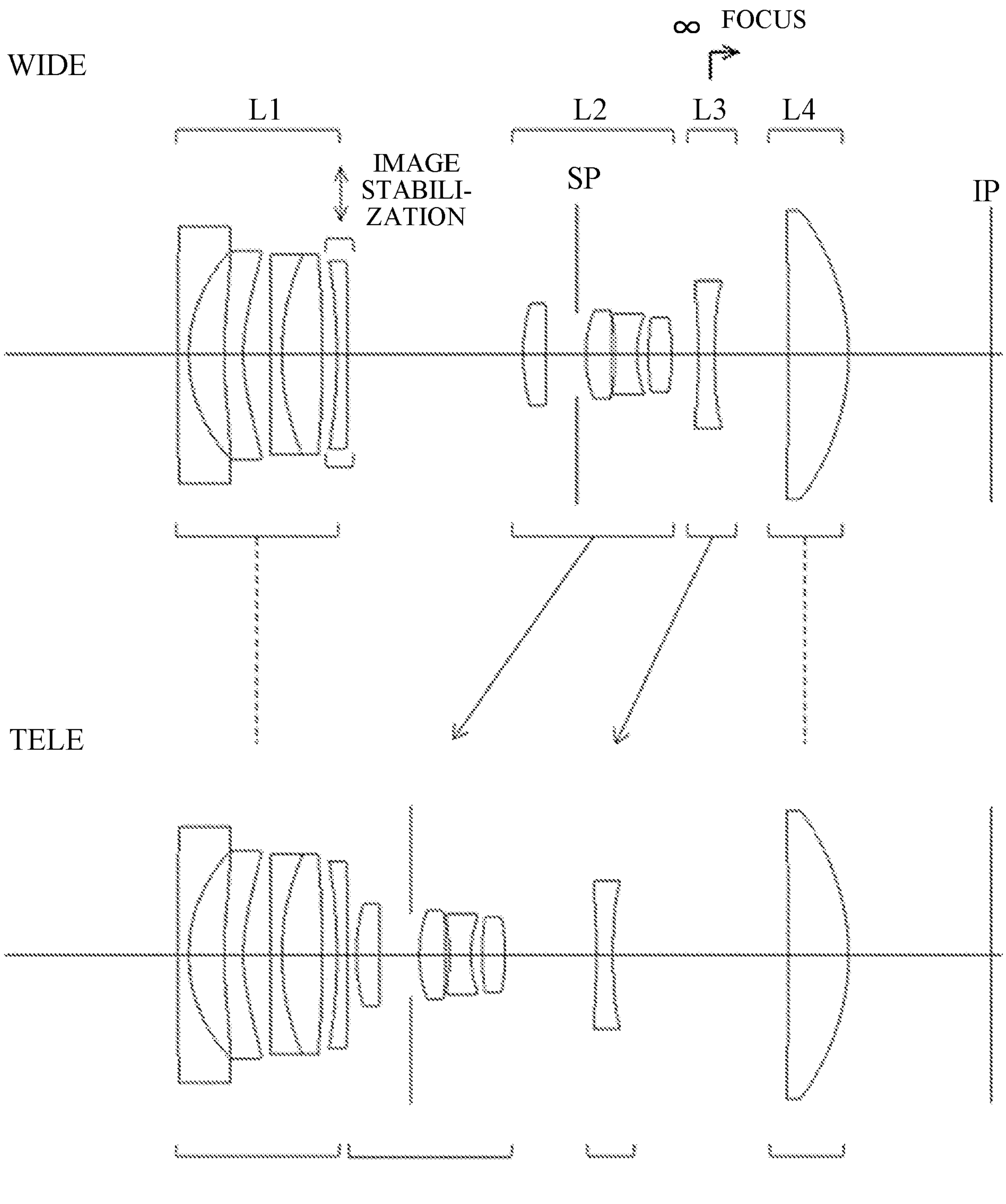

FIG. 21

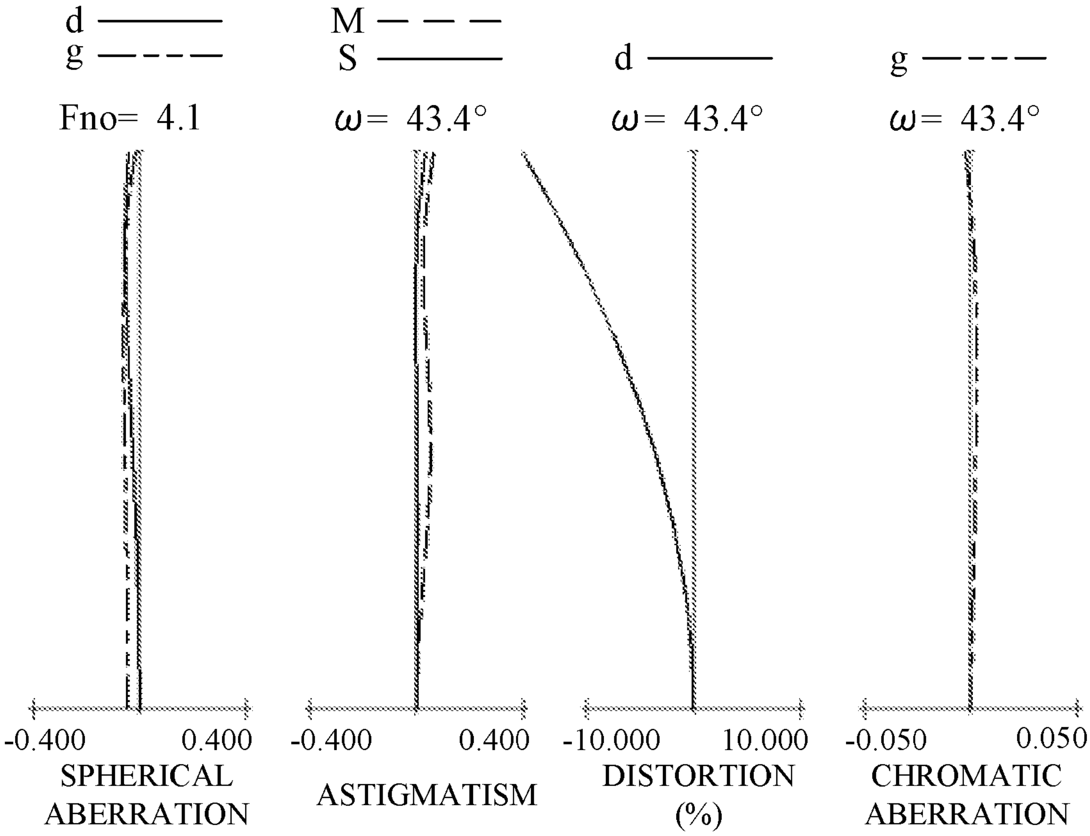

FIG. 22A

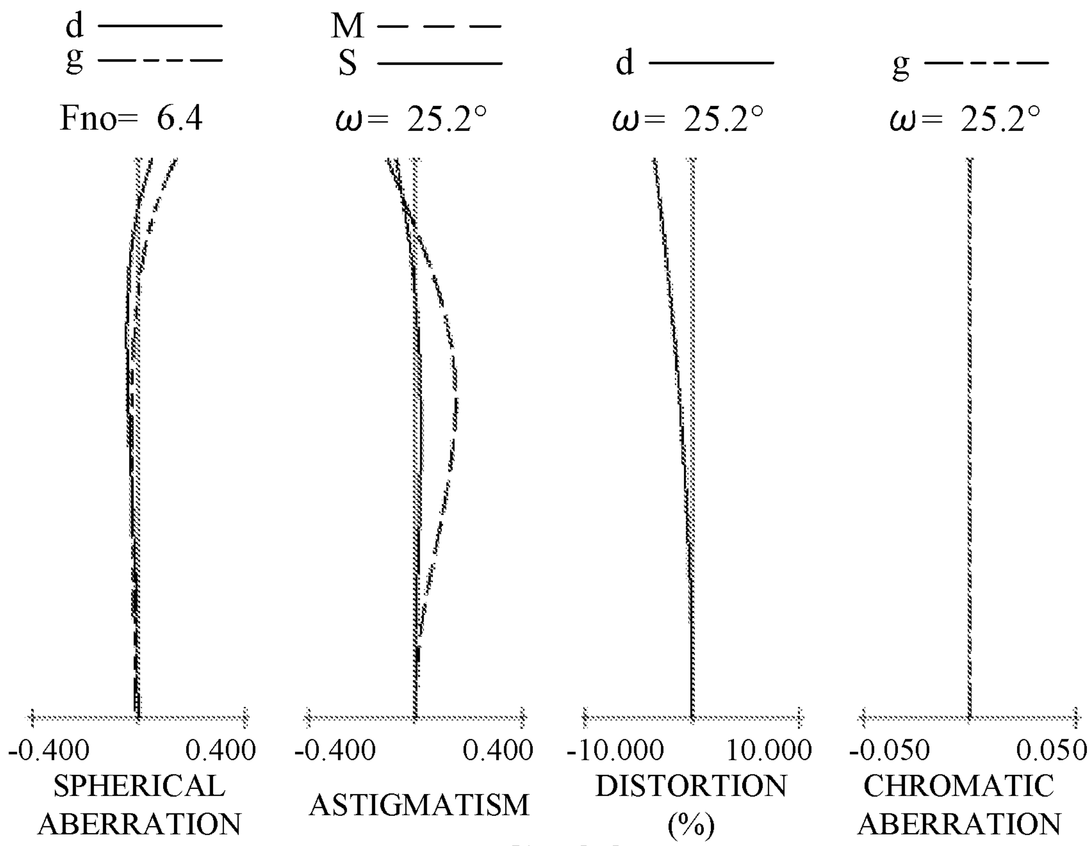

FIG. 22B

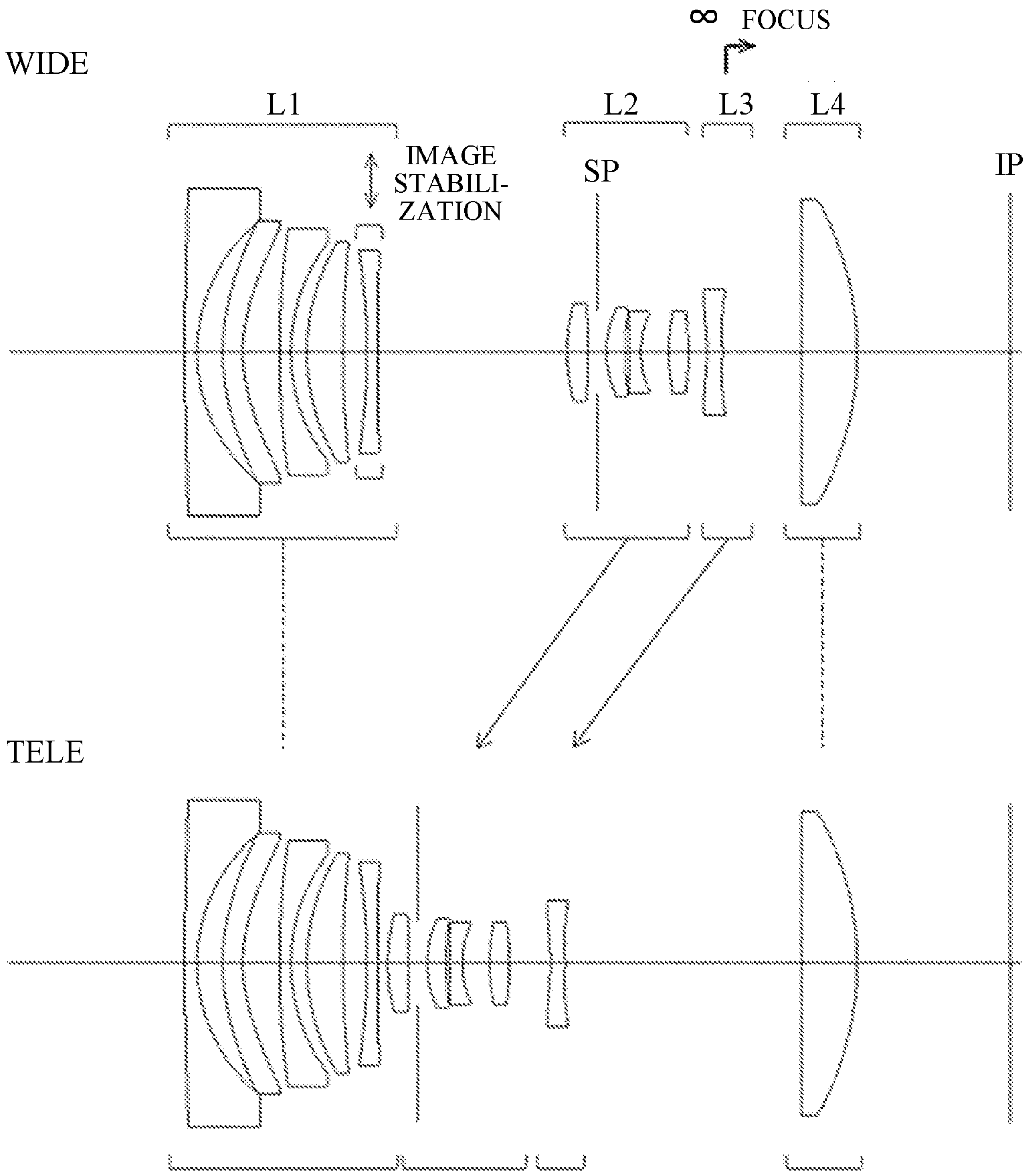

FIG. 23

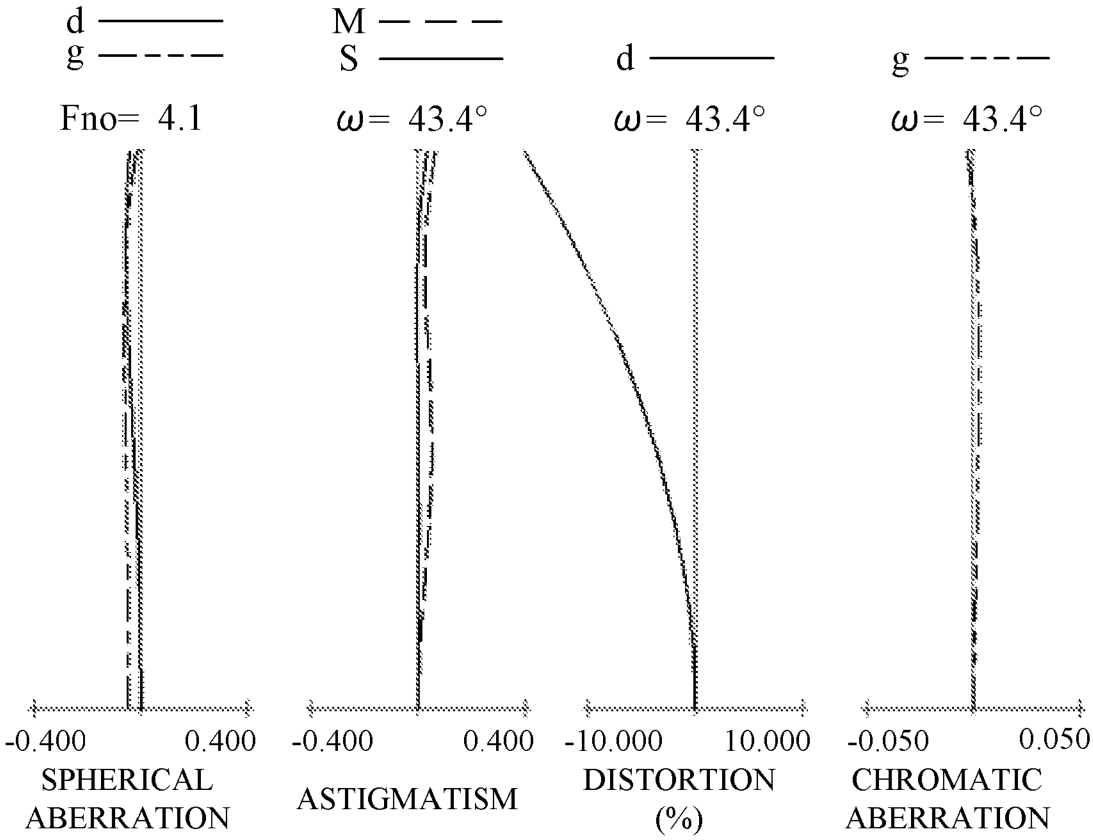

FIG. 24A

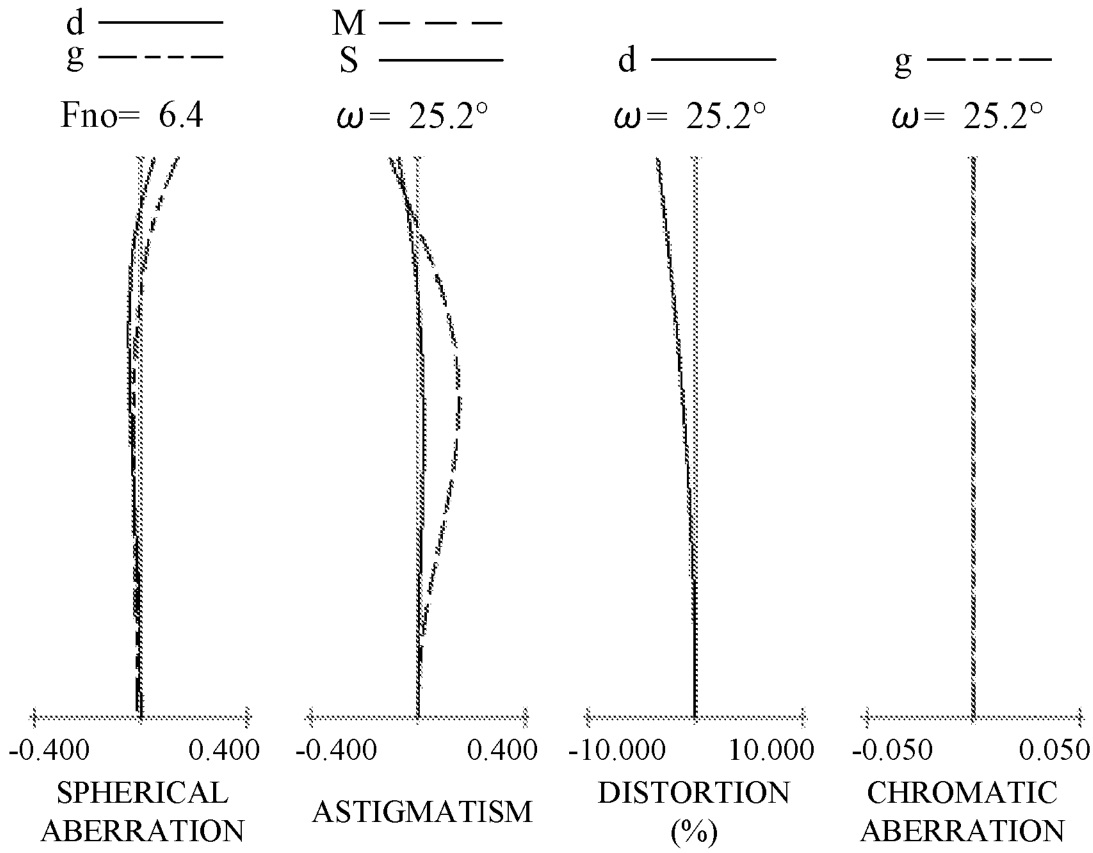

FIG. 24B

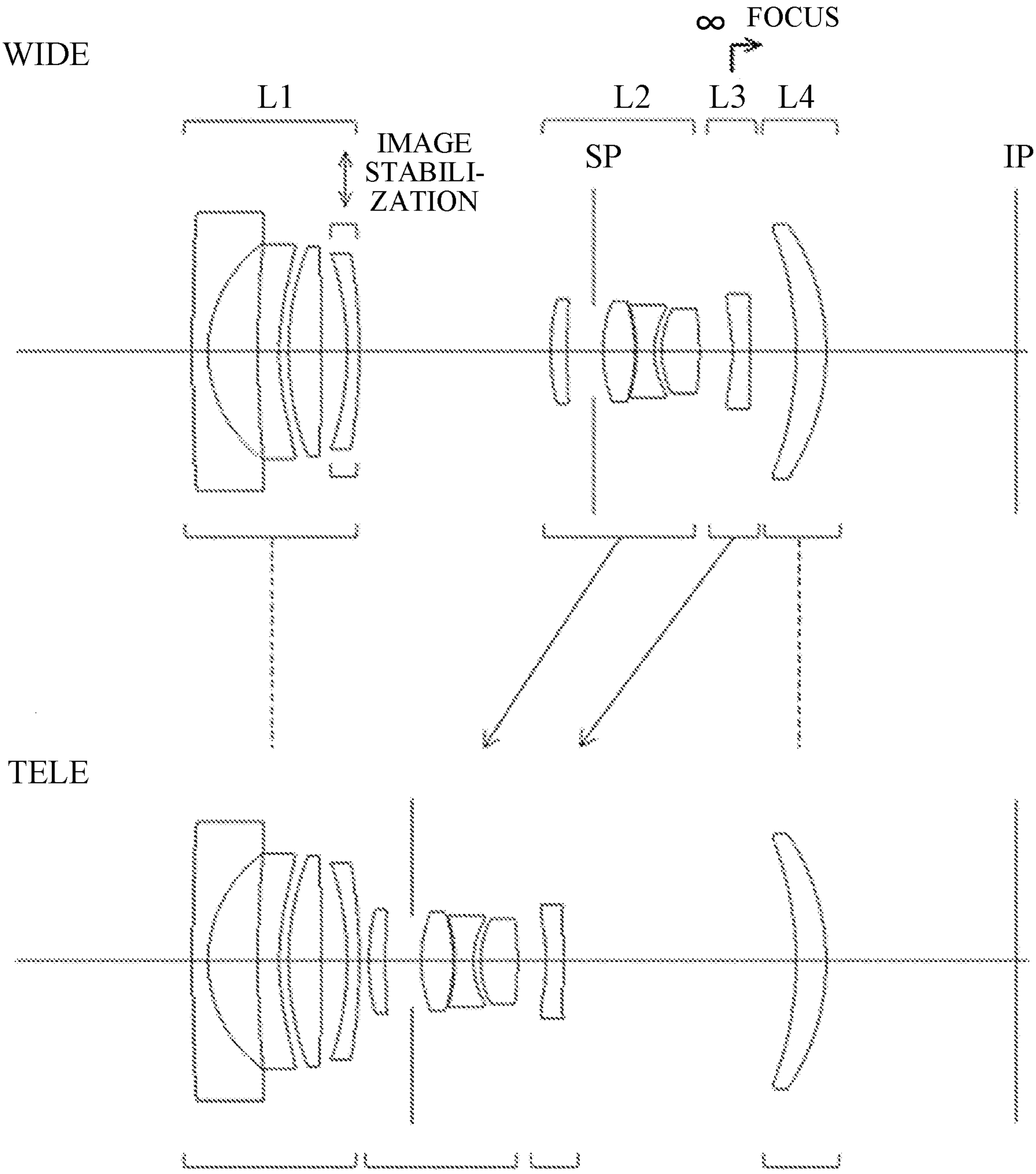

FIG. 25

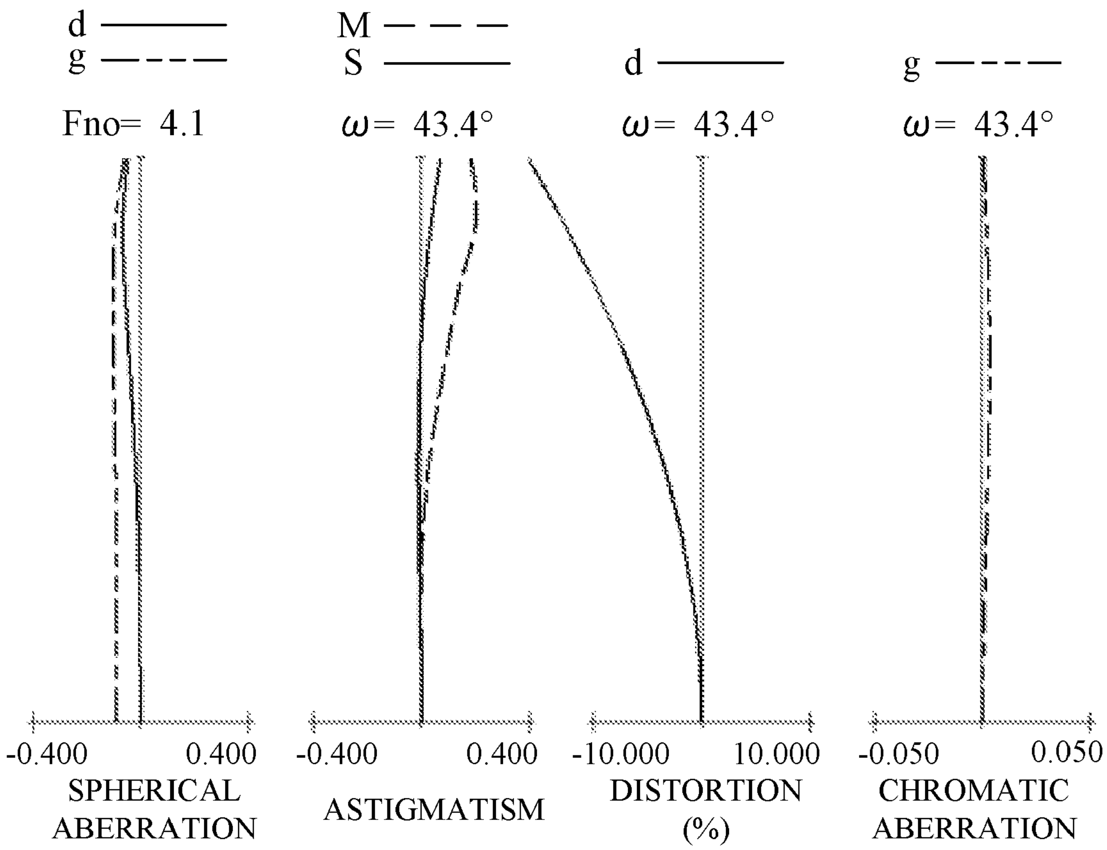

FIG. 26A

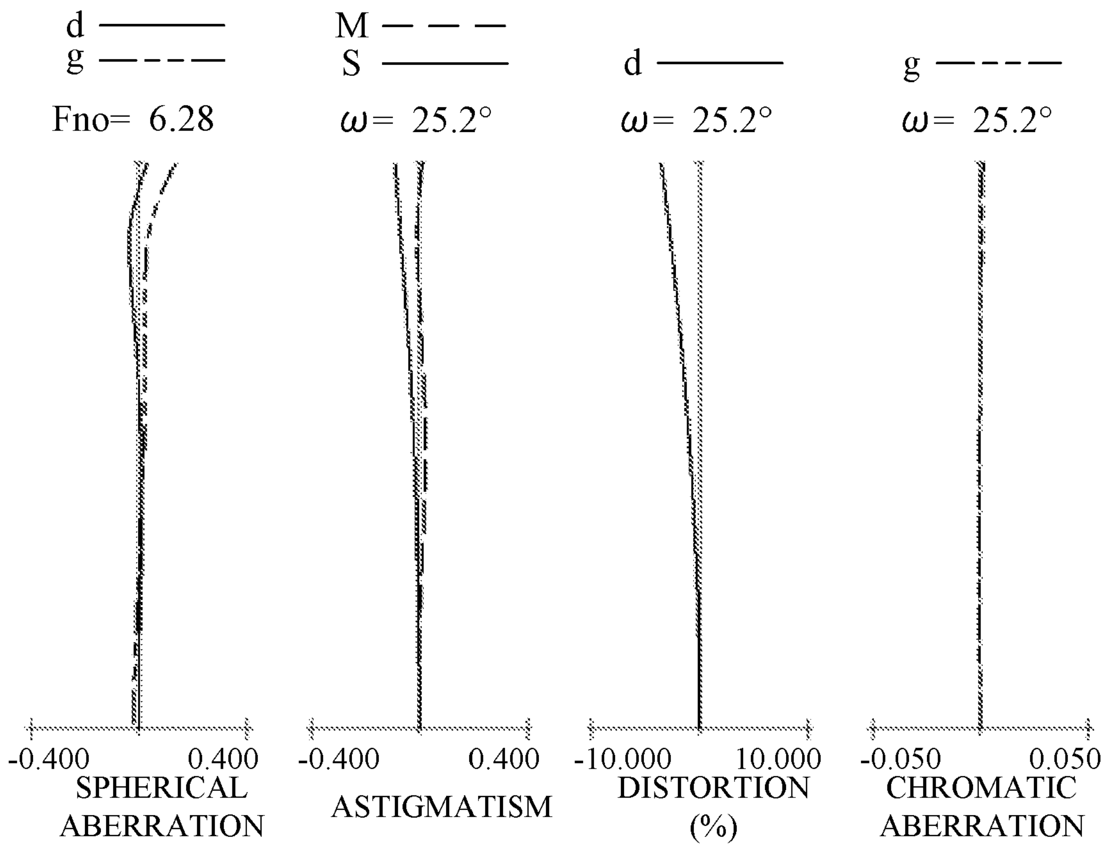

FIG. 26B

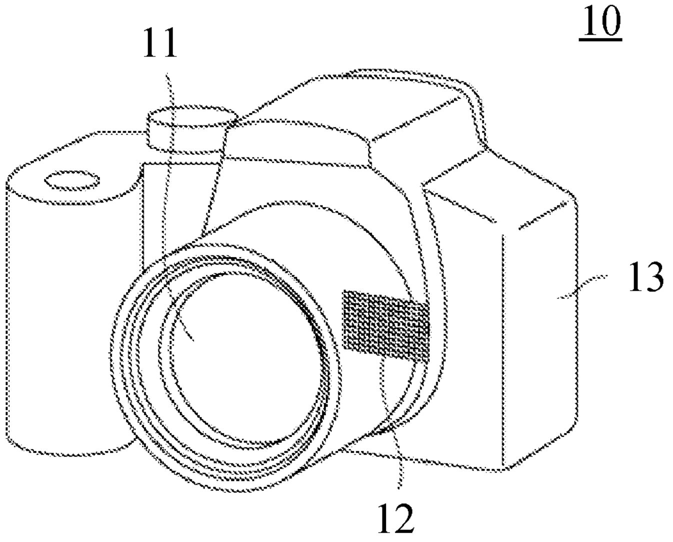

FIG. 27

ZOOM LENS, AND IMAGE PICKUP APPARATUS HAVING THE SAME

BACKGROUND

Technical Field

[0001] The present invention relates generally to a zoom lens, and more particularly to a zoom lens suitable for an image pickup apparatus, such as a digital still camera, a digital video camera, a broadcasting camera, a surveillance camera, an on-board camera (in-vehicle camera), a film-based camera, and the like. The present invention may also relate to an image pickup apparatus comprising a zoom lens.

Description of Related Art

[0002] An imaging optical system for image pickup apparatus has recently been demanded to have a compact zoom lens with a wide angle of view and high optical performance over an overall zoom range.

[0003] Japanese Patent Laid-Open No. 2020-101750 discloses a negative lead type wide-angle zoom lens that includes a first lens unit having negative refractive power disposed closest to an object as a zoom lens with a compact overall system in which a wide angle of view is easy.

[0004] The negative lead type wide-angle zoom lens proposed in Japanese Patent Laid-Open No. 2020-101750 has a wide angle of view and high optical performance by moving the first lens unit having negative refractive power during zooming from a wide-angle end to a telephoto end.

[0005] However, the configuration of moving the large and heavy first lens unit as in the wide-angle zoom lens described in Japanese Patent Laid-Open No. 2020-101750 complicates a moving mechanism and is disadvantageous from the viewpoint of miniaturization and weight reduction.

SUMMARY

[0006] The present invention in its first aspect provides a zoom lens as specified in claims 1.

[0007] Preferable or optional features are specified individually or in combination in claims 2 to 25.

[0008] The present invention in its second aspect provides an image pickup apparatus as specified in claim 26.

[0009] Further features of the present invention will become apparent from the following description of embodiments with reference to the attached drawings. Each of the embodiments of the present invention described below can be implemented solely or as a combination of a plurality of the embodiments. Also, features or elements from different embodiments can be combined where necessary or where the combination of elements or features from individual embodiments in a single embodiment is beneficial.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 1 of the present invention.

[0011] FIGs. 2A and 2B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 1, respectively.

[0012] FIG. 3 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 2 of the present invention.

[0013] FIGs. 4A and 4B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 2, respectively.

[0014] FIG. 5 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 3 of the present invention.

[0015] FIGs. 6A and 6B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 3, respectively.

[0016] FIG. 7 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 4 of the present invention.

[0017] FIGs. 8A and 8B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 4, respectively.

[0018] FIG. 9 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 5 of the present invention.

[0019] FIGs. 10A and 10B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 5, respectively.

[0020] FIG. 11 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 6 of the present invention.

[0021] FIGs. 12A and 12B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 6, respectively.

[0022] FIG. 13 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 7 of the present invention.

[0023] FIGs. 14A and 14B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 7, respectively.

[0024] FIG. 15 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 8 of the present invention.

[0025] FIGs. 16A and 16B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 8, respectively.

[0026] FIG. 17 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 9 of the present invention.

[0027] FIGs. 18A and 18B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 9, respectively.

[0028] FIG. 19 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 10 of the present invention.

[0029] FIGs. 20A and 20B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 10, respectively.

[0030] FIG. 21 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 11 of the present invention.

[0031] FIGs. 22A and 22B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 11, respectively.

[0032] FIG. 23 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 12 of the present invention.

[0033] FIGs. 24A and 24B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 12, respectively.

[0034] FIG. 25 is a lens sectional view in an in-focus state on the infinity object at a wide-angle end and a telephoto end according to Example 13 of the present invention.

[0035] FIGs. 26A and 26B are longitudinal aberration diagrams in the in-focus state on the infinity object at the wide-angle end and telephoto end according to Example 13, respectively.

[0036] FIG. 27 is a schematic diagram of an image pickup apparatus according to the present invention.

DESCRIPTION OF THE EMBODIMENTS

[0037] Referring now to the accompanying drawings, a description will be given of a zoom lens, an image pickup apparatus, and an image pickup system according to the present invention and disclosure.

[0038] FIGs. 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, and 25 are lens sectional views of zoom lenses according to Examples 1 to 13 of the present invention, respectively, in in-focus states at infinity at a wide-angle end (WIDE) and a telephoto end (TELE). A zoom lens according to each example may be a zoom lens for an image pickup apparatus such as a digital still camera, a film-based camera, a digital video camera, a surveillance camera, a broadcasting camera, and an on-board camera.

[0039] In each lens sectional view, a left side is an object side (front) and a right side is an image side (back). The zoom lens according to each example includes a plurality of lens units. In this specification, a lens unit may be a group of lenses that move or stand still during zooming. That is, in the zoom lens according to each example, a distance between adjacent lens units changes during zooming from the wide-angle end to the telephoto end. Each lens unit may include one or more lenses. The lens unit may include an aperture stop.

[0040] In each lens sectional view, Li represents an i-th (where i is a natural number) lens unit counted from the object side in the zoom lens.

[0041] SP denotes the aperture stop. The aperture stop SP determines (limits) a light beam of the maximum aperture F-number (Fno). IP denotes an image plane, and in a case where the zoom lens according to each example is used as an imaging optical system of a digital still camera or video camera, the imaging plane of a solid-state image sensor (photoelectric conversion element) such as a CCD sensor or CMOS sensor is disposed on the image plane IP. In a case where the zoom lens according to any example is used as an imaging optical system of a film-based camera, a photosensitive plane corresponding to the film plane is placed on the image plane IP.

[0042] An arrow in the optical axis direction indicates a moving direction of the focus lens unit during focusing from infinity to a close (or short) distance. A solid arrow illustrated below each lens unit indicates a moving locus of each lens unit during zooming from the wide-angle end to the telephoto end. A vertical broken line below each lens unit indicates that each lens unit is fixed relative to the image plane during zooming from the wide-angle end to the telephoto end. A bidirectional arrow in a direction orthogonal to the optical axis indicates movement of a lens unit during image stabilization.

[0043] In each of the following examples, the wide-angle end and the telephoto end refer to zoom positions in a case where the lens unit for zooming is mechanically located at both ends of the movable range on the optical axis.

[0044] FIGs. 2A, 2B, 4A, 4B, 6A, 6B, 8A, 8B, 10A, 10B, 12A, 12B, 14A, 14B, 16A, 16B, 18A, 18B, 20A, 20B, 22A, 22B, 24A, 24B, 26A, and 26B illustrate zoom lenses according to Examples 1 to 13, respectively. FIGs. 2A, 4A, 6A, 8A, 10A, 12A, 14A, 16A, 18A, 20A, 22A, 24A, and 26A are aberration diagrams at the wide-angle end, and FIGs. 2B, 4B, 6B, 8B, 10B, 12B, 14B, 16B, 18B, 20B, 22B, 24B, and 26B are aberration diagrams at the telephoto end.

[0045] In a spherical aberration diagram, Fno denotes an F-number. The spherical aberration diagram illustrates spherical aberration amounts for the d-line (wavelength 587.6 nm) and g-line (wavelength 435.8 nm). In an astigmatism diagram, S indicates an astigmatism amount on a sagittal image plane, and M indicates an astigmatism amount on a meridional image plane. A distortion diagram illustrates a distortion amount for the d-line. A chromatic aberration diagram illustrates a chromatic aberration amount for the g-line. ω denotes a half angle of view (°) (angle of view in paraxial calculation) and indicates the angle of view according to a ray tracing value.

[0046] A description will now be given of the characteristic configuration of the zoom lens according to each example.

[0047] The zoom lens according to each example includes a plurality of lens units that consist of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. In each example, a distance between adjacent lens units changes during zooming from the wide-angle end to the telephoto end.

[0048] The first lens unit L1 includes three or more lenses. During zooming from the wide-angle end to the telephoto end, the first lens unit L1 is fixed relative to the image plane IP.

[0049] The zoom lens according to each example satisfies the following inequalities (1) to (3), where f1 is a focal length of the first lens unit L1, f2 is a focal length of the second lens unit L2, f4 is a focal length of the fourth lens unit L4. LD1 is a distance on the optical axis from a lens surface on the object side of a lens closest to the object in the first lens unit L1 to a lens surface on the image side of a lens closest to the image plane in the first lens unit L1. In the zoom lens at the wide-angle end, TTL is a distance on the optical axis from the lens surface on the object side of the lens closest to the object to the image plane IP (overall length obtained by removing a parallel plate such as a filter) (overall lens length).

$$0.85 < (-f1)/f2 < 2.00 \quad (1)$$

$$0.00 < (-f1)/f4 < 0.55 \quad (2)$$

$$0.00 < LD1/TTL < 0.27 \quad (3)$$

[0050] Inequality (1) is an inequality that defines a ratio between the focal length f1 of the first lens unit L1 and the focal length f2 of the second lens unit L2. In a case where the refractive power of the second lens unit L2 becomes stronger and the value of (-f1)/f2 becomes higher than the upper limit of inequality (1), it becomes difficult to correct aberrations. In a case where the refractive power of the second lens unit L2 becomes weaker and the value of (-f1)/f2 becomes lower than the lower limit of inequality (1), the moving amount of the second lens unit L2 increases during zooming, and the zoom lens becomes larger.

[0051] Inequality (2) is an inequality that defines a ratio between the focal length f1 of the first lens unit L1 and the focal length f4 of the fourth lens unit L4. Satisfying inequality (2) can reduce the size of the zoom lens while telecentricity is maintained. In a case where the refractive power of the fourth lens unit L4 increases and the value of (-f1)/f4 becomes higher than the upper limit of inequality (2), the telecentricity improves but the zoom lens becomes larger. The value of (-f1)/f4 cannot become lower than the lower limit of inequality (2).

[0052] Inequality (3) is an inequality that defines a distance LD1 on the optical axis from the lens surface on the object side of the lens closest to the object in the first lens unit L1 to the lens surface on the image side of the lens closest to the image plane in the first lens unit L1 and the overall lens length TTL of the zoom lens at the wide-angle end. Satisfying inequality (3) can reduce the weight of the zoom lens. In a case where the value of LD1/TTL becomes higher than the upper limit of inequality (3), the distance LD1 becomes too large, and the first lens unit L1 becomes larger. The value of LD1/TTL cannot become lower than the lower limit of inequality (3).

[0053] Inequalities (1) to (3) may be replaced with the following inequalities (1a) to (3a):

$$0.88 < (-f1)/f2 < 1.70 \quad (1a)$$

$$0.09 < (-f1)/f4 < 0.52 \quad (2a)$$

$$0.07 < LD1/TTL < 0.25 \quad (3a)$$

[0054] Inequalities (1) to (3) may be replaced with the following inequalities (1b) to (3b):

$$0.89 < (-f1)/f2 < 1.41 \quad (1b)$$

$$0.16 < (-f1)/f4 < 0.50 \quad (2b)$$

$$0.13 < LD1/TTL < 0.24 \quad (3b)$$

[0055] As described above, the zoom lens according to each example is configured to satisfy inequalities (1) to (3). Thereby, each example can provide a negative lead type wide-angle zoom lens that is compact and lightweight yet has high optical performance over the entire zoom range.

[0056] A description of configurations of zoom lenses according to each example will be given.

[0057] In the zoom lens of each example, the first lens unit L1 may consist of lenses having refractive powers. Thereby, the aberration generated in the first lens unit L1 can be satisfactorily corrected, which is beneficial in miniaturization of the zoom lens.

[0058] In the zoom lens of each example, the second lens unit L2 may include an aperture stop SP. The third lens unit L3 may be a focus lens unit that moves during focusing. The third lens unit may consist of a single negative fixed focal length lens or two negative fixed focal length lenses. Thereby, high optical performance can be achieved over focusing from a short-distance object to a long-distance object.

[0059] A description will be given of inequalities that the zoom lens according to each example may satisfy. The zoom lens according to each example may satisfy one or more of the following inequalities (4) to (17).

[0060] Here, BFw is an air conversion amount of a distance on the optical axis from the lens surface on the image side of the lens closest to the image plane IP to the image plane IP in the zoom lens at the wide-angle end in an in-focus state on the infinity object (distance obtained by removing a parallel plate, such as a filter) (back focus). fw is a focal length of the zoom lens at the wide-angle end. f3 is a focal length of the third lens unit L3. ft is a focal length of the zoom lens at the telephoto end. β2t is lateral magnification of the second lens unit L2 at the telephoto end in the in-focus state on the infinity object. β2w is lateral magnification of the second lens unit L2 at the wide-angle end in the in-focus state on the infinity object. β3t is lateral magnification of the third lens unit L3 at the telephoto end in the in-focus state on the infinity object. β3w is lateral magnification of the third lens unit L3 at the wide-angle end in the in-focus state on the infinity object. fn1 is a focal length of the first negative lens in the first lens unit L1. fn2 is a focal length of the second negative lens in the first lens unit L1. fp1 is a focal length of the first positive lens in the first lens unit L1.

$$0.30 < BFw/(-f1) < 1.50 \quad (4)$$

$$0.07 < BFw/TTL < 0.30 \quad (5)$$

$$2.0 < TTL/(-f1) < 6.0 \quad (6)$$

$$3.0 < TTL/fw < 7.5 \quad (7)$$

$$0.1 < f2/(-f3) < 1.5 \quad (8)$$

$$0.05 < f2/f4 < 0.80 \quad (9)$$

$$0.1 < (-f3)/f4 < 2.0 \quad (10)$$

$$0.5 < (-f1)/fw < 2.5 \quad (11)$$

$$0.2 < (-f1)/ft < 1.4 \quad (12)$$

$$0.5 < \beta 2t/\beta 2w < 3.0 \quad (13)$$

$$0.5 < \beta 3t/\beta 3w < 2.0 \quad (14)$$

$$0.5 < fn1/f1 < 2.0 \quad (15)$$

$$0.5 < fn2/f1 < 10.0 \quad (16)$$

$$0.5 < fp1/(-f1) < 5.0 \quad (17)$$

[0061] Inequality (4) is an inequality that defines a ratio between the back focus BFw of the zoom lens at the wide-angle end in the in-focus state on the infinity object and the focal length f1 of the first lens unit L1. In a case where the refractive power of the first lens unit L1 becomes stronger and the value of BFw/(-f1) becomes higher than the upper limit of inequality (4), aberration correction becomes difficult. In a case where the refractive power of the first lens unit L1 becomes weaker and the value of BFw/(-f1) becomes lower than the lower limit of inequality (4), the zoom lens becomes larger.

[0062] Inequality (5) is an inequality that defines a ratio between the back focus BFw of the zoom lens at the wide-angle end in the in-focus state on the infinity object and the overall lens length TTL of the zoom lens at the wide-angle end. Satisfying inequality (5) can reduce the size of the zoom lens while telecentricity is maintained. In a case where the value of BFw/TTL becomes higher than the upper limit of inequality (5), the zoom lens becomes larger. In a case where the value of BFw/TTL becomes lower than the lower limit of inequality (5), the back focus BFw becomes too short, and it becomes difficult to maintain telecentricity.

[0063] Inequality (6) is an inequality that defines a ratio between the overall lens length TTL of the zoom lens at the wide-angle end and the focal length f1 of the first lens unit L1. In a case where the refractive power of the first lens unit L1 becomes stronger and the value of TTL/(-f1) becomes higher than the upper limit of inequality (6), aberration correction becomes difficult. In a case where the refractive power of the first lens unit L1 becomes weaker and the value of TTL/(-f1) becomes lower than the lower limit of inequality (6), the zoom lens becomes larger.

[0064] Inequality (7) is an inequality that defines a ratio between the overall lens length TTL of the zoom lens at the wide-angle end and the focal length fw of the zoom lens at the wide-angle end. In a case where the value of TTL/fw becomes higher than the upper limit of inequality (7), the zoom lens becomes larger. In a case where the value of TTL/fw becomes lower than the lower limit of inequality (7), aberration correction becomes difficult.

[0065] Inequality (8) is an inequality that defines a ratio between the focal length f2 of the second lens unit L2 and the focal length f3 of the third lens unit L3. In a case where the refractive power of the second lens unit L2 becomes weaker and the value of f2/(-f3) becomes higher than the upper limit of inequality (8), the zoom lens becomes larger. In a case where the refracting power of the second lens unit L2 becomes stronger and the value of f2/(-f3) becomes lower than the lower limit of inequality (8), aberration correction becomes difficult.

[0066] Inequality (9) is an inequality that defines a ratio between the focal length f2 of the second lens unit L2 and the focal length f4 of the fourth lens unit L4. In a case where the refractive power of the second lens unit L2 becomes weaker and the value of f2/f4 becomes higher than the upper limit of inequality (9), the zoom lens becomes larger. In a case where the refracting power of the second lens unit L2 becomes stronger and the value of f2/f4 becomes lower than the lower limit of inequality (9), aberration correction becomes difficult.

[0067] Inequality (10) is an inequality that defines a ratio between the focal length f3 of the third lens unit L3 and the focal length f4 of the fourth lens unit L4. In a case where the refractive power of the third lens unit L3 becomes weaker and the value of (-f3)/f4 becomes higher than the upper limit of inequality (10), the zoom lens becomes larger. In a case where the refractive power of the third lens unit L3 becomes stronger and the value of (-f3)/f4 becomes lower than the lower limit of inequality (10), aberration correction becomes difficult.

[0068] Inequality (11) is an inequality that defines a ratio between the focal length f1 of the first lens unit L1 and the focal length fw of the zoom lens at the wide-angle end. In a case where the refractive power of the first lens unit L1 becomes weaker and the value of (-f1)/fw becomes higher than the upper limit of inequality (11), the zoom lens becomes larger. In a case where the refracting power of the first lens unit L1 becomes stronger and the value of (-f1)/fw becomes lower than the lower limit of inequality (11), aberration correction becomes difficult.

[0069] Inequality (12) is an inequality that defines a ratio between the focal length f1 of the first lens unit L1 and the focal length ft of the zoom lens at the telephoto end. In a case where the refractive power of the first lens unit L1 becomes weaker and the value of (-f1)/ft becomes higher than the upper limit of inequality (12), the zoom lens becomes larger. In a case where the refractive power of the first lens unit L1 becomes stronger and the value of (-f1)/ft becomes lower than the lower limit of inequality (12), aberration correction becomes difficult.

[0070] Inequality (13) is an inequality that defines a ratio between the lateral magnification β2t of the second lens unit L2 at the telephoto end in the in-focus state on the infinity object and the lateral magnification β2w of the second lens unit L2 at the wide-angle end in the in-focus state on the infinity object. In a case where inequality (13) is not satisfied, aberration correction becomes difficult over the entire zoom range.

[0071] Inequality (14) is an inequality that defines a ratio between the lateral magnification β3t of the third lens unit L3 at the telephoto end in the in-focus state on the infinity object and the lateral magnification β3w of the third lens unit L3 at the wide-angle end in the in-focus state on the infinity object. In a case where inequality (14) is not satisfied, aberration correction becomes difficult over the entire zoom range.

[0072] Inequality (15) is an inequality that defines a ratio between the focal length fn1 of the first negative lens, which is one of the lenses in the first lens unit L1, and the focal length f1 of the first lens unit L1. In a case where inequality (15) is not satisfied, aberration correction becomes difficult over the entire zoom range.

[0073] Inequality (16) is an inequality that defines a ratio between the focal length fn2 of the second negative lens, which is one of the lenses in the first lens unit L1, and the focal length f1 of the first lens unit L1. In a case where inequality (16) is not satisfied, aberration correction becomes difficult over the entire zoom range.

[0074] Inequality (17) is an inequality that defines a ratio between the focal length fp1 of the first positive lens, which is one of the lenses in the first lens unit L1, and the focal length f1 of the first lens unit L1. In a case where inequality (17) is not satisfied, aberration correction becomes difficult over the entire zoom range.

[0075] Inequalities (4) to (17) may be replaced with the following inequalities (4a) to (17a):

$$0.33 < BFw/(-f1) < 1.11 \quad (4a)$$

$$0.10 < BFw/TTL < 0.27 \quad (5a)$$

$$2.3 < TTL/(-f1) < 5.3 \quad (6a)$$

$$3.6 < TTL/fw < 7.1 \quad (7a)$$

$$0.17 < f2/(-f3) < 1.12 \quad (8a)$$

$$0.09 < f2/f4 < 0.62 \quad (9a)$$

$$0.15 < (-f3)/f4 < 1.68 \quad (10a)$$

$$0.89 < (-f1)/fw < 2.11 \quad (11a)$$

$$0.39 < (-f1)/ft < 1.13 \quad (12a)$$

$$1.0 < \beta 2t/\beta 2w < 2.45 \quad (13a)$$

$$0.8 < \beta 3t/\beta 3w < 1.63 \quad (14a)$$

$$0.60 < fn1/f1 < 1.82 \quad (15a)$$

$$0.76 < fn2/f1 < 8.22 \quad (16a)$$

$$0.72 < fp1/(-f1) < 4.16 \quad (17a)$$

[0076] Inequalities (4) to (17) may be replaced with the following inequalities (4b) to (17b):

$$0.37 < BFw/(-f1) < 0.75 \quad (4b)$$

$$0.12 < BFw/TTL < 0.24 \quad (5b)$$

$$2.7 < TTL/(-f1) < 4.7 \quad (6b)$$

$$4.3 < TTL/fw < 6.8 \quad (7b)$$

$$0.23 < f2/(-f3) < 0.76 \quad (8b)$$

$$0.11 < f2/f4 < 0.45 \quad (9b)$$

$$0.17 < (-f3)/f4 < 1.37 \quad (10b)$$

$$1.2 < (-f1)/fw < 1.9 \quad (11b)$$

$$0.58 < (-f1)/ft < 0.90 \quad (12b)$$

$$1.5 < \beta 2t/\beta 2w < 2.0 \quad (13b)$$

$$1.09 < \beta 3t/\beta 3w < 1.26 \quad (14b)$$

$$0.68 < fn1/f1 < 1.65 \quad (15b)$$

$$1.0 < fn2/f1 < 6.5 \quad (16b)$$

$$0.9 < fp1/(-f1) < 3.4 \quad (17b)$$

[0077] A detailed description will now be given of the zoom lens according to each example.

[0078] The zoom lens according to Example 1 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the first lens unit L1 in a direction including a component in a direction orthogonal to the optical axis.

[0079] The zoom lens according to Example 2 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the second lens unit L2 in a direction including a component in a direction orthogonal to the optical axis.

[0080] The zoom lens according to Example 3 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the second lens unit L2 in a direction including a component in a direction orthogonal to the optical axis.

[0081] The zoom lens according to Example 4 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the first lens unit L1 in a direction including a component in a direction orthogonal to the optical axis.

[0082] The zoom lens according to Example 5 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the second lens unit L2 in a direction including a component in a direction orthogonal to the optical axis.

[0083] The zoom lens according to Example 6 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the fourth lens unit L4 in a direction including a component in a direction orthogonal to the optical axis.

[0084] The zoom lens according to Example 7 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the second lens unit L2 in a direction including a component in a direction orthogonal to the optical axis.

[0085] The zoom lens according to Example 8 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the second lens unit L2 in a direction including a component in a direction orthogonal to the optical axis.

[0086] The zoom lens according to Example 9 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the first lens unit L1 in a direction including a component in a direction orthogonal to the optical axis.

[0087] The zoom lens according to Example 10 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the second lens unit L2 in a direction including a component in a direction orthogonal to the optical axis.

[0088] The zoom lens according to Example 11 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the first lens unit L1 in a direction including a component in a direction orthogonal to the optical axis.

[0089] The zoom lens according to Example 12 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the first lens unit L1 in a direction including a component in a direction orthogonal to the optical axis.

[0090] The zoom lens according to Example 13 consists of, in order from the object side to the image side, a first lens unit L1 having negative refractive power, a second lens unit L2 having positive refractive power, a third lens unit L3 having negative refractive power, and a fourth lens unit L4 having positive refractive power. During zooming from the wide-angle end to the telephoto end, a distance between adjacent lens units changes, and the first lens unit L1 and the fourth lens unit L4 are fixed relative to the image plane IP. During focusing, the third lens unit L3 moves. Image stabilization may be performed by moving a part of the first lens unit L1 in a direction including a component in a direction orthogonal to the optical axis.

[0091] Numerical Examples 1 to 13 corresponding to Examples 1 to 13 will be illustrated below.

[0092] In surface data of each numerical example, r represent a radius of curvature of each optical surface, and d (mm) represents an on-axis distance (distance on the optical axis) between an m-th surface and an (m+1)-th surface, where m is a surface number counted from the light incident side. nd represents a refractive index for the d-line of each optical element, and νd represents an Abbe number of the optical element based on the d-line. The Abbe number νd of a certain material is expressed as follows:

$$\nu d = (Nd-1)/(NF-NC)$$

where Nd, NF, and NC are refractive indices based on the d-line (587.6 nm), the F-line (486.1 nm), and the C-line (656.3 nm) in the Fraunhofer line, respectively.

[0093] In each numerical example, values of d, a focal length (mm), an F-number, and a half angle of view (°) are set in a case where the optical system according to each example is in the in-focus state on the infinity object. A back focus BF is a distance on the optical axis from the final lens surface (lens surface closest to the image plane) of the zoom lens L0 to the paraxial image plane expressed in air conversion length. The overall lens length of the zoom lens L0 is a length obtained by adding the back focus to a distance on the optical axis from the first lens surface (lens surface closest to the object) to the final lens surface. The lens unit includes one or more lenses.

[0094] In a case where the optical surface is aspherical, an asterisk * is attached to the right side of the surface number. The aspherical shape is expressed as follows:

$$X=(h^2/R)/[1+\{1-(1+K)(h/R)^2\}^{1/2}]+A4\times h^4+A6\times h^6+A8\times h^8+A10\times h^{10}+A12\times h^{12}$$

where X is a displacement amount from a surface vertex in the optical axis direction, h is a height from the optical axis in a direction orthogonal to the optical axis, a light traveling direction is set positive, R is a paraxial radius of curvature, K is a conic constant, and A4, A6, A8, A10, and A12 are aspheric coefficients. "e±XX" in each aspheric coefficient means "$\times 10^{\pm XX}$."

NUMERICAL EXAMPLE 1

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	vd
1	31.510	1.00	1.80400	46.5
2	13.253	5.81		
3	384.169	1.00	1.59282	68.6
4	16.237	2.57		
5	20.027	2.35	1.85478	24.8

6	43.038	2.86		
7	-122.389	1.00	1.49700	81.5
8	153.848	(Variable)		
9	-132.462	2.51	1.48749	70.2
10	-22.094	2.50		
11 (SP)	∞	0.50		
12	16.955	4.23	1.83481	42.7
13	-15.911	1.90	1.90366	31.3
14	46.587	4.62		
15	20.752	0.90	1.80400	46.5
16	8.522	3.98	1.49700	81.5
17	-23.714	(Variable)		
18	-19.766	0.80	1.56732	42.8
19	209.263	2.07		
20*	-13.721	2.00	1.53110	55.9
21*	-19.057	(Variable)		
22	-129.610	4.47	1.85150	40.8
23	-26.924	12.29		
IP	∞			

ASPHERIC DATA

20th Surface

K = 0.00000e+00 A 4= 3.64281e-04 A 6= 2.03779e-06 A 8=-1.61378e-08

21st Surface

K = 0.00000e+00 A 4= 3.50063e-04 A 6= 1.61923e-06 A 8=-1.64849e-08

Various Data

Zoom Ratio 2.34

	WIDE	MIDDLE	TELE
Focal Length	12.42	18.65	29.07
Fno	4.10	5.13	6.40
Half Angle of View (°)	47.72	36.22	25.17
Image Height	11.37	12.86	13.66
Overall Lens Length	82.97	82.97	82.97
BF	12.29	12.29	12.29
d 8	18.70	10.05	1.39
d17	1.69	2.74	6.86
d21	3.20	10.80	15.34

ZOOM LENS UNIT DATA

Unit No.	Starting Surface	Focal Length
1	1	-17.76
2	9	17.38
3	18	-24.70
4	22	39.13

NUMERICAL EXAMPLE 2

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	vd
1	34.396	1.00	1.77250	49.6
2	13.292	5.69		
3	-323.606	1.00	1.59282	68.6

4	16.748	2.92		
5	20.652	2.29	1.84666	23.8
6	36.566	(Variable)		
7	-301.068	3.73	1.48749	70.2
8	-30.039	4.78		
9 (SP)	∞	0.50		
10	19.485	3.34	1.83481	42.7
11	-14.251	1.90	1.90366	31.3
12	∞	4.14		
13	25.728	1.00	1.83481	42.7
14	9.171	3.79	1.49700	81.5
15	-26.368	(Variable)		
16	-23.072	0.80	1.51742	52.4
17	82.694	2.02		
18*	-15.829	2.00	1.53110	55.9
19*	-21.570	(Variable)		
20	-120.000	4.42	1.77250	49.6
21	-27.671	12.13		
IP	∞			

ASPHERIC DATA

18th Surface

K = 0.00000e+00 A 4= 3.32711e-04 A 6= 1.73403e-06 A 8=-1.45204e-08

19th Surface

K = 0.00000e+00 A 4= 3.39522e-04 A 6= 1.63472e-06 A 8=-1.61755e-08

Various Data

Zoom Ratio 2.35

	WIDE	MIDDLE	TELE
Focal Length	12.40	18.66	29.10
Fno	4.10	5.10	6.40
Half Angle of View (°)	47.76	36.21	25.15
Image Height	11.37	12.86	13.66
Overall Lens Length	83.44	83.44	83.44
BF	12.13	12.13	12.13

d 6	19.82	10.85	1.88
d15	1.77	2.36	6.01
d19	4.41	12.78	18.10
d21	12.13	12.13	12.13

ZOOM LENS UNIT DATA

Unit No.	Starting Surface	Focal Length
1	1	-18.26
2	7	17.57
3	16	-27.60
4	20	45.60

NUMERICAL EXAMPLE 3

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	vd
1	35.706	1.00	1.77250	49.6
2	14.414	5.20		

3	-441.444	1.00	1.59282	68.6
4	16.131	3.30		
5	21.292	3.27	1.84666	23.8
6	38.733	(Variable)		
7	-260.840	2.46	1.48749	70.2
8	-33.213	2.00		
9 (SP)	∞	2.00		
10	20.926	4.64	1.85150	40.8
11	-18.671	0.22		
12	-17.428	0.80	1.85478	24.8
13	218.347	4.07		
14	28.492	1.00	1.72916	54.7
15	9.356	5.18	1.49700	81.5
16	-24.952	(Variable)		
17	-22.720	0.80	1.57099	50.8
18	148.402	1.72		
19*	-23.196	2.00	1.53110	55.9
20*	-30.564	(Variable)		
21	-120.000	4.34	1.77250	49.6
22	-27.692	(Variable)		
IP	∞			

ASPHERIC DATA

19th Surface

K = 0.00000e+00 A 4= 2.94393e-04 A 6= 7.13003e-07 A 8=-1.72892e-08

20th Surface

K = 0.00000e+00 A 4= 3.24911e-04 A 6= 1.01599e-06 A 8=-1.72183e-08

Various Data

Zoom Ratio 2.35

	WIDE	MIDDLE	TELE
Focal Length	12.40	18.69	29.10
Fno	4.10	4.10	4.10
Half Angle of View (°)	47.76	36.16	25.15
Image Height	11.37	12.86	13.66
Overall Lens Length	82.02	82.02	82.02
BF	12.79	12.79	12.79
d 6	19.99	10.92	1.84
d16	1.66	2.03	5.63
d20	2.58	11.29	16.76
d22	12.79	12.79	12.79

ZOOM LENS UNIT DATA

Unit No.	Starting Surface	Focal Length
1	1	-19.53
2	7	17.94
3	17	-29.69
4	21	45.67

NUMERICAL EXAMPLE 4

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	vd

1	114.124	1.00	1.77250	49.6
2	12.042	4.29		
3*	43.105	2.50	1.53110	55.9
4*	20.966	1.99		
5	35.204	2.90	1.77047	29.7
6	-114.527	1.97		
7	-32.492	1.00	1.49700	81.5
8	-70.456	(Variable)		
9	18.171	1.94	1.77250	49.6
10	-529.066	2.48		
11 (SP)	∞	1.38		
12	12.421	1.79	1.59282	68.6
13	44.069	0.36		
14	-46.037	1.00	1.68893	31.1
15	10.684	0.48		
16	25.111	3.36	1.59282	68.6
17	-21.982	(Variable)		
18*	-18.435	2.00	1.53110	55.9
19*	-32.813	(Variable)		
20	-120.000	4.59	1.63854	55.4
21	-29.908	11.78		
IP	∞			

ASPHERIC DATA

3rd Surface

K = 0.00000e+00   A 4=-8.94309e-05   A 6= 7.11824e-07   A 8=-3.52027e-09

4th Surface

K = 0.00000e+00 A 4=-1.48535e-04 A 6= 6.59805e-07 A 8=-5.15433e-09

18th Surface

K = 0.00000e+00 A 4= 2.68346e-04 A 6= 2.81044e-06 A 8=-9.40023e-08

19th Surface

K = 0.00000e+00 A 4= 2.67097e-04 A 6= 1.59679e-06 A 8=-5.11740e-08

Various Data

Zoom Ratio 2.02

	WIDE	MIDDLE	TELE
Focal Length	14.40	20.07	29.10
Fno	4.10	5.02	6.29
Half Angle of View (°)	43.40	34.24	25.14
Image Height	11.46	12.40	13.17
Overall Lens Length	75.06	75.06	75.06
BF	11.78	11.78	11.78
d 8	16.11	8.43	0.74
d17	1.84	1.00	6.15
d19	10.29	18.81	21.35
d21	11.78	11.78	11.78

ZOOM LENS UNIT DATA

Unit No.	Starting Surface	Focal Length
1	1	-21.90
2	9	19.73
3	18	-83.23

4	20	61.17

NUMERICAL EXAMPLE 5

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	vd
1	235.833	1.00	1.77250	49.6
2	10.085	4.16		
3*	-895.559	2.50	1.53110	55.9
4*	44.647	1.74		
5	64.099	1.78	2.05090	26.9
6	-162.178	(Variable)		
7	-459.615	2.29	1.48749	70.2
8	-33.943	4.00		
9	18.560	3.57	1.69680	55.5
10	-16.150	1.00	1.90043	37.4
11	-62.644	1.84		
12 (SP)	∞	4.68		
13	25.922	1.00	1.83481	42.7
14	8.456	4.21	1.49700	81.5
15	-26.343	(Variable)		
16	-34.878	0.80	1.61772	49.8
17	139.823	4.14		
18*	-9.417	2.00	1.53110	55.9
19*	-12.991	(Variable)		
20	-120.000	4.63	1.63854	55.4
21	-24.348	11.50		

IP ∞

ASPHERIC DATA

3rd Surface

K = 0.00000e+00 A 4=-8.12193e-05 A 6= 8.99724e-07 A 8=-1.19209e-08

4th Surface

K = 0.00000e+00 A 4=-1.28410e-04 A 6= 3.69150e-07 A 8=-1.09948e-08

18th Surface

K = 0.00000e+00 A 4= 2.77887e-04 A 6= 6.15575e-06 A 8=-2.56537e-08

19th Surface

K = 0.00000e+00 A 4= 2.14784e-04 A 6= 3.85389e-06 A 8=-2.47687e-08

Various Data

Zoom Ratio 2.02

	WIDE	MIDDLE	TELE
Focal Length	14.40	20.23	29.10
Fno	4.10	5.04	6.40
Half Angle of View (°)	43.30	34.02	25.14
Image Height	11.42	12.56	13.22
Overall Lens Length	78.52	78.52	78.52
BF	11.50	11.50	11.50
d 6	16.23	8.82	1.41
d15	1.45	2.48	6.02
d19	3.98	10.37	14.24

d21	11.50	11.50	11.50

ZOOM LENS UNIT DATA

Unit No.	Starting Surface	Focal Length
1	1	-18.40
2	7	18.55
3	16	-28.78
4	20	46.95

NUMERICAL EXAMPLE 6

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	vd
1	93.086	1.00	1.77250	49.6
2	11.534	5.04		
3*	35.096	2.50	1.53110	55.9
4*	18.745	1.76		
5	34.034	2.40	1.84666	23.8
6	247.520	(Variable)		
7	21.135	3.07	1.77250	49.6
8	-83.384	2.42		
9 (SP)	∞	1.42		
10	11.906	1.79	1.60311	60.6
11	24.109	0.36		
12	-32.365	1.05	1.72151	29.2
13	11.247	0.46		
14	18.005	2.74	1.60311	60.6

15	-16.851	(Variable)		
16*	-20.785	2.00	1.53110	55.9
17*	-46.785	(Variable)		
18	227.811	1.00	1.65844	50.9
19	39.504	5.98		
20	41.856	6.15	1.72916	54.7
21	-63.192	13.08		
IP	∞			

ASPHERIC DATA

3rd Surface

K = 0.00000e+00 A 4=-1.05255e-04 A 6= 6.96967e-07 A 8=-3.20460e-09

4th Surface

K = 0.00000e+00 A 4=-1.71621e-04 A 6= 6.71606e-07 A 8=-5.21171e-09

16th Surface

K = 0.00000e+00 A 4= 2.57526e-04 A 6= 2.11426e-06 A 8=-6.79744e-08

17th Surface

K = 0.00000e+00 A 4= 2.59203e-04 A 6= 1.45831e-06 A 8=-4.89468e-08

Various Data

Zoom Ratio 1.97

	WIDE	MIDDLE	TELE
Focal Length	14.47	19.96	28.47
Fno	4.10	5.01	6.22
Half Angle of View (°)	43.35	34.39	25.63

Image Height	11.42	12.56	13.22
Overall Lens Length	72.82	72.82	72.82
BF	13.08	13.08	13.08

d 6	15.12	7.96	0.79
d15	1.64	0.67	4.33
d17	1.83	9.96	13.47
d21	13.08	13.08	13.08

ZOOM LENS UNIT DATA

Unit No.	Starting Surface	Focal Length
1	1	-22.02
2	7	18.72
3	16	-72.35
4	18	57.69

NUMERICAL EXAMPLE 7

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	vd
1	∞	1.50		
2	49.839	1.40	1.77250	49.6
3	17.865	9.70		
4	-74.024	1.10	1.59282	68.6
5	26.453	2.18		
6	28.144	5.42	1.80610	33.3
7	155.531	(Variable)		

8	24.363	3.01	1.72916	54.7
9	133.320	2.61		
10 (SP)	∞	2.00		
11	42.759	1.00	1.76634	35.8
12	11.137	5.77	1.72916	54.7
13	-107.618	2.85		
14	-20.935	1.00	1.53172	48.8
15	38.508	0.15		
16*	29.415	7.00	1.49700	81.5
17*	-16.643	(Variable)		
18	26.091	0.80	1.60342	38.0
19	16.431	9.30		
20*	-50.394	2.40	1.53110	55.9
21*	-1001.831	(Variable)		
22	-200.000	3.26	1.90065	31.6
23	-61.168	12.68		
IP	∞			

ASPHERIC DATA

16th Surface

K = 0.00000e+00 A 4=-5.16959e-05 A 6=-1.53463e-07 A 8=-3.31876e-09

17th Surface

K = 0.00000e+00 A 4= 3.33206e-05 A 6=-2.05294e-07 A 8=-1.88875e-09

20th Surface

K = 0.00000e+00 A 4=-3.57991e-05 A 6=-1.41049e-07 A 8=-1.54522e-09

21st Surface

K = 0.00000e+00 A 4=-4.36025e-05 A 6=-1.02183e-07 A 8=-4.60803e-10

Various Data

Zoom Ratio 1.89

	WIDE	MIDDLE	TELE
Focal Length	20.60	28.40	39.00
Fno	4.10	4.10	4.10
Half Angle of View (°)	46.40	37.29	29.01
Image Height	17.94	19.62	20.74
Overall Lens Length	97.01	97.01	97.01
BF	12.68	12.68	12.68
d 7	18.11	9.58	1.05
d17	1.79	1.00	2.86
d21	2.00	11.32	18.00
d23	12.68	12.68	12.68

ZOOM LENS UNIT DATA

Unit No.	Starting Surface	Focal Length
1	1	-30.37
2	8	24.27
3	18	-41.20
4	22	96.76

NUMERICAL EXAMPLE 8

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	vd
1	42.299	1.50	1.75500	52.3
2	18.914	8.16		
3	-142.144	1.20	1.59282	68.6
4	30.217	5.54		
5	33.034	2.03	1.96300	24.1
6	50.217	(Variable)		
7	3588.151	3.04	1.53775	74.7
8	-40.853	1.62		
9	23.007	4.07	1.79952	42.2
10	-26.519	1.01	1.95375	32.3
11	79.436	3.46		
12 (SP)	∞	5.69		
13	28.102	1.00	1.85150	40.8
14	11.348	4.25	1.59522	67.7
15	-45.381	(Variable)		
16	41.052	0.80	1.51742	52.4
17	15.294	6.27		
18*	-51.838	2.10	1.53110	55.9
19*	-1006.304	(Variable)		
20	-200.000	5.59	1.77250	49.6
21	-45.565	(Variable)		
IP	∞			

ASPHERIC DATA

18th Surface

K = 0.00000e+00 A 4=-2.18376e-04 A 6= 8.06571e-07 A 8=-7.88304e-09

19th Surface

K = 0.00000e+00 A 4=-1.88281e-04 A 6= 7.88400e-07 A 8=-4.74781e-09

Various Data

Zoom Ratio 2.35

	WIDE	MIDDLE	TELE
Focal Length	20.60	31.11	48.50
Fno	4.10	5.20	5.88
Half Angle of View (°)	46.40	34.81	24.04
Image Height	18.22	20.32	21.64
Overall Lens Length	106.52	106.52	106.52
BF	19.41	19.41	19.41
d 6	26.05	13.88	1.70
d15	1.00	2.05	6.67
d19	2.72	13.84	21.40
d21	19.41	19.41	19.41

ZOOM LENS UNIT DATA

Unit No.	Starting Surface	Focal Length
1	1	-28.51
2	7	23.49
3	16	-31.34
4	20	75.20

NUMERICAL EXAMPLE 9

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	vd
1	60.703	1.30	1.95375	32.3
2	10.568	5.26		
3*	-158.794	2.00	1.53110	55.9
4*	35.904	0.68		
5	69.552	2.59	1.85478	24.8
6	-37.356	0.90		
7	-41.573	1.00	1.43875	94.7
8	-114.793	(Variable)		
9	19.470	2.27	1.65160	58.5
10	-126.753	6.20		
11 (SP)	∞	0.80		
12	13.509	2.32	1.49700	81.5
13	-29.196	0.23		
14	-18.502	2.50	1.59551	39.2
15	10.390	1.45		
16	16.003	2.95	1.43875	94.7
17	-17.071	(Variable)		
18*	-18.646	1.50	1.53110	55.9
19*	-46.212	(Variable)		
20	-40.654	3.48	1.43875	94.7
21	-20.238	13.34		
IP	∞			

ASPHERIC DATA

3rd Surface

K = 0.00000e+00 A 4=-1.84708e-04 A 6= 1.47430e-06 A 8=-1.09499e-08

4th Surface

K = 0.00000e+00 A 4=-2.31582e-04 A 6= 1.38450e-06 A 8=-1.10945e-08

18th Surface

K = 0.00000e+00 A 4= 4.14762e-04 A 6=-1.81540e-06 A 8=-1.40506e-09

19th Surface

K = 0.00000e+00 A 4= 4.21395e-04 A 6=-2.16529e-06 A 8= 8.23735e-09

Various Data

Zoom Ratio 2.01

	WIDE	MIDDLE	TELE
Focal Length	14.45	20.17	29.09
Fno	4.10	5.05	6.40
Half Angle of View (°)	43.39	34.10	25.15
Image Height	11.46	12.41	13.18
Overall Lens Length	77.99	77.99	77.99
BF	13.34	13.34	13.34
d 8	16.17	8.48	0.80
d17	0.80	1.51	7.58
d19	10.26	17.23	18.84
d21	13.34	13.34	13.34

ZOOM LENS UNIT DATA

Unit No. Starting Surface Focal Length

1	1	-18.40
2	9	20.41
3	18	-59.99
4	20	87.31

NUMERICAL EXAMPLE 10

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	νd
1	42.644	1.30	1.72916	54.7
2	17.764	8.77		
3	-70.406	1.20	1.53775	74.7
4	25.301	2.36		
5	25.884	4.26	1.62588	35.7
6	209.726	(Variable)		
7	25.792	2.12	1.59522	67.7
8	539.599	5.57		
9 (SP)	∞	0.88		
10	59.108	1.00	1.69895	30.1
11	19.640	2.76	1.72916	54.7
12	-88.410	2.69		
13	-18.122	1.01	1.54072	47.2
14	71.719	2.69		
15*	23.626	4.90	1.43875	94.7
16*	-14.207	(Variable)		
17	24.461	1.00	1.51633	64.1
18	15.091	9.99		

19*	-51.360	2.00	1.53110	55.9
20*	199.736	(Variable)		
21	-991.849	2.03	2.05090	26.9
22	-167.475	12.67		
IP	∞			

ASPHERIC DATA

15th Surface

K = 0.00000e+00 A 4=-2.76672e-05 A 6=-3.81028e-08 A 8= 1.77147e-09

16th Surface

K = 0.00000e+00 A 4= 8.66431e-05 A 6=-1.50654e-07 A 8= 3.16848e-09

19th Surface

K = 0.00000e+00 A 4=-2.50400e-05 A 6=-1.73349e-07 A 8=-1.30647e-09

20th Surface

K = 0.00000e+00 A 4=-4.36025e-05 A 6=-1.02183e-07 A 8=-4.60803e-10

Various Data

Zoom Ratio 1.88

	WIDE	MIDDLE	TELE
Focal Length	20.92	28.94	39.31
Fno	4.10	4.10	4.10
Half Angle of View (°)	45.96	36.78	28.82
Image Height	18.00	19.62	20.76
Overall Lens Length	91.22	91.22	91.22
BF	12.67	12.67	12.67

d 6	17.87	9.33	0.80
d16	2.47	0.80	1.28
d20	1.69	11.90	19.95
d22	12.67	12.67	12.67

ZOOM LENS UNIT DATA

Unit No.	Starting Surface	Focal Length
1	1	-33.47
2	7	23.91
3	17	-36.80
4	21	191.50

NUMERICAL EXAMPLE 11

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	vd
1	620.156	1.00	1.80610	40.9
2	13.951	3.20		
3*	31.386	1.77	1.53110	55.9
4*	16.340	2.55		
5	-2188.375	1.00	1.43875	94.7
6	22.775	3.74	1.90043	37.4
7	-107.410	1.34		
8	-53.431	1.00	1.43875	94.7
9	-351.116	(Variable)		
10	18.205	2.17	1.69680	55.5

11	-182.560	2.82		
12 (SP)	∞	0.80		
13	11.712	2.38	1.43875	94.7
14	-80.486	0.31		
15	-25.729	2.00	1.60342	38.0
16	10.136	1.04		
17	20.451	2.17	1.43875	94.7
18	-17.817	(Variable)		
19*	-40.343	1.50	1.53110	55.9
20*	106.642	(Variable)		
21	-547.596	5.61	1.49700	81.5
22	-21.883	(Variable)		
IP	∞			

ASPHERIC DATA

3rd Surface

K = 0.00000e+00 A 4=-1.92346e-04 A 6= 1.46585e-06 A 8=-5.19278e-09

4th Surface

K = 0.00000e+00 A 4=-2.49552e-04 A 6= 1.56459e-06 A 8=-7.02285e-09

19th Surface

K = 0.00000e+00 A 4= 2.25885e-04 A 6=-7.11818e-07 A 8=-1.70513e-08

20th Surface

K = 0.00000e+00 A 4= 2.83610e-04 A 6=-1.54983e-06 A 8=-2.79368e-09

Various Data

Zoom Ratio 2.01

	WIDE	MIDDLE	TELE
Focal Length	14.44	20.17	29.09
Fno	4.10	5.07	6.40
Half Angle of View (°)	43.41	34.11	25.15
Image Height	11.46	12.41	13.18
Overall Lens Length	74.83	74.83	74.83
BF	13.10	13.10	13.10

d 9	16.17	8.48	0.80
d18	2.41	3.08	8.46
d20	6.75	13.76	16.06
d22	13.10	13.10	13.10

ZOOM LENS UNIT DATA

Unit No.	Starting Surface	Focal Length
1	1	-22.35
2	10	20.11
3	19	-54.92
4	21	45.70

NUMERICAL EXAMPLE 12

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	vd
1	333.322	1.00	1.59145	68.4
2	14.457	2.17		

3*	16.664	1.75	1.53110	55.9
4*	13.429	3.12		
5	72.731	0.99	1.43830	95.0
6	15.506	1.36		
7	18.208	3.08	1.80652	46.7
8	82.353	2.05		
9	-59.712	1.00	1.43846	94.8
10	1265.032	(Variable)		
11	16.222	1.79	1.69462	57.7
12	-120.338	0.80		
13 (SP)	∞	0.80		
14	8.920	1.59	1.51616	79.3
15	24.467	0.35		
16	-291.423	1.00	1.60753	37.9
17	7.730	2.37		
18	15.894	1.71	1.43787	95.3
19	-25.062	(Variable)		
20*	-20.249	1.28	1.53110	55.9
21*	-67.405	(Variable)		
22	1468.914	4.86	1.49667	81.9
23	-26.178	13.10		
IP	∞			

ASPHERIC DATA

3rd Surface

K = 0.00000e+00 A 4=-1.53281e-04 A 6= 1.08426e-06 A 8=-4.18904e-09

4th Surface

K = 0.00000e+00 A 4=-2.14777e-04 A 6= 1.34839e-06 A 8=-7.81236e-09

20th Surface

K = 0.00000e+00 A 4= 6.82662e-04 A 6=-2.35509e-06 A 8=-8.17593e-08

21st Surface

K = 0.00000e+00 A 4= 7.14470e-04 A 6=-3.68516e-06 A 8=-2.76365e-08

Various Data

Zoom Ratio 2.02

	WIDE	MIDDLE	TELE
Focal Length	14.43	20.17	29.10
Fno	4.10	5.00	6.16
Half Angle of View (°)	43.42	34.11	25.14
Image Height	11.46	12.41	13.18
Overall Lens Length	70.63	70.63	70.63
BF	13.10	13.10	13.10
d10	16.17	8.49	0.80
d19	1.57	0.80	3.54
d21	6.72	15.18	20.12
d23	13.10	13.10	13.10

ZOOM LENS UNIT DATA

Unit No.	Starting Surface	Focal Length
1	1	-24.90
2	11	18.46
3	20	-55.02

4	22	51.84

NUMERICAL EXAMPLE 13

UNIT: mm

SURFACE DATA

Surface No.	r	d	nd	vd
1	206.545	1.30	1.72916	54.7
2	11.330	4.19		
3*	62.888	1.81	1.53110	55.9
4*	20.219	0.80		
5	24.916	2.72	1.90043	37.4
6	-390.408	2.23		
7	-25.898	1.02	1.43875	94.7
8	-47.695	(Variable)		
9	18.212	1.40	1.69680	55.5
10	63.288	2.25		
11 (SP)	∞	0.80		
12	11.731	2.68	1.53775	74.7
13	-13.536	0.17		
14	-12.668	1.50	1.57099	50.8
15	6.966	0.63		
16	8.050	3.16	1.43875	94.7
17	-26.152	(Variable)		
18*	-12.552	1.50	1.53110	55.9
19*	-21.575	(Variable)		
20	-28.270	2.55	1.49700	81.5
21	-19.416	16.10		

IP ∞

ASPHERIC DATA

3rd Surface

K = 0.00000e+00 A 4=-1.14002e-04 A 6= 1.79201e-06 A 8=-9.57523e-09

4th Surface

K = 0.00000e+00 A 4=-1.76654e-04 A 6= 1.89620e-06 A 8=-1.42839e-08

18th Surface

K = 0.00000e+00 A 4= 9.49757e-04 A 6= 5.59399e-06 A 8=-2.76077e-07

19th Surface

K = 0.00000e+00 A 4= 8.99649e-04 A 6= 3.06165e-06 A 8=-1.04329e-07

Various Data

Zoom Ratio 2.02

	WIDE	MIDDLE	TELE
Focal Length	14.42	20.24	29.10
Fno	4.10	5.06	6.28
Half Angle of View (°)	43.44	34.01	25.15
Image Height	11.46	12.41	13.18
Overall Lens Length	69.58	69.58	69.58
BF	16.10	16.10	16.10
d 8	16.17	8.48	0.80
d17	2.79	0.79	2.42
d19	3.84	13.52	19.58

d21	16.10	16.10	16.10

ZOOM LENS UNIT DATA

Unit No.	Starting Surface	Focal Length
1	1	-23.46
2	9	18.06
3	18	-59.97
4	20	113.86

[0095] TABLES 1 and 2 summarize various values in each example.

TABLE 1

		Ex 1	Ex 2	Ex 3	Ex 4	Ex 5	Ex 6	Ex 7
	fw	12.42	12.40	12.40	14.40	14.40	14.47	20.60
	ft	29.07	29.10	29.10	29.10	29.10	28.47	39.00
	f1	-17.76	-18.26	-19.53	-21.90	-18.40	-22.02	-30.37
	f2	17.38	17.57	17.94	19.73	18.55	18.72	24.27
	f3	-24.70	-27.60	-29.69	-83.23	-28.78	-72.35	-41.20
	f4	39.13	45.60	45.67	61.17	46.95	57.69	96.76
	LD1	16.60	12.91	13.77	15.65	11.18	12.69	19.79
	TTL	82.97	83.44	82.02	75.06	78.52	72.82	95.51
	BFw	12.29	12.13	12.79	11.78	11.50	13.08	12.68
	fn1	-29.16	-28.64	-31.94	-17.50	-13.66	-17.13	-36.75
	fn2	-28.63	-26.83	-26.23	-79.99	-80.00	-80.00	-32.74
	fp1	41.85	52.58	51.42	35.25	43.89	46.37	41.83
(1)	(-f1) / f2	1.02	1.04	1.09	1.11	0.99	1.18	1.25
(2)	(-f1) / f4	0.45	0.40	0.43	0.36	0.39	0.38	0.31
(3)	LD1 / TTL	0.20	0.15	0.17	0.21	0.14	0.17	0.21
(4)	BFw / (-f1)	0.69	0.66	0.65	0.54	0.62	0.59	0.42
(5)	BFw / TTL	0.15	0.15	0.16	0.16	0.15	0.18	0.13
(6)	TTL / (-f1)	4.67	4.57	4.20	3.43	4.27	3.31	3.14
(7)	TTL / fw	6.68	6.73	6.61	5.21	5.45	5.03	4.64
(8)	f2 / (-f3)	0.70	0.64	0.60	0.24	0.64	0.26	0.59
(9)	f2 / f4	0.44	0.39	0.39	0.32	0.40	0.32	0.25
(10)	(-f3) / f4	0.63	0.61	0.65	1.36	0.61	1.25	0.43
(11)	(-f1) / fw	1.43	1.47	1.57	1.52	1.28	1.52	1.47
(12)	(-f1) / ft	0.61	0.63	0.67	0.75	0.63	0.77	0.78
(13)	β2t / β2w	1.90	1.88	1.87	1.84	1.71	1.76	1.52
(14)	β3t / β3w	1.23	1.25	1.25	1.10	1.18	1.12	1.24
(15)	fn1 / f1	1.64	1.57	1.64	0.80	0.74	0.78	1.21
(16)	fn2 / f1	1.61	1.47	1.34	3.65	4.35	3.63	1.08
(17)	fp1 / (-f1)	2.36	2.88	2.63	1.61	2.39	2.11	1.38

TABLE 2

		Ex 8	Ex 9	Ex 10	Ex 11	Ex 12	Ex 13
	fw	20.60	14.45	20.92	14.44	14.43	14.42
	ft	48.50	29.09	39.31	29.09	29.10	29.10
	f1	-28.51	-18.40	-33.47	-22.35	-24.90	-23.46
	f2	23.49	20.41	23.91	20.11	18.46	18.06
	f3	-31.34	-59.99	-36.80	-54.92	-55.02	-59.97
	f4	75.20	87.31	191.50	45.70	51.84	113.86
	LD1	18.43	13.73	17.88	15.60	16.52	14.07
	TTL	106.52	77.99	91.22	74.83	70.63	69.58
	BFw	19.41	13.34	12.67	13.10	13.10	16.10
	fn1	-46.60	-13.59	-42.70	-17.72	-25.58	-16.49
	fn2	-41.93	-54.94	-34.46	-66.91	-160.29	-56.95
	fp1	94.76	28.75	46.76	21.16	28.38	26.09
(1)	(-f1) / f2	1.21	0.90	1.40	1.11	1.35	1.30
(2)	(-f1) / f4	0.38	0.21	0.17	0.49	0.48	0.21
(3)	LD1 / TTL	0.17	0.18	0.20	0.21	0.23	0.20
(4)	BFw / (-f1)	0.68	0.73	0.38	0.59	0.53	0.69
(5)	BFw / TTL	0.18	0.17	0.14	0.18	0.19	0.23
(6)	TTL / (-f1)	3.74	4.24	2.73	3.35	2.84	2.97
(7)	TTL / fw	5.17	5.40	4.36	5.18	4.89	4.82
(8)	f2 / (-f3)	0.75	0.34	0.65	0.37	0.34	0.30
(9)	f2 / f4	0.31	0.23	0.12	0.44	0.36	0.16
(10)	(-f3) / f4	0.42	0.69	0.19	1.20	1.06	0.53
(11)	(-f1) / fw	1.38	1.27	1.60	1.55	1.73	1.63
(12)	(-f1) / ft	0.59	0.63	0.85	0.77	0.86	0.81
(13)	β2t / β2w	1.90	1.88	1.87	1.84	1.71	1.76
(14)	β3t / β3w	1.23	1.25	1.25	1.10	1.18	1.12
(15)	fn1 / f1	1.63	0.74	1.28	0.79	1.03	0.70
(16)	fn2 / f1	1.47	2.99	1.03	2.99	6.44	2.43
(17)	fp1 / (-f1)	3.32	1.56	1.40	0.95	1.14	1.11

IMAGE PICKUP APPARATUS

[0096] Referring now to FIG. 27, a description will be given of a digital still camera (image pickup apparatus) using a zoom lens as an imaging optical system. The zoom lens may be configured according to each of the examples discussed above.

FIG. 27 illustrates a configuration of an image pickup apparatus 10. The image pickup apparatus 10 includes a camera body 13, a lens apparatus 11 including a zoom lens according to any one of Examples 1 to 13, and an image sensor (light receiving element) 12 configured to photoelectrically convert an image formed by the zoom lens. The image sensor 12 can use a CCD sensor or a CMOS sensor. The lens apparatus 11 and the camera body 13 may be integrated with each other, or may be detachably configured. The camera body 13 may be a so-called single-lens reflex camera having a quick turn mirror, or a so-called mirrorless camera without a quick turn mirror. The image pickup apparatus 10 according to this example can be small and lightweight, and have high optical performance.

[0097] The image pickup apparatus 10 according to this example is not limited to the digital still camera illustrated in FIG. 27, but is applicable to various image pickup apparatuses such as a broadcasting camera, a film-based camera, a surveillance camera, and the like.

IMAGE PICKUP SYSTEM

[0098] An image pickup system (surveillance camera system) may include the zoom lens according to any one of the above examples and a control unit configured to control the zoom lens. In this case, the control unit is configured to control the zoom lens so that each lens unit moves as described above during zooming, focusing, and image stabilization. The control unit does not have to be integrated with the zoom lens, and may be separate from the zoom lens. For example, a control unit (control apparatus) disposed remotely from a driving unit configured to drive each lens in the zoom lens may include a transmission unit configured to transmit a control signal (command) for controlling the zoom lens. This control unit can remotely control the zoom lens.

[0099] By providing an operation unit such as a controller and buttons for remotely operating the zoom lens to the control unit, the zoom lens may be controlled according to the user's input to the operation unit. For example, the operation unit may include an enlargement button and a reduction button. A signal may be sent from the control unit to the driving unit of the zoom lens L0 so that in a case where the user presses the enlargement button, the magnification of the zoom lens increases, and in a case where the user presses the reduction button, the magnification of the zoom lens decreases.

[0100] The image pickup system may include a display unit such as a liquid crystal panel configured to display information (moving state) about the zoom of the zoom lens. The information about the zoom of the zoom lens is, for example, the zoom magnification (zoom state) and a moving amount (moving state) of each lens unit. In this case, the user can remotely operate the zoom lens through the operation unit while viewing information about the zoom of the zoom lens displayed on the display unit. The display unit and the operation unit may be integrated by adopting a touch panel or the like.

[0101] The fourth lens unit in the zoom lens according to any one of the above examples may consist of a single positive fixed focal length lens.

[0102] While the present invention has been described with reference to the above example embodiments, it is to be understood that the disclosure is not limited solely to the disclosed embodiments.

[0103] Each example can provide a negative lead type wide-angle zoom lens that is compact and lightweight yet has high optical performance over the entire zoom range.

CLAIMS

1. A zoom lens comprising a plurality of lens units, the plurality of lens units consisting of, in order from an object side to an image side, a first lens unit having negative refractive power, a second lens unit having positive refractive power, a third lens unit having negative refractive power, and a fourth lens unit having positive refractive power,

wherein a distance between adjacent lens units changes during zooming from a wide-angle end to a telephoto end,

wherein the first lens unit includes three or more lenses,

wherein the first lens unit is fixed relative to an image plane during zooming, and

wherein the following inequalities are satisfied:

$0.85 < (-f1)/f2 < 2.00$

$0.00 < (-f1)/f4 < 0.55$

$0.00 < LD1/TTL < 0.27$

where f1 is a focal length of the first lens unit, f2 is a focal length of the second lens unit, f4 is a focal length of the fourth lens unit, LD1 is a distance on an optical axis from a lens surface on the object side of a lens closest to an object in the first lens unit to a lens surface on the image side of a lens closest to the image plane in the first lens unit, and TTL is a distance on the optical axis from the lens surface on the object side of the lens closest to the object in the zoom lens at the wide-angle end to the image plane.

2. The zoom lens according to claim 1, wherein the following inequality is satisfied:

$0.30 < BFw/(-f1) < 1.50$

where BFw an air conversion amount of a distance on the optical axis from a lens surface on the image side of the lens closest to the image plane in the zoom lens at the wide-angle end to the image plane.

3. The zoom lens according to claim 1 or 2, wherein the following inequality is satisfied:

$$0.07 < BFw/TTL < 0.30$$

where BFw an air conversion amount of a distance on the optical axis from a lens surface on the image side of the lens closest to the image plane in the zoom lens at the wide-angle end to the image plane.

4. The zoom lens according to any one of claims 1 to 3, wherein the following inequality is satisfied:

$$2.0 < TTL/(-f1) < 6.0.$$

5. The zoom lens according to any one of claims 1 to 4, wherein the following inequality is satisfied:

$$3.0 < TTL/fw < 7.5$$

where fw is a focal length of the zoom lens at the wide-angle end.

6. The zoom lens according to any one of claims 1 to 5, wherein the following inequality is satisfied:

$$0.1 < f2/(-f3) < 1.5$$

where f3 is a focal length of the third lens unit.

7. The zoom lens according to any one of claims 1 to 6, wherein the following inequality is satisfied:

$$0.05 < f2/f4 < 0.80.$$

8. The zoom lens according to any one of claims 1 to 7, wherein the following inequality is satisfied:

$0.1 < (-f3)/f4 < 2.0$

where f3 is a focal length of the third lens unit.

9. The zoom lens according to any one of claims 1 to 8, wherein the following inequality is satisfied:

$0.5 < (-f1)/fw < 2.5$

where fw is a focal length of the zoom lens at the wide-angle end.

10. The zoom lens according to any one of claims 1 to 9, wherein the following inequality is satisfied:

$0.2 < (-f1)/ft < 1.4$

where ft is a focal length of the zoom lens at the telephoto end.

11. The zoom lens according to any one of claims 1 to 10, wherein the following inequality is satisfied:

$0.5 < \beta 2t/\beta 2w < 3.0$

where β2t is lateral magnification of the second lens unit at the telephoto end, and β2w is lateral magnification of the second lens unit at the wide-angle end.

12. The zoom lens according to any one of claims 1 to 11, wherein the following inequality is satisfied:

$0.5 < \beta 3t/\beta 3w < 2.0$

where β3t is lateral magnification of the third lens unit at the telephoto end, and β3w is lateral magnification of the third lens unit at the wide-angle end.

13. The zoom lens according to any one of claims 1 to 12, wherein the

first lens unit includes a first negative lens, and the following inequality is satisfied:

$$0.5 < fn1/f1 < 2.0$$

where fn1 is a focal length of the first negative lens.

14. The zoom lens according to any one of claims 1 to 13, wherein the first lens unit includes a second negative lens, and the following inequality is satisfied:

$$0.5 < fn2/f1 < 10.0$$

where fn2 is a focal length of the second negative lens.

15. The zoom lens according to any one of claims 1 to 14, wherein the first lens unit includes a first positive lens, and the following inequality is satisfied:

$$0.5 < fp1/(-f1) < 5.0$$

where fp1 is a focal length of the first positive lens.

16. The zoom lens according to any one of claims 1 to 15, wherein the first lens unit consists of lenses having refractive powers.

17. The zoom lens according to any one of claims 1 to 16, wherein the fourth lens unit is fixed relative to the image plane during zooming from the wide-angle end to the telephoto end.

18. The zoom lens according to any one of claims 1 to 17, wherein the second lens unit includes an aperture stop.

19. The zoom lens according to any one of claims 1 to 18, wherein the fourth lens unit consists of a single positive fixed focal length lens.

20. The zoom lens according to any one of claims 1 to 19, wherein the first lens unit consists of, in order from the object side to the image side, a negative lens, a negative lens, and a positive lens.

21. The zoom lens according to any one of claims 1 to 20, wherein the first lens unit consists of, in order from the object side to the image side, a negative lens, a negative lens, a positive lens, and a negative lens.

22. The zoom lens according to any one of claims 1 to 21, wherein the first lens unit consists of, in order from the object side to the image side, a negative lens, a negative lens, a negative lens, a positive lens, and a negative lens.

23. The zoom lens according to any one of claims 1 to 22, wherein the third lens unit is a focus lens unit that moves during focusing.

24. The zoom lens according to claim 23, wherein the third lens unit consists of a single negative fixed focal length lens.

25. The zoom lens according to claim 23, wherein the third lens unit consists of two negative fixed focal length lenses.

26. An image pickup apparatus comprising:

a zoom lens according to any one of claims 1 to 25; and

an image sensor configured to receive image light formed by the zoom lens.

Intellectual Property Office

Application No:	GB2317355.2	**Examiner:**	Mr Steven Scott
Claims searched:	1-26	**Date of search:**	26 April 2024

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-26	JP2012027262 A (OLYMPUS IMAGING CORP) see figure 4 and the corresponding parts of the description for the third embodiment including the data tables on pages 20-22 especially.
X	1-22,26	US2014/0152887 A1 (SAMSUNG ELECTRONICS CO LTD [KR]) see figure 1 and the corresponding parts of the description for the first embodiment including the data tables on page 5 especially.
X	1-26	US 2018/0074300 A1 (CANON KK [JP]) see figures 1,7 and the corresponding parts of the description including the data tables for embodiment 4.
X	1-26	US 2021/0018721 A1 (CANON KK [JP]) see figures 7,9 and the corresponding parts of the description including the data tables for examples 4 and 5.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

G02B

The following online and other databases have been used in the preparation of this search report

SEARCH - PATENT

Intellectual Property Office

International Classification:

Subclass	Subgroup	Valid From
G02B	0015/14	01/01/2006
G02B	0015/167	01/01/2006
G02B	0015/177	01/01/2006
G02B	0015/20	01/01/2006
G02B	0015/24	01/01/2006