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PROVISIONAL SPECIFICATION

No. 21314, A.D. 1947.

Improvements in or relating to Microscopy

I, FRANCIS HUGHES SMITH, a British Subject, of 76, Scalby Mills Lane, Scarborough, Yorkshire, do hereby declare the nature of this invention to be as follows:—

This invention is for improvements in or relating to microscopy and has particular reference to interference microscopy.

Although translucent objects can be studied comparatively easily under the usual visual microscope, there are obvious difficulties in studying objects which are transparent or nearly transparent. There are methods available for the study of transparent and like objects under the visual microscope. For example, the object may be stained in one or more colours in order to render it visible in ordinary daylight. In many cases however, such a staining technique may destroy or markedly alter the object.

It is an object of the present invention to provide means whereby objects, e.g. transparent or nearly transparent objects, may be studied without staining or other treatment.

The principles underlying the present invention may be understood by considering two light beams from the same source (or from two separate sources exactly in phase) hereinafter referred to as "beams from the same source". If both beams traverse paths of equal optical length then they will not produce interference effects on being combined. However, if the optical path length of one beam is different from that of the other, interference effects may be produced. Differences in the optical path length of two beams may be caused by allowing the beams to traverse an object to be examined in different manners. These interference effects enable a transparent or like object to be examined more easily than is possible by the use of the usual form

of visual microscope. For example one beam may traverse the object once and the other a different number of times or not at all. Further, one beam may traverse the object at a different angle from the other and thus caused to have a different optical path-length. So long as one beam traverses the object in a different manner from the other, interference will be produced.

A transparent or like object of varying thickness will produce interference effects depending on its thickness variations and an object of heterogeneous refractive index will similarly produce interference effects depending on its heterogeneity.

According to the present invention a method for examining transparent and the like objects comprises combining together two light beams from the same source, one beam having been caused to traverse the object in a different manner from the other, or one beam having been caused to traverse the object and the other not.

If the light employed is white light, or is a mixture of light of various wavelengths the interference effects reveal themselves as colour variations. If monochromatic light is used then the interference effects show up as intensity variations.

Although it is not an essential feature of the present invention it is often advantageous to use light which has been polarised. The use of polarised light often makes for greater definition and may afford a convenient method of ray-splitting, e.g. by the use of a Wollastons or other double-image prism. For example, the two beams may be plane polarised in planes perpendicular to one another and after having passed through the object in different manners they may be brought into parallel polarised relationship and thereafter allowed to interfere to render the object visible.

Dated this 5th day of August, 1947.

BOULT, WADE & TENNANT,
111 & 112, Hatton Garden,
London, E.C.1,
Chartered Patent Agents.

PROVISIONAL SPECIFICATION
No. 21995, A.D. 1947.

Improvements in or relating to Interferometry

I, FRANCIS HUGHES SMITH, a British Subject, of 76, Scalby Mills Lane, Scarborough, Yorkshire, do hereby declare the nature of this invention to be as follows:—

This invention is for improvements in or relating to interferometry and has particular reference to interference microscopy.

- 10 An object of the present invention is to provide means whereby transparent or like objects (being objects which are transparent or nearly transparent with respect to the medium in which they are being studied) can be examined e.g. microscopically, more easily than has heretofore been possible. The present invention also provides improved means for examining physically, e.g. optically, transparent or like objects in order, for example, to study the optical properties of materials such as glass.

- There are obvious difficulties associated with the microscopic examination of transparent or nearly transparent objects. Thus if an object, which is nearly transparent in air, is being examined in that medium it is very difficult to see or, e.g. to photograph, the structural features of the object without adopting a technique such as staining. In many cases, however, it is not possible to stain an object since it may be destroyed, damaged or markedly altered by the stain.

- According to the present invention apparatus for examining transparent or like objects comprises means for dividing a beam of light into two beams plane polarised in planes at right angles to one another, means for supporting the object in one of said polarised beams, means for recombining the divided beams, and means for bringing the recombined beams into parallel polarised relationship.

- The nature of the invention will be clearly understood from the drawing attached hereto which is a diagrammatic representation of one form of apparatus in accordance with the present invention. In the drawing, like figures denote like parts:—

- 11 is a monochromatic light source.
12 is a parallel beam of light from the source 11.
13 and 13' are double-image prisms.
14 are plane polarised beams (the upper

beam being polarised in a plane at right angles to the plane of polarisation of the lower).

15 and 15' are prisms.

16 is an analyser.

A parallel beam 12 from the monochromatic light source 11 traverses a double-image prism 13 (e.g. a Wollaston's prism) positioned at A and emerges as two divergent beams 14, plane polarised in planes at right angles to one another.

The beams 14 are then caused to continue parallel to one another by the prisms 15 positioned at B and B' respectively. Thereafter one beam (the upper in the particular drawing) passes through the supported object 17. Both beams are then caused to converge by the prisms 15' positioned at C and C' and are subsequently recombined by means of the double-image prism 13' positioned at D. A single beam consisting of two superimposed beams plane polarized in two mutually perpendicular planes emerges from this prism. The analyser 16 then causes the two planes of polarization to become parallel one to the other. In this condition the recombined beam, one part of which has passed through the object and the other part has not, exhibits interference effects by means of which the object may be examined.

It will be appreciated that the cause of interference between the two components of the recombined beam is the difference in optical path length of one component with respect to that of the other, due to its having traversed the object. Ideally the geometric path lengths of the beams, when divided, should be identical. However, such a condition is rarely obtainable in practice and it is usually necessary to introduce an optical-length compensating means in the system. For example, a Babinet compensator may be introduced before A or between D and the analyser 16. Alternatively any other suitable compensating means may be introduced between the double-image prisms 13 and 13', preferably between one pair of the prisms 15 and 15' (i.e. between B and C or between B' and C').

Dated this 8th day of August, 1947.

BOULT, WADE & TENNANT,
111 & 112, Hatton Garden,
London, E.C.1,
Chartered Patent Agents.

PROVISIONAL SPECIFICATION
No. 21996, A.D. 1947.

Improvements in or relating to Microscopy

I, FRANCIS HUGHES SMITH, a British Subject, of 76, Scalby Mills Lane, Scarborough, Yorkshire, do hereby declare the nature of this invention to be as follows:—

This invention is for improvements in or relating to microscopy and has particular reference to interference microscopy.

Although translucent objects can be studied comparatively easily under the usual visual microscope there are obvious difficulties in studying objects which are transparent or nearly transparent. There are methods available for the study of transparent and like objects under the visual microscope. For example, the object may be stained in one or more colours in order to render it visible in ordinary daylight. In many cases however, a staining technique may destroy or markedly alter the object.

It is an object of the present invention to provide means whereby objects, e.g. transparent or nearly transparent objects, may be studied without staining or other treatment.

The principles underlying the present invention may be understood by considering two light-beams from the same source (or from two separate sources exactly in phase). If both beams traverse paths of equal optical length they will not produce interference effects on being combined. However, if the optical path-length of one beam is different from that of the other, interference effects may be produced.

Differences in the optical path-lengths of two beams may be caused by allowing the beams to traverse an object to be examined in different manners. These interference effects enable a transparent or like object to be examined more easily than is possible by the use of the usual form of visual microscope.

According to the present invention apparatus for examining transparent or like objects comprises means for dividing a beam of light into two beams, means for bringing said beams to separate co-planar focii, means for supporting the object at the focus of one beam and means for combining the two beams.

The nature of the invention will be clearly understood from the drawings attached hereto which are diagrammatic representations of two forms of apparatus in accordance with the present invention.

Figure 1 represents a uniaxial optical system;

Figure 2 represents a bi-axial optical system.

In the drawings, like figures denoting like parts:—

11 are two approximately parallel beams of light from the same source (or from two sources exactly in phase);

12 and 12' are double-image prisms situated at A and C respectively;

13 and 13' are corrected lenses;

14 is an analyser;

15 and 15' are prisms;

OO' is the object plane.

Considering Figure 1 in detail, each beam of light 11 is incident normally on the double image prism 12 situated at A. Emerging from this prism each beam, now divided into two divergent beams, is brought to two co-planar focii B and B' in the object plane OO'. The transparent or like object is placed in this plane at the focus of one of the parallel beams, e.g. at B. Thus one of the beams divided from the original beams 11 is caused to pass through the transparent or like object, the other not passing therethrough. Both beams of light are then caused to converge by the upper lens 13' and the two beams are then brought together by passing through the upper double-image prism 12'. The two beams will then interfere and the object may be viewed by means of any suitable optical system.

It will readily be seen that Figure 2 is merely a bi-axial variation of the system of which Figure 1 is a diagrammatic representation. In Figure 2 four lenses are used and the prisms 15 and 15' form convenient means for causing the two beams to take the desired paths.

Unlike the form of apparatus represented by Figure 1 the form represented by Figure 2 places little or no restriction on the linear dimensions and form of the objects under examination.

If the light employed for viewing the object is a mixture of light of various wave-lengths, or is white light, the interference effects reveal themselves as colour variations. If monochromatic light is used then the interference effects show up as intensity variations.

It will be appreciated that in constructing an optical instrument in accordance with the present invention use may be made of any suitable optical components or compound optical components. Thus, if the double image prism 12 is a Wollaston's prism the two emergent beams will be plane polarised in planes at right angles one to the other. The means for viewing the recombined beams must then include some form of analyser (such as are indi-

cated by 14 in Figures 1 and 2) in order that the two beams can be brought into plane polarised relationship to enable them to interfere. Although it is not an essential feature of the present invention it is often advantageous to use a system involving polarised light. The use of polarised light often makes for greater definition and may afford a convenient method of ray splitting and for recombining e.g. by the use of a Wollaston's or other similar double-image prism. Also when used in conjunction with a birefringent device such as a Babinet compensator or tiltable birefringent plate it affords a very precise means of path control.

It will be realised that while the ideal condition of an optical system in accord-

ance with the present invention is for the geometric path-lengths of the divided beams to be identical, such a condition is rarely obtainable in practice. However, small adjustments of path-length can readily be made by introducing into the system a path-length compensating means such as a Babinet compensator. Any other form of compensator may be used, and the different positions in which various types of compensating means may be placed will be readily apparent to one skilled in the art.

Dated this 8th day of August, 1947.
BOULT, WADE & TENNANT,
111 & 112, Hatton Garden,
London, E.C.1,
Chartered Patent Agents.

PROVISIONAL SPECIFICATION No. 22665, A.D. 1947.

Improvements in or relating to Microscopy

I, FRANCIS HUGHES SMITH, a British Subject, of 76, Scalby Mills Lane, Scarborough, Yorkshire, do hereby declare the nature of this invention to be as follows:—

This invention is for improvements in or relating to microscopy and has particular reference to interference microscopy.

Although translucent objects can be studied comparatively easily under the usual-visual microscope, there are obvious difficulties in studying objects which are transparent or nearly transparent. There are methods available for the study of transparent and like objects under the visual microscope. For example, the object may be stained in one or more colours in order to render it visible in ordinary daylight. In many cases however, such a staining technique may destroy or markedly alter the object.

It is an object of the present invention to provide means whereby objects e.g. transparent or nearly transparent objects may be studied without staining or other treatment.

The principles underlying the present invention may be understood by considering two light-beams from the same source (or from two separate sources exactly in phase). If both beams traverse paths of equal optical length they will not produce interference effects on being combined. However, if the optical path-length of one beam is different from that of the other, interference may be produced. Differences in the optical path-lengths of two beams may be caused by allowing the beams to traverse an object in different manners. These interference effects enable a transparent or like object to be examined more

easily than is possible by the use of the usual form of visual microscope.

According to the present invention apparatus for examining transparent or like objects comprises means for dividing a single beam of light into two beams consisting of a central beam and a concentric annular beam, means for bringing the two beams to separate co-axial foci, means for supporting the object at one of the foci, and means for recombining said beams to a single focus.

The nature of the invention will be clearly understood from the drawing attached hereto which is a diagrammatic representation of one form of apparatus in accordance with the present invention. In the drawing:—

11 is a parallel beam of light subsequently divided into a central beam 11a and a concentric annular beam 11b.

12 is a compound beam-dividing means.

13 are positive lens systems.

14 is a negative lens system.

Considering the Figure in detail, the parallel beam of light 11 is incident normally on the lower face of the compound beam-dividing means 12. It will be seen that the compound beam-dividing means provides an internal partially-reflecting conical surface *a* and a 45° air-glass totally reflecting surface *b*. It is apparent that the beam emerging from the compound beam-dividing means will be divided into the requisite central beam and concentric annular beam. In order to make the effective optical path-length of the two emergent beams identical the central beam is caused to pass through an extra path-compensating portion *c*. The beams then pass through the com-

pound system of lenses 13. It will be seen that this system of lenses causes the central beam to be brought to a lower focus A and the concentric annular beam to be brought to an upper focus B. The lower focus A is in the object plane. The object is so arranged that rays forming the central beam pass therethrough. Rays forming the concentric annular beam do not pass through the object and do not have their optical path-lengths altered thereby. The two beams of light diverging from the foci A and B then pass through the lens system 13¹. In addition the central beam passes through the concave lens 14. Both beams are thus brought to a single focus. The two superimposed images, one having a slight phase retardation with respect to the other, may then be viewed by means of any suitable optical system.

It will be appreciated that in practice it is usually necessary to be able to make small adjustments in the optical path-lengths of one or other of the beams. Such adjustments may be effected by interpos-

ing a path-length compensating plate in one of the beams.

Ideally the object under examination should not intercept any of the rays in the concentric annular beam, but in practice there may be considerable tolerance.

It is not necessary for the object plane to pass through A. The system could be so arranged that the object plane pass through the focus of the concentric annular beam. However, there are obvious advantages associated with arranging the system so that the object plane passes through the focus of the central beam.

If white light or a mixture of light of various wavelengths is used the interference effects will show colour variations. If monochromatic light is used the interference effects will show as intensity variations.

Dated this 14th day of August, 1947.

BOULT, WADE & TENNANT,
111 & 112, Hatton Garden,
London, E.C.1,
Chartered Patent Agents.

PROVISIONAL SPECIFICATION

No. 25761, A.D. 1947.

Improvements in or relating to Interferometry

I, FRANCIS HUGHES SMITH, a British Subject, of 76, Scalby Mills Lane, Scarborough, Yorkshire, do hereby declare the nature of this invention to be as follows:—

This invention is for improvements in or relating to interferometry, and has particular reference to a modification of the well-known Michelson interferometer optical system in order that the latter may be suitably adapted for the microscopic examination of transparent and like objects.

According to the present invention apparatus for the examination of transparent or like objects comprises means for dividing a beam of light into two mutually divergent beams, means thereafter for bringing one of the beams twice to one focus, means for supporting the object at said focus, means for combining and bringing said beams to a focus (separate from the afore-mentioned focus), means for ensuring that the two beams, at the latter focus, are precisely superposed and means associated with at least one of said beams for substantially equalizing the optical path-lengths of both beams between the initial dividing means and the final focus.

The nature of the invention will be clearly understood from the drawing attached hereto which is a diagrammatic representation of one form of apparatus in accordance with the present invention.

In the drawing:—

11 is a beam of light subsequently divided into two beams 11a and 11b.

12 is a beam dividing means.

13 and 13¹ and 14 and 14¹ are corrected lenses of positive dioptric powers.

15 and 15¹ are concave spherical reflecting surfaces.

O—O¹ is the object plane.

Considering the drawing in detail the beam of light 11, which is preferably substantially parallel, is incident on the beam dividing means 12 shown as a partially-reflecting plane inclined surface and is thereby divided into the two mutually divergent beams 11a and 11b. The beam 11a is then caused to be incident axially on the lens 13 and is brought thereby to a focus in the object plane O—O¹.

After being brought to a focus the beam is made to converge towards a point on the surface of the mirror 15 by the lens 13¹. The mirror 15 is so placed and has such a radius of curvature that the incident and reflected beams coincide. Thus it will be apparent that the beam 11a is thereafter brought for a second time to the focus in the object plane O—O¹.

After leaving the focus in the plane O—O¹, the lens 13 will cause the beam to proceed substantially parallel. It passes through the initial partially-reflecting beam dividing means and is joined there with the second beam 11b.

Beam 11b after leaving the dividing means 12, has been brought to a focus on the surface mirror 15¹ by the lens 14. Mirror 15¹ is so placed and is of such a radius of curvature that the reflected beam is returned along the incident path and joins the beam 11a at the surface 12.

The two combined beams after leaving the surface 12 are then brought to a single focus by the lens 14¹.

It will be appreciated that at this focus it is imperative that the two beams 11a and 11b are precisely superimposed. This may be accomplished, for example, by suitable adjustment of the mirrors. Provided that the optical path-lengths of these two beams are not too dissimilar an object placed in the focus at O—O¹ will give rise to the desired interference figures.

Referring to the drawing attached hereto, it will be appreciated that beams of light have for the sake of clarity been indicated by single lines. This leads to the apparent indication that the beams incident on the mirrors 15 and 15¹ do not return along their original paths. How-

ever, it will be quite clear to one skilled in the art that whilst individual rays which make up a beam may not have superposed incident and return paths the beams *per se* do have such paths.

Optical path-length control may be effected advantageously in accordance with any of the well-known methods of interferometry. Extremely precise control may be obtained if means are employed to polarize the two beams in mutually perpendicular planes. For instance, a Babinet compensator or like device in or close to the focus of the combined beams would enable very precise path-difference adjustments to be made. This device could be calibrated in one or more scales, such as degrees of retardation due to an object, rendering the instrument even more informative than if used merely as a microscope.

Dated this 22nd day of September, 1947.
BOULT, WADE & TENNANT,
111 & 112, Hatton Garden,
London, E.C.1,
Chartered Patent Agents.

PROVISIONAL SPECIFICATION

No. 29918, A.D. 1947.

Improvements in or relating to Microscopy

I, FRANCIS HUGHES SMITH, a British Subject, of 76, Scalby Mills Lane, Scarborough, Yorkshire, do hereby declare the nature of this invention to be as follows:—

This invention is for improvements in or relating to microscopy and has particular reference to improvements relating to my copending Application No. 22865/47.

In my prior specification numbered as above I have described apparatus for examining transparent or like objects which comprises means for dividing a single beam of light into two beams consisting of a central beam and a concentric annular beam, means for bringing the two beams to separate co-axial foci, means for supporting the object at one of these foci and means for recombining said beams to a single focus.

I have now found that it is by no means necessary for the divided beams to consist of a central beam and a concentric annular beam. So long as the form or condition of the two beams is such that they can be brought to two separate substantially co-axial foci then the apparatus will function.

In accordance with the present invention there is provided apparatus for examining transparent or nearly trans-

parent objects which comprises means for dividing a beam of light into two beams, means for bringing said beams to two separate substantially co-axial foci, means for supporting the object at one of said foci and means for recombining said beams to a single focus whereat they are mutually superimposed point for point.

Thus, while my two prior applications were limited to a special form of beam division whereby a central beam and a concentric annular beam were caused to converge to two separate foci on the optical axis, I now contemplate the use of optical systems wherein a central beam and/or an outer beam may be composed of discrete parts, one beam being substantially hollow and radially distributed about the other. Thus a cross-section of the beams emerging from the beam dividing means would show a substantially symmetrical plane diagram divided into an outer, hollow figure substantially co-axial with and wholly or partially enclosing a central figure. The precise shape of this cross-section would obviously depend upon the particular geometrical form of the dividing means. For example, if the dividing means were pyramidal then the outer figure would show the same number of separate parts as the dividing surface of the means has sides.

Moreover, I also contemplate apparatus wherein a beam of light is divided into two plane-polarized beams, said beams being brought to two separate substantially co-axial foci at one of which the object is supported. While in this latter case the initial beam is not divided into a central and an outer beam, it has the common feature that the two beams are brought to two separate substantially co-axial foci.

This latter form of apparatus in accordance with an aspect of the present invention will be understood from the drawing attached thereto, which represents a uniaxial optical system.

In the drawing, 11 is a beam of light subsequently divided into two beams 11a and 11b.

12 is a corrected lens system of positive dioptric power associated with a lens or lenses made from some suitable birefringent material whose reflecting surfaces are so orientated in relation to the optical axis or axes of said material as to make said lens or lenses bifocal.

13 is a second lens system of positive dioptric power associated with a birefringent lens or lenses of such dioptric power, position and axial orientation as precisely to counteract the bifocal effect of said lens or lenses in 12.

14 is an analyzer.

OO' is the object plane.

Considering the drawing in detail, the beam of light 11 is incident normally on the positive lens system 12 and is divided into two beams polarized in mutually perpendicular planes by the birefringent lens or lenses associated therewith. Due to the two distinct dioptric powers of the said

birefringent lens or lenses beam 11a is caused to converge to a focus A co-axial with but above that of beam 11b, i.e. B. Whilst the object plane OO' is shown passing through A, it may equally well pass through B. Thus in the case illustrated by the drawing, provided that the object supported at A has reasonably limited linear dimensions it will transmit a much greater proportion of beam 11a than of 11b. Thus the object introduces a phase difference between the greater part of beam 11a and of 11b.

Hereafter beams 11a and 11b are brought to one and the same focus by means of the positive lens system 13 and into parallel polarized relationship by the analyzer 14. The analyzer 14 may be placed anywhere in the optical system between 13 and the eye or receiving surface.

It will be realized that in order to improve the intensity and/or colour contrast by means of which a substantially transparent structure would be made visible in this form of apparatus it may often be desirable to adjust the path difference between the two beams. Since this is a double-refracting form of apparatus this may readily be effected by means of a Babinet compensator or like device placed at some convenient and appropriate position in the optical system. A tiltable birefringent plate or plates may also be employed for this purpose.

Dated this 10th day of November, 1947.
BOULT, WADE & TENNANT,
111 & 112, Hatton Garden,
London, E.C.1,
Chartered Patent Agents.

COMPLETE SPECIFICATION

Improvements in or relating to Microscopy

I, FRANCIS HUGHES SMITH, a British Subject, of 30, West Park Avenue, Newby, Nr. Scarborough, Yorkshire, formerly of 76, Scalby Mills Lane, Scarborough, Yorkshire, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to microscopy and has particular reference to interference microscopy.

Although translucent objects can be studied comparatively easily under the usual visual microscope, there are obvious difficulties in studying objects which are transparent or nearly transparent. It is usual to stain transparent or like objects in order to render them more visible, but in many cases, however, such a staining

technique may destroy or markedly alter the object.

It is an object of the present invention to provide a microscope which can be used to study unstained transparent or nearly transparent objects.

The principles underlying the present invention may be understood by considering two light beams from the same source. If both beams traverse paths of equal optical length, then they will not produce interference effects on being combined. However, if the optical path length of one beam is different from that of the other, interference effects may be produced. Such differences in the optical path lengths of the two beams may be caused by allowing the beams to traverse an object to be examined, in different manners (i.e. along distinguishable paths) or by making one

beam traverse the object and the other not. These interference effects enable a transparent or like object to be examined more easily than is possible by the use of the usual form of visual microscope.

This effect is achieved in some measure in the well-known phase-contrast microscope in which the object is illuminated by a single beam of light and interference effects are produced in the image plane between that part of the beam which passes through the object without deviation and that portion which has been diffracted by the object. However, it is known that only very small refractively differentiated elements of the object are capable of generating a beam sufficiently diffracted for this purpose, so that the phase-contrast method is virtually limited to relatively small features of the object.

The present invention overcomes these limitations of the phase-contrast microscope by utilising the interference effects between two distinguishable beams of light.

Thus, according to the present invention, apparatus for microscopically examining transparent or like objects comprises a compound microscope wherein there are provided means for dividing the object illuminating beam of light into two distinguishable coherent beams before it reaches the object, means for subsequently directing at least one of said distinguishable beams through the object in such a manner that the optical path lengths of said distinguishable beams differ due at least in part to the nature of the object, and means for subsequently combining said distinguishable beams so as to produce interference effects which are coincidentally viewable with the image, of the object, formed by said compound microscope.

The means for dividing the object illuminating beam into two beams may be arranged to provide beams mutually distinguishable in respect of their general directions of propagation or their states of dioptric divergence or convergence or the geometrical forms of their cross-sections or with respect to a combination of these properties.

The objective lens of the microscope or the condenser lens of the microscope or the objective lens and condenser lens of the microscope may be, or have components, disposed optically between the beam dividing means and beam combining means.

The beam dividing means may comprise at least one anisotropic optical member such as a birefringent lens and/or a double refracting double image prism, the birefringence of the anisotropic mem-

ber causing it to divide the object illuminating beam into two differently polarized beams, and the optical surfaces of the said member or members being arranged to double refract the said differently polarized beams along mutually distinguishable paths, and in these arrangements, means are provided to polarize the object illuminating beam of light before it reaches said beam dividing means. Similarly the beam combining means may comprise at least one anisotropic optical member such as a birefringent lens and/or a double refracting double image prism, the optical surfaces of said member being arranged to double refract the originally distinguishable beams along coincidental paths, and in these arrangements means are provided for subsequently bringing the beams into parallel plane polarized relationship.

Preferably means are provided for adjusting the relative optical path lengths of said distinguishable beams.

Reflecting means may be arranged in the paths of the two divided beams so as to reflect the two beams back through the beam dividing means which thus functions also as the beam combining means, and in this arrangement a vertical illuminator may be provided, e.g. comprising a partially reflecting surface disposed between the beam dividing means and the eye-piece of the microscope.

Preferably the said distinguishable beams pass through an optical member comprising the beam combining means and are combined at a surface of said member remote from the object.

The following is a description of a number of embodiments of the invention, reference being made to the accompanying drawings in which:—

Figure 1 is a diagrammatic view of one embodiment, the optical elements being shown in conventional manner as a section along the optical axis of the microscope.

Figure 2 is a similar diagrammatic view of a second form of the microscope of the present invention.

Figure 3 is a diagrammatic view of a beam dividing unit which is substantially achromatic for both the beams.

Figures 4 and 5 illustrate modifications of the microscope shown in Figure 2, and

Figures 6, 7, 8, 9 and 10 are diagrammatic views of microscopes in which partially reflecting surfaces are utilised in the beam dividing means.

Referring to Figure 1, the microscope includes, in the conventional manner, an objective lens 10 and an achromatic condenser lens 11 arranged on either side of the object supporting means which is dis-

posed so that the plane of the object mounted between the usual slide and cover glass, is at the position indicated by the dashed line OO^1 . The eye-piece 12 is also of conventional construction and there is provided the usual sub-stage mirror 13 for directing the light from source 14 through the condenser lens 11. These components are shown in a conventional manner and it will be appreciated that, for example, the condenser and objective normally comprise a number of lens components.

A polarizing screen 15 is arranged in the sub-stage so that a plane polarized beam of light is directed towards the condenser lens 11. Immediately below the condenser is a lens 16 which is constructed of birefringent material or materials so that the lens is bi-focal. For example, the positive lens element may be made from calcite which has a shorter focal length for the ordinary rays than for the extraordinary rays, the refractive index of calcite being in general greater for the ordinary than for the extraordinary rays. Thus, as is shown in the figure, the incident light is divided into two beams which, as is well known, are polarised in planes at right angles to one another. The condenser lens 11 brings these two beams to separate foci at points spaced apart along the optical axis of the microscope and it will be noted that one of these foci is in the plane OO^1 in which the object is supported by the stage of the microscope.

A second lens 17, also of birefringent material and of opposite dioptric power to lens 16, is disposed between the objective 10 and the eye-piece to combine the two beams and bring them to a common focus where an image is formed which is viewed through the eye-piece. If a cross-section in the object plane is considered, it will be realised that the light passing this plane comprises an inner beam of one plane of polarization, which is brought to a focus on the object and an outer beam of a transverse plane of polarization which is not in focus on this plane and which surrounds the inner beam. Thus one of the beams passes through the object, whilst the greater part of the other does not. As described above, these two beams when combined will produce interference effects at the image plane of the microscope. To enable these beams to interfere, their planes of polarization must be parallel and an analyser 18 is provided to enable the planes of polarization to be adjusted to parallelism. The interference effects which are produced will depend on the nature of the path through the object being examined and will be seen when

viewed through the eye-piece coincident with the image of the object.

If the light employed is white light or a mixture of light of various wavelengths, the interference effects record themselves as colour variations. If monochromatic light is used then the interference effects show up as intensity variations.

Preferably the analyser 18 is made rotatable so that the maximum interference contrast can be obtained.

It will be appreciated that the cause of interference between the two components of the recombined beams is the difference in optical path lengths of one beam with respect to the other, due to its having traversed the object. Ideally, the optical path lengths of the beams, when they reach the eye, viewing screen, or photographic emulsion should not differ by more than a few wavelengths of light. In practice it is normally necessary to provide an optical path length compensating means which should preferably permit of very fine adjustment so that the best interference contrast can be obtained for the particular part of the object under examination. The compensating means may advantageously be calibrated in terms of differences in optical path length making the system more precisely informative. For example, a Soleil-Babinet compensator 19 may be introduced at a suitable point in the system, for example immediately beneath the analyser as shown in the drawing. As an alternative form of compensator, a tilting birefringent retarding plate compensator 20 could be used. This could be mounted in any convenient position between the polarizer and analyser, for example, between the polarizing screen 15 and the beam dividing means 16.

When, as has been described above, the bifocal lenses are made to be used in addition to existing objective and condenser lenses, each bifocal lens would consist of two or more elements which may be cemented together and which have a mean power for both beams which is very small. For example, it is recommended that a lens to be added to an objective should be of zero power for the beam which the condenser has focussed in the plane of the object being examined. The precise amount of bi-focal dioptric power employed cannot be laid down but for the objective the difference between the dioptric power for one beam and that for the other may well be in the region of plus or minus three diopters. Once the bi-focal power of the objective's bi-focal lens has been decided upon, that for the condenser lens can readily be computed for any particular combination of objec-

tive and condenser from the ratio of the dioptric powers of each such pair by the well known formulae relating to the geometrical optics of lenses. As a close approximation it may be taken that the ratio of the dioptric bi-focal power of the condenser's bi-focal lens to the dioptric power of the condenser should be equal to the corresponding ratio for the objective and its bi-focal lens. In its simplest form, each bi-focal lens would consist of a positive and negative lens element, one made from calcite and the other from glass, the latter being designed to correct the chromatic aberration of the calcite element for one of the two beams, for example, the beam formed by the ordinary rays. It will be appreciated that this correction for dispersion is only necessary for one beam if the object to be examined is always viewed in that beam.

In the case of low and medium power objectives, the birefringent lens may be mounted in a sleeve by means of which it can be slid into the usual mounting of the objective. In this way a single lens unit would suffice for at least two objectives, although the corresponding condenser lens would have to be changed unless the power of the condenser would be correspondingly changed by adding or subtracting lens components forming part of the condenser lens train. Preferably, the birefringent lenses are located as near as possible to the back focal planes of the objective and condenser with which they are associated, and should, in any case, be mutually conjugate. In the case of the higher powers, this means that they may have to be fitted between two lens elements of the condenser and/or of the objective. It may be found advantageous to make special condensers and objectives fitted with these additional birefringent lenses and, these lenses may not be additional, but, in fact, form an essential part of the lens train. For this purpose, quartz may be a more convenient material than calcite in spite of its comparatively low birefringence owing to the fact that its indices of refraction are nearer to those of the glasses commonly used in most objectives and condensers.

Although this instrument has been described as having an eye-piece 12, it is readily apparent to all those skilled in the art that it or any of the other microscopes to be described hereinafter may be modified to provide a viewing screen or be adapted for photography.

Instead of using birefringent lenses, it is possible to use double refracting, double image prisms, as illustrated in Figure 2. In this microscope, the objective 10, condenser 11, eye-piece 12, mirror

13, light source 14 and polarizing screen 15 are arranged as before. Between the condenser and mirror is disposed a double refracting double image prism, for example, a Wollaston prism, which divides the incident beam of light into two mutually divergent beams which are polarized in planes at right angles to one another. As is clearly seen in the Figure, these two beams are brought to foci at points 21, 22 spaced apart in a plane transverse to the optical axis. The condenser is adjusted to bring these foci into the plane OO' in which the object is supported by the stage 23 of the microscope.

The two beams emerging from the objective pass through a second double image prism which causes them to combine so that they are brought to a focus at coincident points. As in the previously described embodiment, the viewing means must include an analyser 25 which in this case is illustrated as a polarizing screen disposed immediately over the eye-piece, phase adjustment is provided as before, for example, by means of the Soleil-Babinet compensator 19. A pair of collimating lenses 26, 27 may be provided in the positions shown if required.

A Wollaston prism deviates both beams and so introduces dispersion. This is corrected for by the additional prisms 27a shown in dotted lines which are made from a glass whose dispersion is suitably high and which are cemented to the double image prisms. With these prisms added one of the coplanar foci would be located substantially on the optical axis of the microscope as shown in the drawing.

On the other hand, a Rochon variety of double image prism might be used. This form of prism is achromatic for one beam, namely, for the beam which does not deviate and hence it requires no chromatic correction but the large phase difference which it introduces (since only one of its elements is substantially double refracting) must be balanced out. The preferred means for this purpose is a birefringent plate made from the same material as that of the double refracting element of the prism but orientated so that its relative retarding effect opposes that of the said element, the plate being made about the same thickness as that of the double refracting element of the prism in the region of the optical axis of the microscope. This phase balancing plate can conveniently be cemented to one of the exposed surfaces of the prism.

As is well known, there are double image prisms similar to the Rochon prism in so far as only one of the two prismatic elements is double refracting but the element which is not double

refracting is made of glass. Such prisms may readily be adapted to the present forms if the glass element is designed to achromatize the other double refracting element for one of the two beams.

The angle of the prismatic elements, of whatever form of double image prism is used, will depend on the strength of the birefringence of the material employed and upon the angular field over which the condenser and objective retain their correction. If the prism is a Rochon prism made from calcite (the preferred material) a convenient angle may be in the region of 6 degrees for the prism associated with the objective. Once the angle for the objective part has been decided upon, that for the prism associated with the condenser can be computed from the known focal length relationship between the objective and the condenser. Only if the focal lengths of these lenses be equal can the angles of the corresponding prisms be equal. For example, if the focal length of the condenser is twice that of the objective, then the angles of the prism associated with the condenser must be such as to produce half the angular deviation of that produced by the objective prism. In general, the angles of the prism must be such that their angular deviations are proportional to the dioptric powers of the objective and condenser with which they are respectively associated.

Chromatic correction to the prisms for both beams may be achieved by making the correcting prismatic element from birefringent material whose birefringent dispersion differs substantially from that of the double refracting element or elements in the prism. For example, the element or elements in the prism might be made from quartz while the correcting element is made of calcite. In Figure 3, there is illustrated a unit which is substantially achromatic for both beams, functioning on the selective total reflection principle which is met with in the Nicol's polarizing prism. The illuminating beam which is polarized by means of the polarizer 31 is directed upon a calcite-air surface 32 at an angle which is greater than the critical angle for one of the two plane polarized beams into which the calcite divides the initial beam but less than the critical angle for the other beam. A surface mirror 33 is mounted in close proximity to the aforementioned calcite-air surface but slightly inclined to this surface so that the beam which is transmitted through the calcite-air surface is reflected back into the calcite after which it proceeds in the same general direction as the totally

reflected beam but slightly divergent therefrom. Since this is a reflecting unit, it may conveniently be mounted immediately over the microscope's mirror 13 whose function it would thus replace. A similar unit would be mounted above the objective to combine the beams and would be associated with an additional reflecting system to direct the combined beams up the tube of the microscope. This form of unit is specially adaptable to the vertical illumination form of the microscope which will be described below for it may perform the function of the vertical illuminator as well as that of the beam dividing and combining means. A further feature of the unit, which is also particularly applicable to a microscope with a vertical illuminator, is that the inclined surface mirror may be made tiltable so that the amount of angular deviation may be controlled. Like the Rochon form of prism, this unit introduces a large phase difference between the two beams which may be balanced out by means of a birefringent plate or plates, although in the case of the first mentioned variable form, a wide range of birefringent compensator would have to be employed so that the phase relationship could be kept constant when the plate has been tilted. The calcite-air surface in the unit illustrated in Figure 3 is formed by cementing a thin calcite plate 34 to a suitably shaped glass prism 35 and in the case of the non-variable form, the thickness of the plate 34 could be such as to balance out the excessive phase difference. In this latter case, the plate would have to be of substantial thickness.

Another means of obtaining variable deviation between the two beams consists in making each of the dividing and combining parts comprise a pair of double refracting double image prisms mounted one above the other so that their deviations are in opposition. Then, by providing a rocking movement for at least one of the prisms, the deviation could be varied. Even in the non-variable form which is illustrated in Figure 2, it is preferable to mount at least one of the prisms, so that it may be rocked in order to facilitate the optical matching of the parts for the objective and condenser with which they are associated.

It will be appreciated that it would be possible to make the two beams so widely spaced in a plane transverse to the optical axis that separate objective and condenser lenses could be used for each beam. If the beams have been so separated they can be deviated, for example by prisms, to increase the separation and thus an instrument can be constructed having little or

no restriction on the linear dimensions and form of the object under examination.

However, it is not essential for the two beams to be separated so that only one passes through the object being examined. If the two beams are slightly separated corresponding parts of the beams will pass through different parts of the object and thus be subject to relative differences in optical path length and hence interference effects would be produced.

In the arrangement illustrated in Figure 2, the optical path length adjustment between the two beams is effected by means of a Soleil-Babinet compensator. As has been described with reference to Figure 1, a tilting birefringent retarding plate compensator might be employed for this purpose. This optical path length adjustment may also be made by providing a sliding horizontal movement to one of the double refracting double image prisms, the movement being parallel to the principal section of the prisms. If this method, which eliminates the necessity for a separate compensator, is adopted the prisms must be larger than the diameter of the aperture with which it is associated. Whatever form of optical path length adjuster is employed it is recommended that it be calibrated, for example, in terms of optical path length.

It may be found that, when high power objectives are used to examine thick objects, the interference contrast is impaired owing to the object modifying the corrections of the objective for the beam which has passed through it, since the increase in thickness of the object is equivalent to a change in cover glass thickness. In the embodiments illustrated in both Figures 1 and 2, both beams pass through the objective so that it may be necessary to adjust its corrections for one beam in a different manner from the other beam. This adjustment is quite apart from the aforementioned optical path length adjustment and the preferred method of effecting it consists in providing an additional lens or lenses made from birefringent material so that the dioptric states of the two plane polarised beams are altered to different extents. Variations in this correction could be effected by providing means for sliding the additional lens or lenses relative to the objective along the axis of the microscope. If the additional correcting part consists of more than one lens these could be moved towards or away from one another. It will be appreciated that this method of correction can be applied only when the two beams are polarised in mutually perpendicular planes, as is the

case in the arrangements illustrated in Figures 1 and 2.

In the case of systems such as that illustrated in Figure 2, it may be found that the visual field is crossed by a series of interference bands due to the two beams passing through the condenser and objective in different directions. If this effect is found objectionable it can be eliminated by means of a quartz wedge of suitable angle mounted, for example in the eye-piece as is common practice with polarising microscopes. Such a wedge may be arranged to slide horizontally to perform the additional function of adjusting the overall optical path length relationship between the two beams.

As has been indicated above, the microscope of Figure 2 can be modified into a reflex version such as is illustrated in Figure 4. The light from the source 14 passes through a polarising screen 15 and a collimator lens 27 (if required) to a partially reflecting surface 36 of a vertical illuminator. The prism 37 produces the required two beams as before which are then focussed in the plane OO^1 by the objective 10, the object to be examined being situated at one of the foci. The light then passes through the condenser lens 11 to a reflecting surface 38. The condenser lens is adjusted so that it forms an image of the object on or near the mirror whose surface is substantially normal to the incident beams. As a result of this arrangement the beams are reflected back to the object through the condenser and pass through the objective to form the real image of the object in the image plane of the objective. This is viewed as before by means of the eye-piece 12 and analyser 25. In this arrangement it is not necessary to make the prism rockable for matching purposes since the single prism 37 serves the double function of dividing and combining the beams. However, it may be advantageous to mount the prism (which is between the objective and the vertical illuminator) at a small angle of inclination to the optical axis of the microscope so as to divert reflections from its surfaces away from the image of the object.

For the present purpose these reflex systems have the advantage over the direct transmission forms in that the beam dividing unit, located between the vertical illuminator and the objective, also performs the function of beam recombination. However, the focussing of the condenser is made almost as delicate as that of the microscope body. This disadvantage can be overcome by providing a focussing stage so that once the condenser has been correctly focussed, the object can be

focussed without disturbing the condenser.

For convenience and neatness it is desirable that the mirror 38 should be mounted in the substage, e.g. immediately over the usual microscope mirror. The usual microscope mirror might be adapted for the present purpose so dispensing with the need of an additional mirror. However, corrected condensers are usually corrected for a distance far in excess of that required for either of these arrangements and it becomes necessary to provide an additional lens or lenses to effect the required change in the correction of the condenser. Alternatively, a condenser provided with a correction collar (i.e. a collar which is rotatable to vary the separation of the component lenses of the condenser by cam, screw-thread or like action) may be employed. The effective focal length of the mirror should be made approximately equal to its distance from the back focal plane of the condenser. Ideally, a special concave mirror should be provided whose radius of curvature is about the same as the distance of the mirror from the aforesaid back focal plane. The required focal length may be obtained by mounting a lens or lenses immediately above, for example, a plane mirror but it will be appreciated that surface mirrors are preferable. In all these reflex forms of microscope, it is proposed that the effective area of the light source be kept small relative to the field of vision in the eyepiece in order to minimize flare caused by reflections from the several reflecting surfaces.

In this arrangement, optical path length adjustment may be effected in the same way as has been described with reference to Figure 2, e.g. by sliding the prism 37 in a plane transverse to the optical axis of the microscope or by a separate compensator such as the Soleil-Babinet compensator 19 (shown in Figure 4) or a tilting birefringent retarding plate compensator. Coarse phase adjustment could be effected by rocking the beam returning mirror 38.

There is illustrated in Figure 5, a modification of the arrangement of Figure 4, in which the single prism 37 is replaced by a pair of prisms 39, 39a, which are arranged so that their deviations are in opposition. One of the prisms is mounted so that it can be rocked. In this reflex version, the beam dividing and combining are performed by the same components and the rocking of the prism is not for matching purposes (as was mentioned with reference to Figure 2) but to enable the separation of the beams to be made variable.

In all the arrangements hereinbefore described, it is preferred that the beam dividing and combining means should be mounted in slides so as to facilitate obtaining the required accuracy or orientation. This is particularly the case when these dividing and combining means are separate, as for example, in Figures 1 and 2. If these dividing and combining means are fitted into the mountings of the condenser and objective it is desirable to mount the objective and condenser on slides.

It will be appreciated that the two basic arrangements illustrated in Figures 2 and 4 provide different means for separating the two images of the light source, in one arrangement the separation being along the axis of the microscope and in the other case in a plane transverse to the axis. By using both birefringent lenses and double refracting double image prisms it is possible to form the images of the light source at separate points one or both of which do not lie on the axis of the microscope, and which do not lie in a plane perpendicular to that axis.

Many other methods may be employed to divide and recombine the two beams. For example, one form of dividing and combining device which may be employed is a diffraction grating or zone plate. Such a device gives rise to a number of diffracted beams but for the purpose of the present invention these may be regarded as one beam since they can be caused to pass round the outer boundary of a small object. The central undiffracted beam is arranged to pass through the object and one or more of the diffracted beams which pass around the object are directed back to the central beam by means of a second grating arranged to function as a combining device.

A diffraction grating can be arranged to combine the distinguishable beams generated by means of a prior diffraction grating employed as beam dividing means by supporting the former at a position in the microscope's optical system where there is a real image of the beam dividing grating optically after the object position, and by arranging the elements of the combining grating in such a manner that they are geometrically coincidental with those features of the real image which correspond with the elements of the beam dividing grating. At such a position the distinguishable beams generated by the beam dividing grating are brought precisely together so that, under the above conditions, each element of the beam combining grating is illuminated by both the mutually coherent

beams from the beam dividing grating. Consequently, the luminous energy associated with each of the beams originating by diffraction at the beam combining grating is derived equally from both the originally distinguishable beams from the beam dividing grating, so that the latter are combined, as required.

A diffraction grating can also be arranged to combine the distinguishable beams generated by a beam dividing device which is not itself a diffraction grating, e.g. a birefringent lens. In this feature the disposition is closely analogous to the above but the real image is now of the interference fringes produced by the beam dividing device, the elements of the combining grating being so arranged that they are in geometrical accord with the interference fringes. As before, each element of the combining grating is illuminated by both of the mutually coherent beams from the dividing device and these beams are consequently combined as already described. Particularly in this case the preferred type of combining grating is one having elements which are alternately transparent and opaque, the transparent ones preferably being narrower than the opaque ones. In a normal microscope system the required position of the beam combining grating will be found to be near the objective's back focal plane or near the Ramsden circle of the eye-piece.

Adjustment of the relative optical path-lengths of the beams is more difficult with gratings or zone plates than with the systems previously described but may be facilitated by providing means for polarizing the central undiffracted beams in a plane perpendicular to that of the diffracted beams before the object is reached so that their phase relationship could be controlled by birefringent retarding plates or birefringent compensators. This might be done by making the grating of birefringent material. This can be done by using a form of diffraction grating whose elements are all transparent but in which at least one member of each adjacent pair is of birefringent material, the two refractive indices of which cause the grating to function differently for the two plane polarized components associated respectively with the two refractive indices. The grating can then be arranged so that adjacent elements have the same optical thickness for one of the two plane polarized components but whose optical thickness differs for the other component by about half a wavelength. All the luminous energy associated with the former component will then pass directly through the grating without being diffracted

while that associated with the latter component will be almost entirely deviated by diffraction, in accordance with a well-known property of half-wave diffraction gratings. The grating thus generates two distinguishable beams which are polarized in perpendicular planes. For example, a plate of calcite, cemented to a glass plate, could be ground down to an extent such that it introduces a phase difference of about half a period between its ordinary and extraordinary components. The calcite plate would then be converted into a diffraction grating or zone plate by etching away alternate strips or concentric circles by means of an etchant (e.g. dilute hydrochloric acid) which erodes only the calcite and not the glass or cement. The surface of the grating or zone plate would then be immersed in a fluid or cement whose index of refraction is as near as possible to that of one of the two principal indices of the calcite. This fluid or cement would in turn be covered and contained by a plate of glass. Linseed oil is an example of an appropriate fluid for that purpose. It is known that cements having refractive indices close to one of the two principal indices of calcite are now available. If selenite is employed instead of calcite then Canada Balsam is a suitable cement. A diffraction grating having a set of alternate birefringent elements can alternatively be made by forming grooves in one surface of a birefringent plate (e.g. of calcite or quartz), cementing that surface to an optical plate, say, of glass and then working the other, now exposed surface down until the bottoms of the grooves are passed. The depth of the grooves should, of course, be rather more than the required thickness of the birefringent elements. In an alternative construction a relatively thick plate of calcite has grating elements formed by etching grooves in one surface of the plate to a depth equivalent to half-wave birefringent thickness and then covering that surface of the plate with a medium having a refractive index substantially equal to one of the two principal indices of calcite.

The resulting device would be substantially equivalent to a plain glass plate for one of the plane polarized components of the calcite but would be a half wave grating (or zone plate) for the other component. Now, it is known that an ordinary half-wave grating concentrates practically all the light into the diffracted beams so that there is almost no light in the central undiffracted beam. In consequence the present device will provide a central beam polarized in one plane and diffracted beams polarized in a plane per-

pendicular to that of the central beam. Hence the optical path length relation between the two beams can be adjusted by a birefringent compensator as in the double refracting interferometer microscopes described above.

Yet a further method of dividing and recombining the beam is employed in the microscope illustrated in Figure 6. The objective 10, condenser 11, eye-piece 12, sub-stage mirror 13 and light source 14 are again arranged in the conventional manner and collimating lenses 26 and 27 may be provided as in the arrangements described above. The beam dividing means 40 and the beam combining means 41 are similar and are each provided with an internal partially reflecting conical surface 42 and a second reflecting conical surface 43 so that an incident beam falling on the outer part of the beam dividing means 40 is divided into a central beam and an outer surrounding beam. It may be noted that incident light falling on the inner part of the device will be totally reflected from the inner side of surface 43 and will have no effect. The lenses 44 and 45 each comprise an inner lens for the central beam and an annular lens for the outer beam. The inner beam is thus brought to a focus on the object plane OO^1 whilst the outer beam is focussed at a point spaced axially away from the object plane. The two beams are combined by the combining device 41 so that coincident images of the light source are formed which are viewed through eye-piece 12, the interference effects between the two beams being obtained as before. The lenses 44 and 45 may be omitted in which case both the beams will be brought to one and the same focus in the plane of the object but will pass through the object at different mean angles. The path lengths of the two beams through the object will thus differ and interference effects will be produced as before.

It will be appreciated that it is not essential that the inner beam be circular and the outer annular so long as one beam surrounds the other. The outer beam may comprise a number of separate parts. Thus the reflecting surfaces 42 and 43 could be pyramidal instead of conical.

Since this system does not use polarised light beams, adjustment of the relative optical path length of the two beams cannot be effected by the compensators previously described and instead there may be used a rocking plate 46 (as with the Jamin compensator) or a sliding wedge. As with the previously described compensators these would preferably be calibrated in terms of optical path length.

As is illustrated in Figure 7, the

arrangement of Figure 6, may be modified to a form with vertical illumination by using a vertical illuminator 49 to direct the incident beam of light through a single beam dividing means 47 which also functions as the beam combining means (as in the microscope of Figure 4). The two beams pass through the double lens 45 and the objective 10 and are brought to foci separately at points spaced axially. The object is supported at one of these foci in the plane OO^1 . The two beams continue through the condenser 11, double lens 44 and collimator 27 which bring them to a focus on the mirror 48. This mirror is arranged to reflect the beams back so that they are again brought to a focus separately at the same two axially spaced points. The device 47 combines the two beams and focusses them to form coincident images of the light source which are viewed through the eye-piece 12, interference effects being observed as before. For optical path length adjustment there is provided a rockable plate 50 having an inner part 51 for retarding the inner beam and outer part 52 for retarding the outer beam.

The double lenses 44 and 45 may be removed when it is desired to use the microscope as a difference of path length system in the same manner as has been described with reference to Figure 6.

In Figure 8 there is shown another method of producing two co-planar images of the light source. In this case, use is made of reflections from the two surfaces of a wedge 51 to separate the light into two beams and a similar wedge 52 is used for recombining the beams. Two prisms 53 and 54 are used as total reflectors in order to bring the combined beam back to the tube of the microscope. The wedge 51 is made slidable in order to enable adjustment of the optical path length relationship between the beams to be effected.

This arrangement may also be modified into a "reflux" system as is shown in Figure 9. In this case the wedge 55 acts as the partially reflecting surface as well as forming the beam dividing device. The light passes through the objective 10 and condenser 11 to the mirror 56 and is reflected back as in the previously described vertical illumination systems so that the beams are brought to a focus by the condenser 11 at the same spaced points as they are brought to a focus by the objective 10. In this arrangement the wedge 55 does not function to recombine the beams and a second wedge 57 is provided for this purpose.

Yet a further form of beam dividing means is illustrated in Figure 10. In this

case use is made of the partially reflecting internal surface 60 between two prismatic elements 61, 62 which are cemented together. The reflected light 5 passes through the objective 10 and condenser 11 to the mirror 63 whilst the transmitted light passes through the positive lens 64 to the reflecting surface 65. The two beams return by the same paths 10 and are combined by the prismatic elements 61, 62 in a manner which is obvious from the figure.

In this arrangement, a rocking plate 66 is provided to effect fine optical path 15 length adjustment, the coarse adjustment being made by movement of the mirror 65.

As has been mentioned above, when high power objectives are used to examine 20 thick objects, the interference contrast may be impaired owing to the object modifying the corrections of the objective for the beam which has passed through it and so it becomes necessary to adjust 25 the correction of the objective for one beam in a different manner from the other. In the arrangements described with reference to Figure 10 only one beam passes through the objective and 30 this correction can readily be made by fitting the condenser with a correction collar.

Although in most of the arrangements described above, the beam dividing and 35 combining means are closely associated with the objective or objective and condenser this is not essential for carrying out the invention. For example, in the arrangements described with reference to 40 Figures 1 and 2, the combining double image prism or birefringent lens might be mounted close to or immediately above the eye-piece. Ideally the combining means should be located at a real image 45 of the dividing means. If mounted immediately above the eye-piece, in or near the Ramsden circle, a polarizing screen should be used as analyser so that the eye may be placed as near to the 50 Ramsden circle as possible.

If, as for example, in the instruments illustrated in Figures 1, 2, 4 and 5, two polarised beams are employed, it is essential that the illuminating beam should 55 be plane polarized and that there be an analyser between the last birefringent element and the eye, viewing screen or photographic emulsion.

Having now particularly described and 60 ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. Apparatus for microscopically 65 examining transparent or like objects

comprising a compound microscope wherein there are provided means for dividing the object illuminating beam of light into two distinguishable coherent beams before it reaches the object, means 70 for subsequently directing at least one of said distinguishable beams through the object in such a manner that the optical path lengths of said distinguishable beams mutually differ due at least in part 75 to the nature of the object, and means for subsequently combining said distinguishable beams so as to produce interference effects which are coincidentally viewable with the image, of the object, formed by 80 said compound microscope.

2. Apparatus for microscopically examining transparent or like objects comprising a compound microscope wherein 85 there are provided means for dividing the object illuminating beam of light into two distinguishable coherent beams before it reaches the object, means for directing at least one of said distinguishable beams 90 through the object in such a manner that the optical path lengths of said distinguishable beams mutually differ due at least in part to the nature of the object, means for subsequently combining said 95 distinguishable beams so as to produce interference effects which are coincidentally viewable with the image, of the object, formed by said compound microscope, and means for adjusting (preferably in a continuous manner) the relative 100 optical path lengths of said distinguishable beams.

3. Apparatus for microscopically examining transparent or like objects comprising a compound microscope 105 wherein there are provided means for dividing the object illuminating beam of light into two distinguishable coherent beams before it reaches the object, means for subsequently directing 110 at least one of said distinguishable beams through the object in such a manner that the optical path length relationship between the two beams is changed due to the optical thickness of the object, means 115 for subsequently recombining said distinguishable beams so that they can mutually interfere and means for producing a further change in the optical path length relationship between said distinguishable beams. 120

4. Apparatus according to any one of claims 1 to 3 wherein the means for dividing the object illuminating beam of light into two beams is arranged to 125 provide beams which mutually are distinguishable in respect of their general directions of propagation or their states of dioptric divergence or convergence or the geometrical forms of their cross- 130

sections or with respect to a combination of these properties.

5. Apparatus according to any one of the preceding claims wherein at least one birefringent retarding plate, is disposed optically between the beam dividing means and beam combining means.

6. Apparatus according to any one of the preceding claims wherein the object, mounted between the usual slide and cover glass, is arranged to be positioned optically between the beam dividing means and beam combining means.

7. Apparatus according to any of the preceding claims in which the beam combining means are disposed optically between two lens elements of the objective.

8. Apparatus according to any of the preceding claims in which the beam dividing means are disposed optically between two lens elements of the condenser.

9. Apparatus according to any of claims 1 to 6 wherein the objective lens of the microscope or the objective lens and condenser lens of the microscope are disposed optically between the beam dividing means and beam combining means.

10. Apparatus according to any of the preceding claims wherein both said distinguishable beams are directed through the object, means being provided for causing the beams to traverse the object along distinguishable paths.

11. Apparatus according to any of claims 1 to 9 wherein means are provided for bringing said two distinguishable beams into foci at positions spaced apart at least one of which foci is located substantially in the plane in which the object being examined is supported by the stage of the microscope.

12. Apparatus according to claim 11 when said foci lie on the optical axis of the microscope or in a plane perpendicular to that axis.

13. Apparatus according to any of the preceding claims wherein the means for combining said distinguishable beams is arranged to produce discernable interference effects coincidentally viewable with the real image of the object formed in the foci plane of the eye-piece or on a viewing screen or photographic emulsion by the objective lens or by the objective lens and eye-piece of the microscope.

14. Apparatus according to any of the preceding claims wherein at least one of the distinguishable beams is directed upon the object through the objective lens of the microscope by a vertical illuminator (e.g. a semi-transparent reflector) and wherein reflecting means is arranged in the paths of the two distinguishable

beams to reflect them back beyond the vertical illuminator.

15. Apparatus according to claim 14 wherein the beam dividing means is arranged to function also as the beam combining means.

16. Apparatus according to any one of the preceding claims wherein it is arranged that the said distinguishable beams pass through an optical member comprising the beam combining means and are combined at a surface of said member remote from the object.

17. Apparatus according to either claim 14 or claim 15 wherein the vertical illuminator comprises a semi-transparent reflector and is arranged to function as the beam dividing means or as beam dividing and combining means.

18. Apparatus according to any of claims 1 to 15 wherein the beam dividing means incorporates at least one anisotropic optical member such as a birefringent lens and/or a double refracting double image prism and wherein means are provided to polarise the object illuminating beam of light before it reaches said beam dividing means.

19. Apparatus according to any one of claims 1 to 16 or claim 18, wherein the beam combining means incorporates at least one anisotropic optical member such as a birefringent lens and/or a double refracting double image prism and means for bringing the recombined beams into parallel plane polarised relationship.

20. Apparatus according to either claim 18 or claim 19 wherein a birefringent lens or a double refracting double image prism is provided with at least one additional lens or prism respectively arranged to correct the dispersion of at least one of the beams.

21. Apparatus according to any of the preceding claims wherein there are provided means for polarising the object illuminating beam of light before it is divided and wherein the beam dividing means are arranged to divide the polarised beam into two differently polarised beams and wherein analysing means are provided to bring the beams into parallel plane polarised relationship.

22. Apparatus according to any claims 1 to 15 wherein the beam dividing means and/or beam combining means comprise a diffraction grating or zone plate.

23. Apparatus according to claim 22 wherein means are provided for introducing a difference in optical path length or for adjusting the optical path length relation between the direct beam produced by the diffraction grating or zone plate and those diffracted beams which are subsequently combined therewith.

24. Apparatus according to claim 22 and in which the grating or zone plate produces direct and diffracted beams, the direct beam being passed through the object, wherein means are provided for polarising the direct and diffracted beams in mutually differing manners prior to the direct beam passing through the object.
25. Apparatus according to claim 22 wherein the diffraction grating is made of birefringent material whereby the optical path length relationship between the beams can be controlled by birefringent compensating means or a quarter-wave retarding plate in combination with a rotatable polariser or analyser.
26. Apparatus according to any of the preceding claims wherein means are provided for adjusting the separation of said distinguishable beams.
27. Apparatus according to any one of the preceding claims wherein the beam combining means is close to the eyepiece.
28. Apparatus according to claim 27 wherein the beam combining means is located in the path of the light emerging from the eyepiece.
29. Apparatus for microscopically examining transparent or like objects substantially as described with reference to, and diagrammatically illustrated in, any one of Figures 1 to 10 of the accompanying drawings.
- Dated this 5th day of August, 1948.
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Fig. 1.

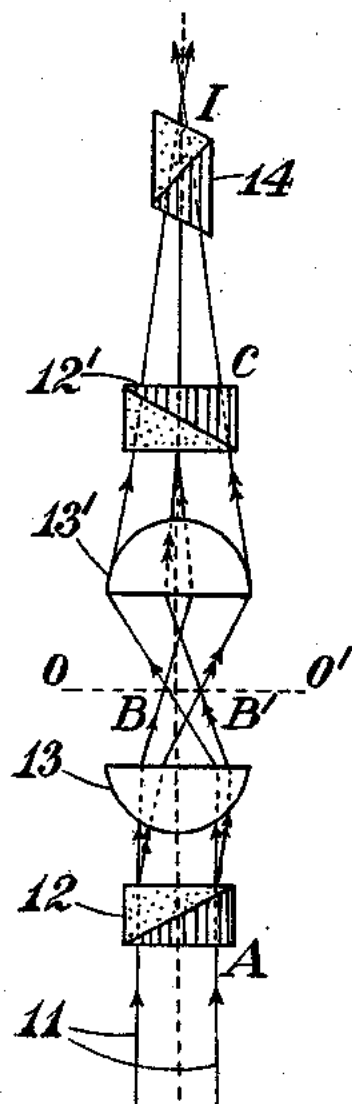
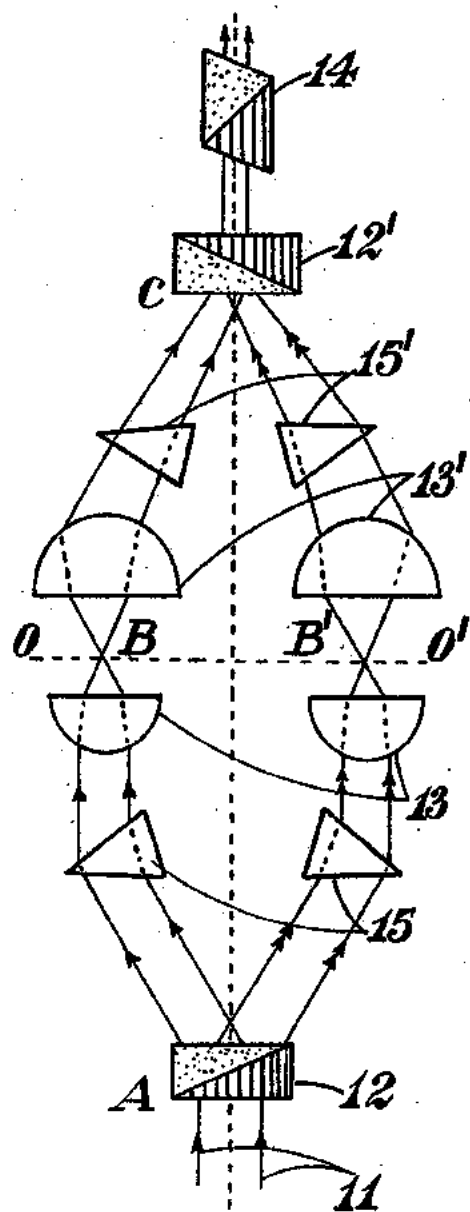
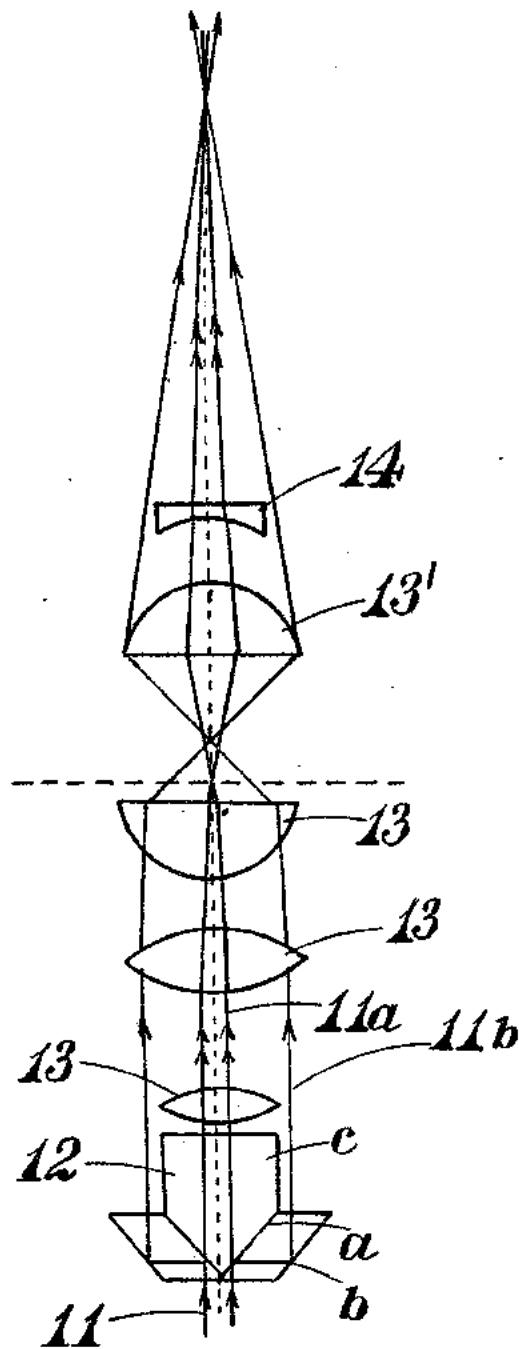


Fig. 2.

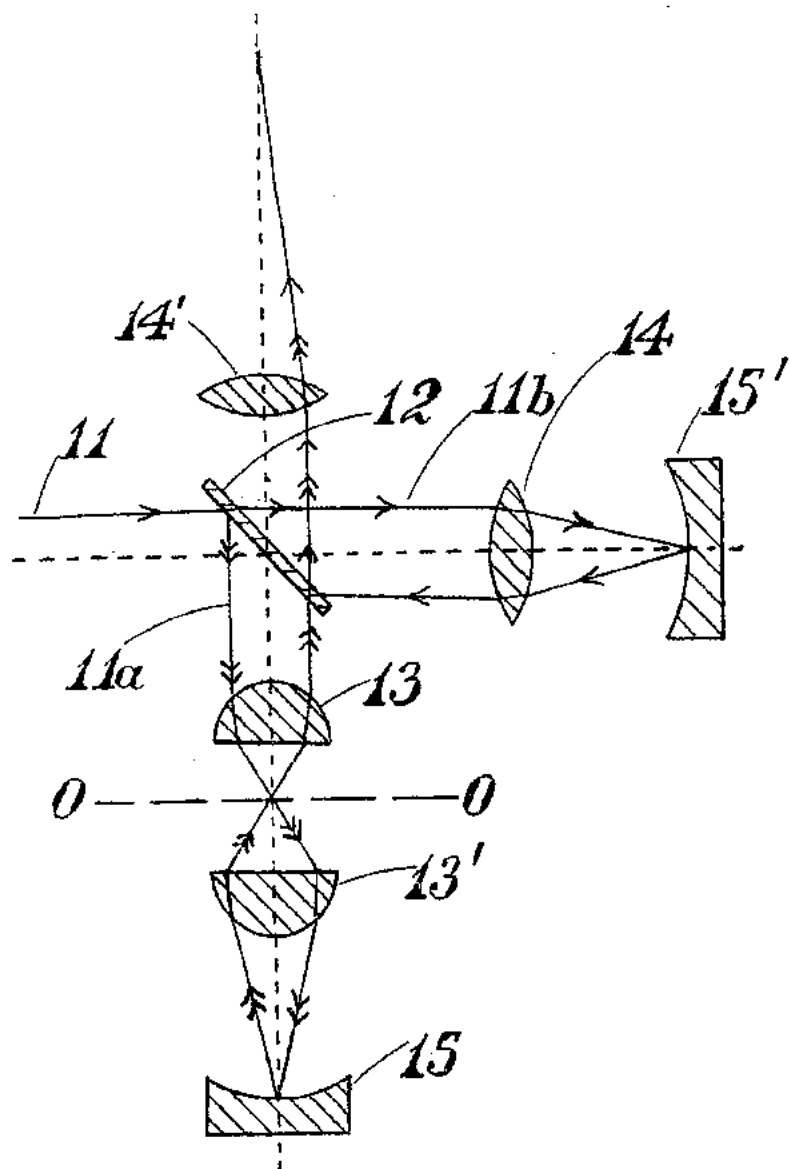


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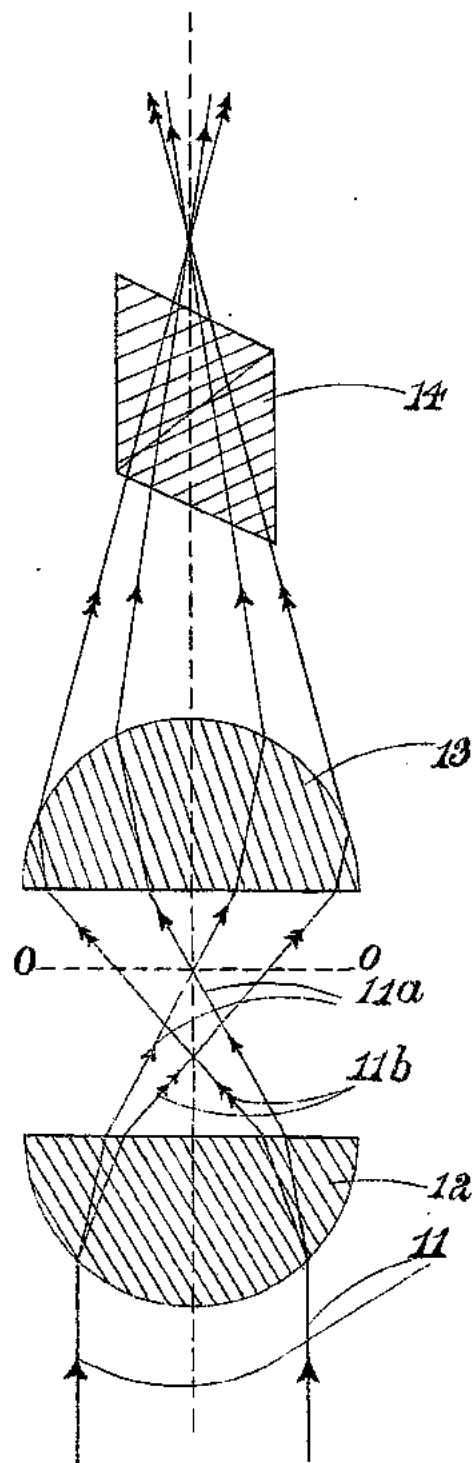
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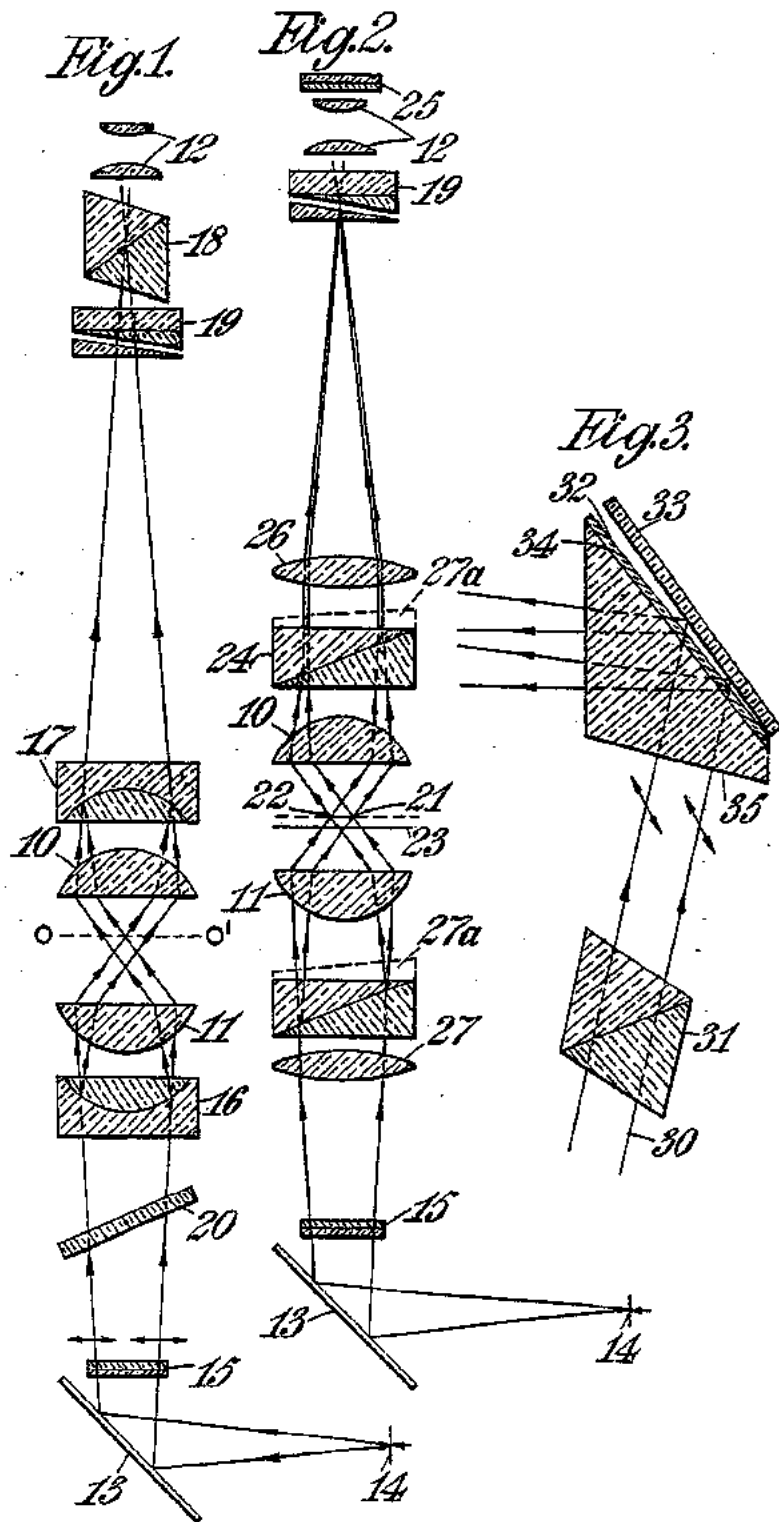
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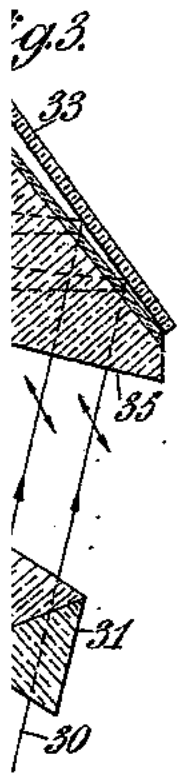


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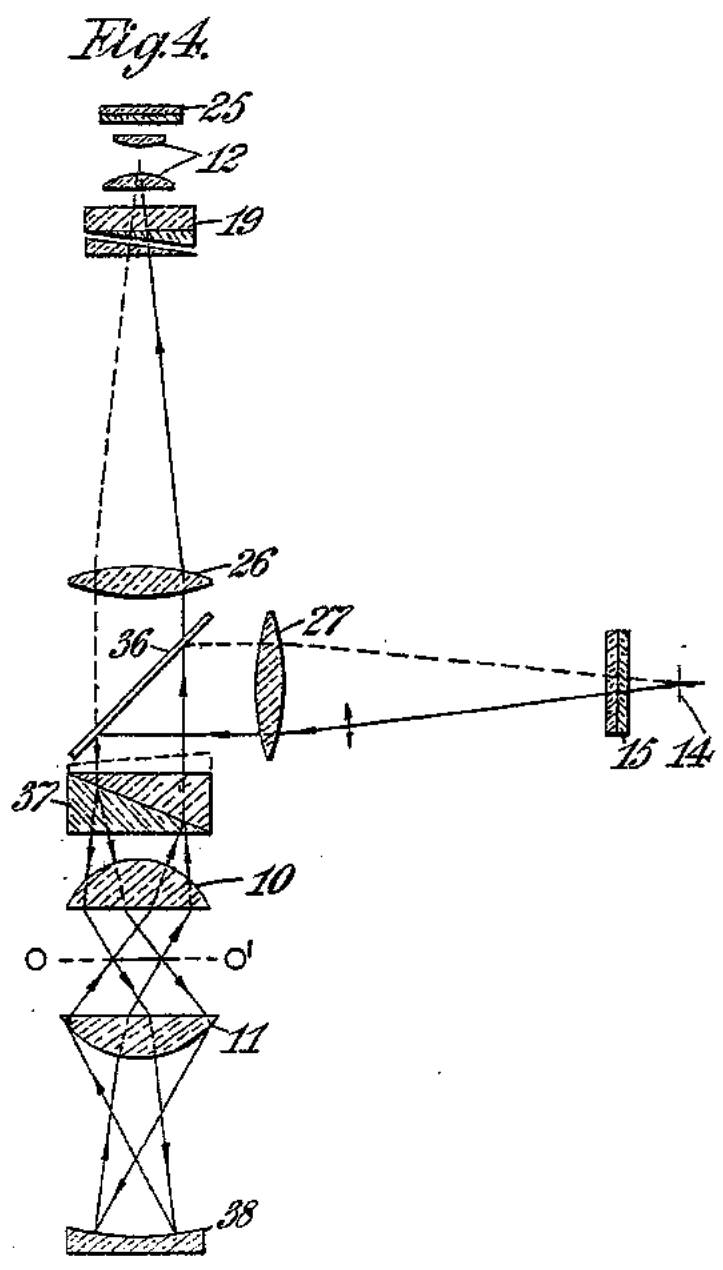


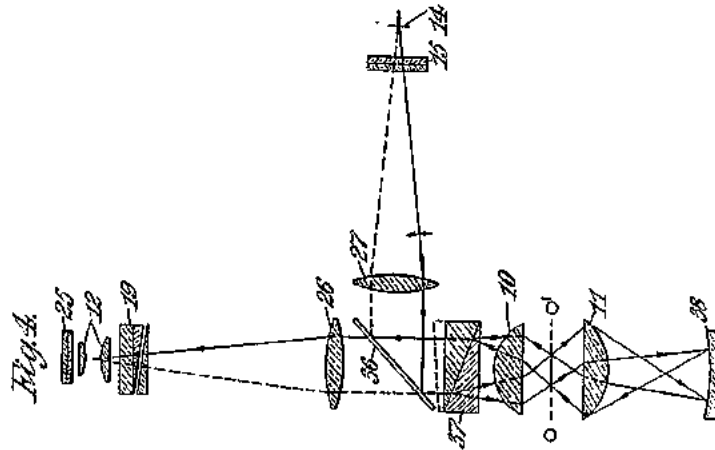
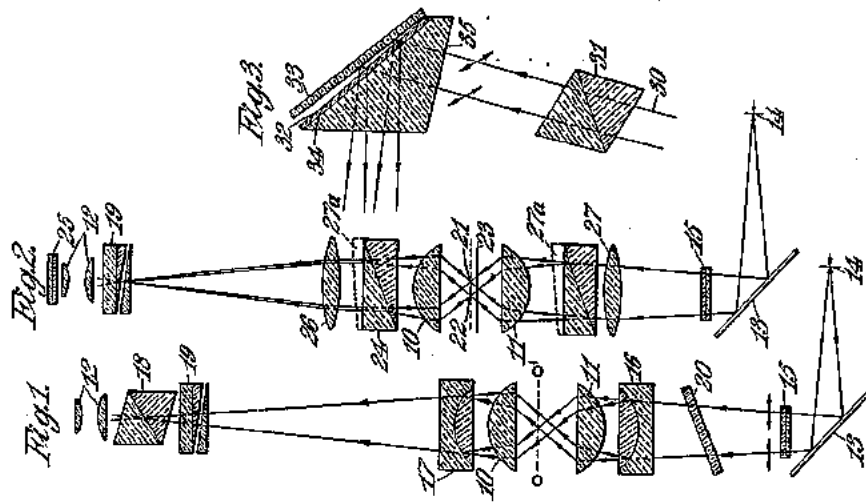
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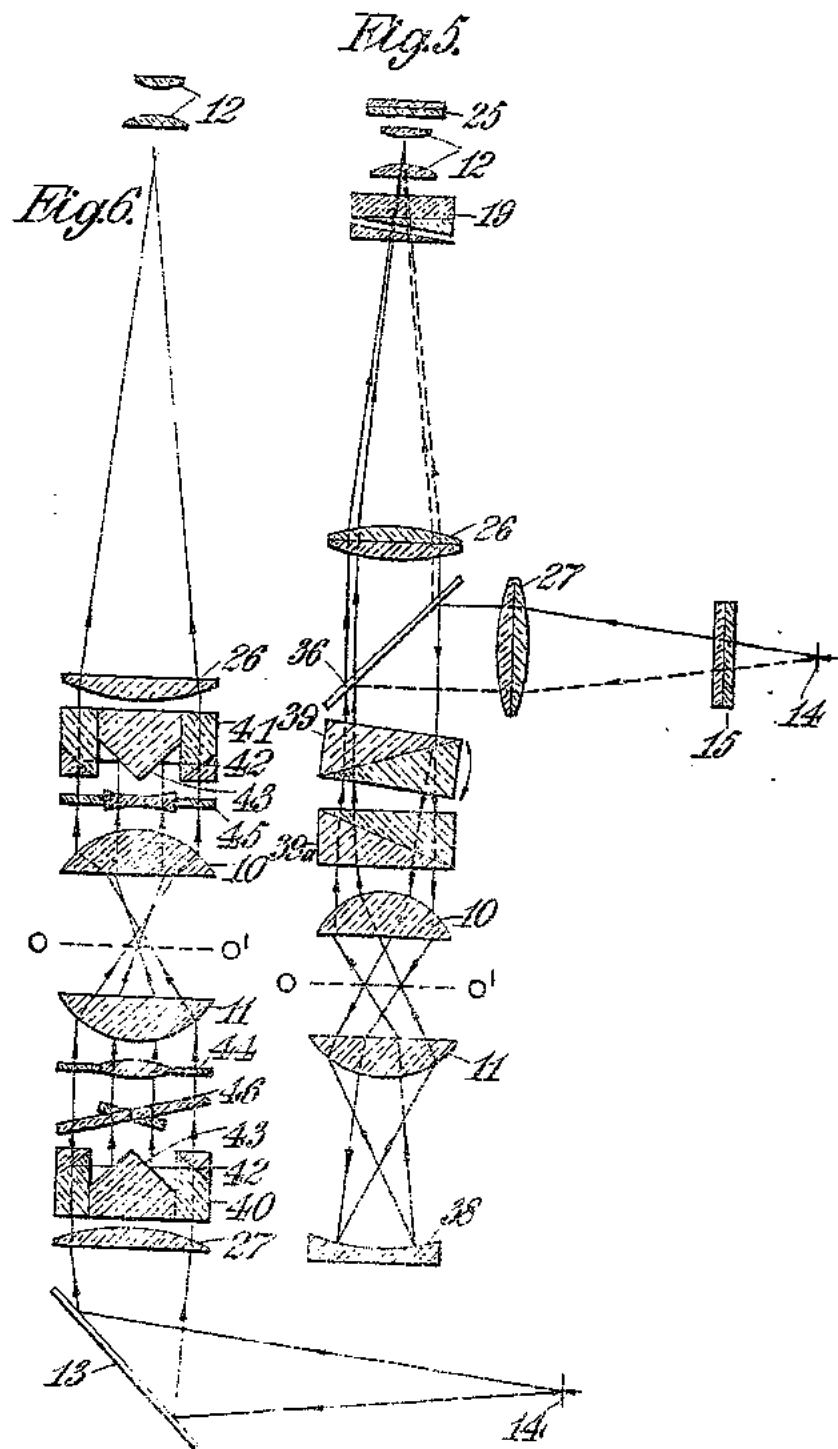
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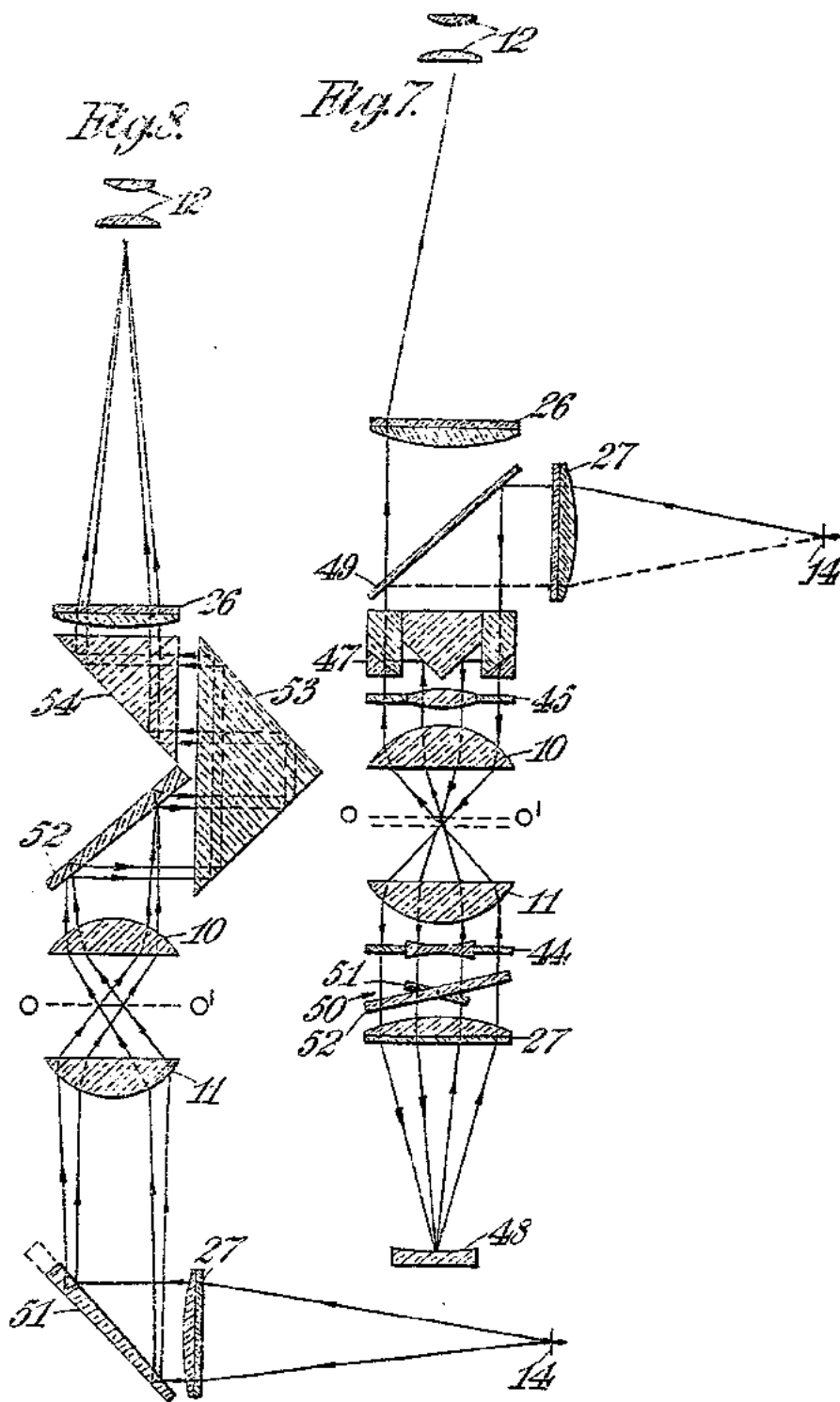


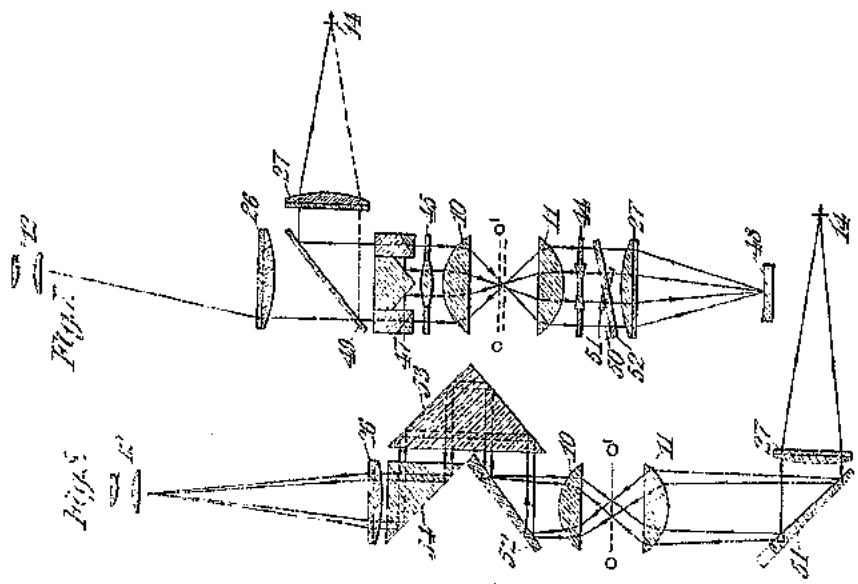
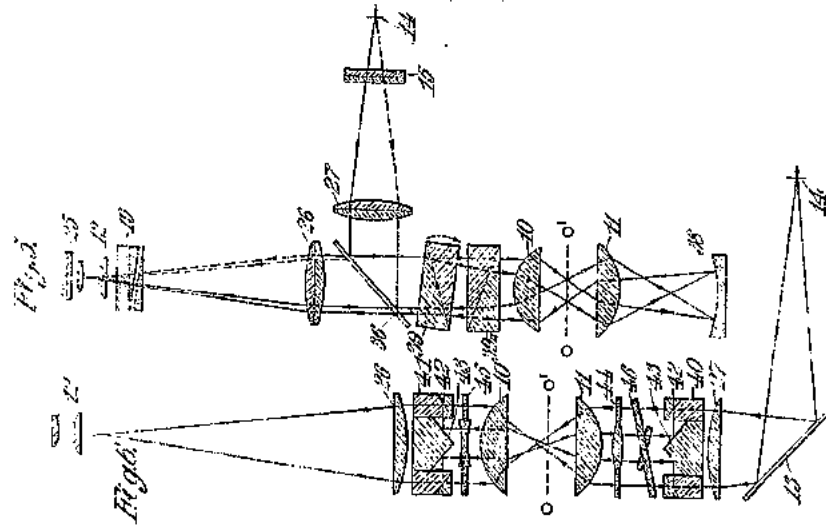


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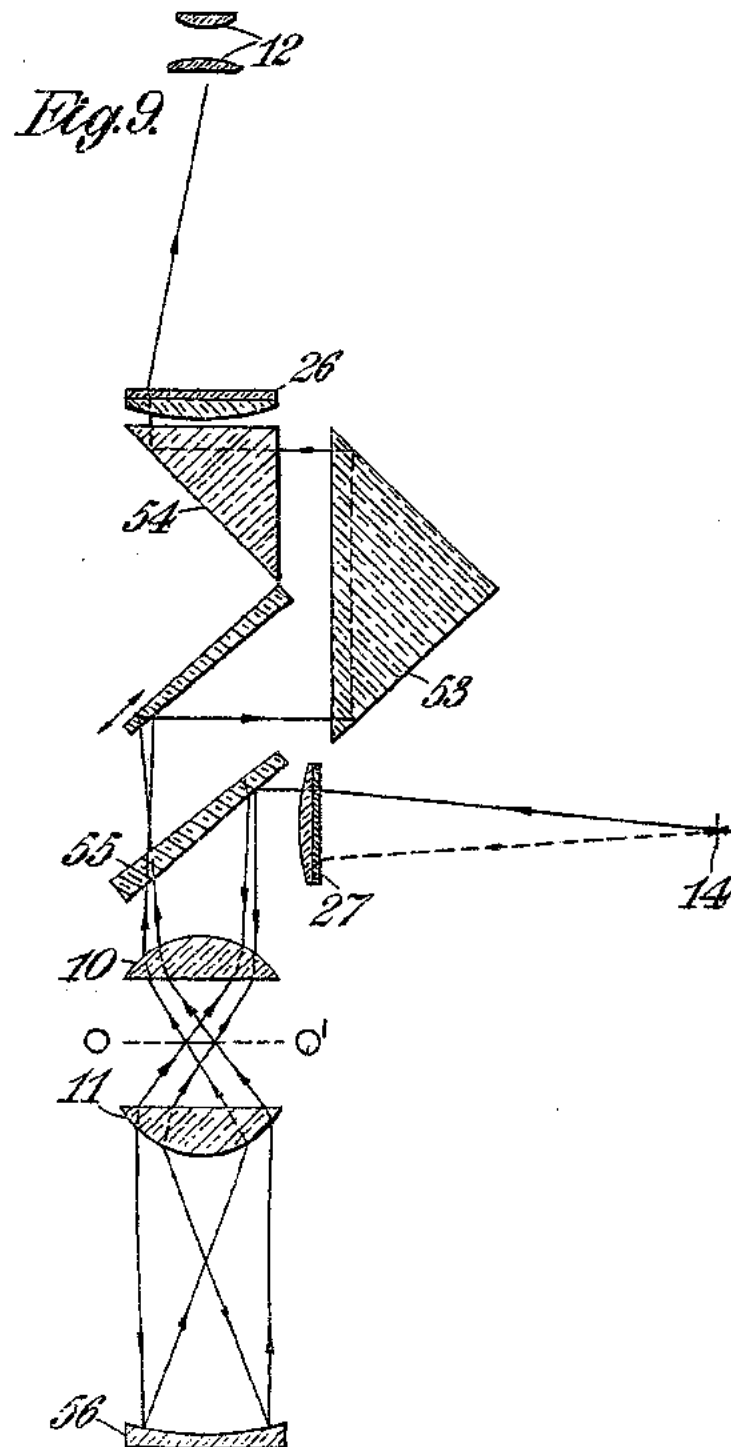


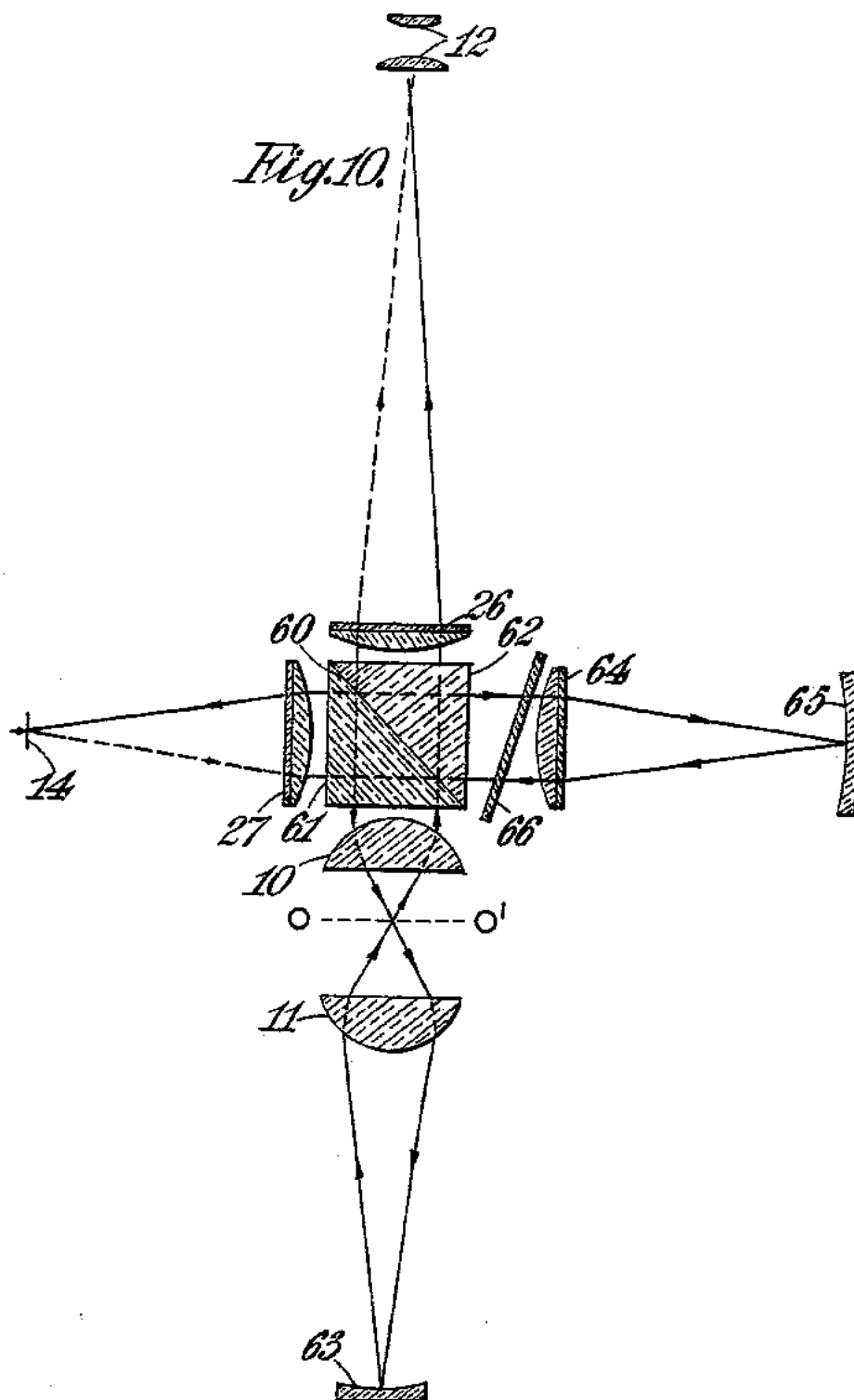


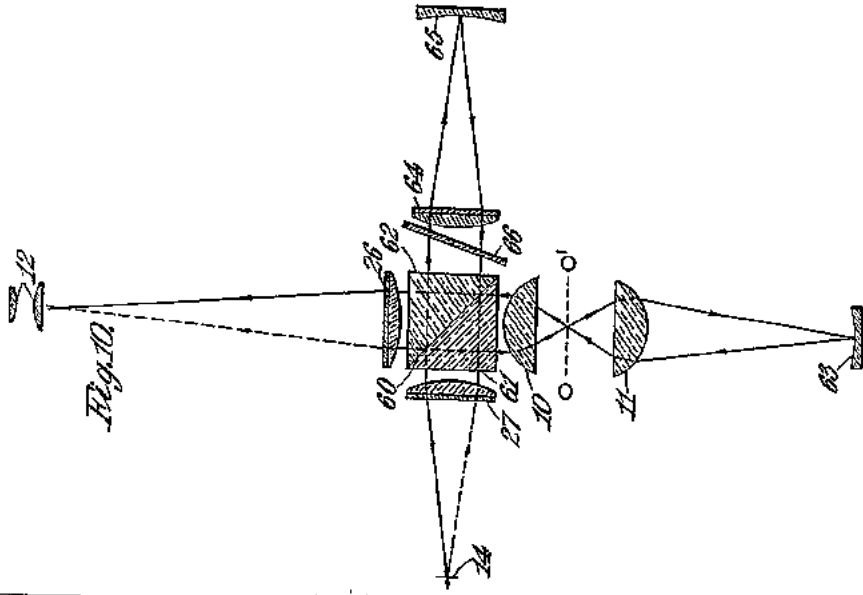
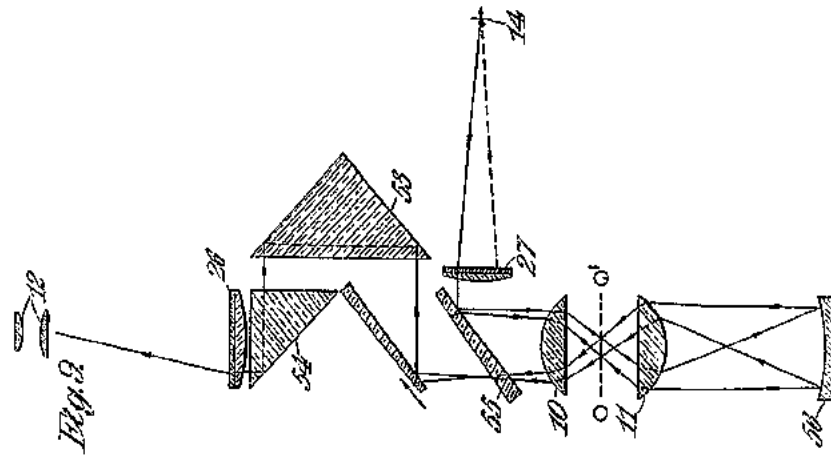


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