AMENDED SPECIFICATION

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PATENT SPECIFICATION

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695,352

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COMPLETE SPECIFICATION

Improvements in and relating to Microscopes and Microscope Objectives

We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, a British Company, of 1, Tilney Street, London, W.1, do hereby declare the invention, for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to microscope objectives in which magnification is effected by means of reflecting surfaces, and to microscopes having such objectives.

Various proposals have been made from the days of Newton onwards in connection with microscopes in which magnification is effected by reflecting surfaces.

Reflecting microscopes have been previously constructed using a concave and a convex mirror in which one or both of the mirrors are aspherized. It has been previously believed, however, that purely spherical mirrors could only be satisfactorily used when the ratio of radii of the mirrors was close to $\frac{\sqrt{5}+1}{\sqrt{5}-1}$ (i.e. approximately 2.6) and the numerical aperture not greater than about 0.5. We have now discovered that in general this is not a limitation at all and that other ratios sometimes of much larger value can be used, the resulting objective being of markedly higher performance. The separation of the mirrors is obtained roughly from the empirical data to be given and is adjusted exactly on a trial and error basis after the other requirements have been satisfied.

An objective has been recently proposed with a larger ratio of radii but that objective required the use of lenses in conjunction with the spherical mirrors.

An object of the present invention is to provide microscope objectives in which magnification is secured by means of spherical reflecting surfaces and in particular to provide objectives of this kind adapted for use with microscope tubes of the length and diameter customarily employed with objectives of the refracting kind or tubes not materially greater in diameter or length, and condensers.

The present invention consists of a microscope objective in which the optical elements which determine the numerical aperture of the objective consist solely of a concave and a convex spherical mirror coaxial therewith, the concave mirror being the larger and a central aperture being provided in the concave mirror to allow transmission of the light rays, in which the ratio of the radii of curvature of said mirrors is in the range 3.5 : 1 to 30 : 1 inclusive.

The separation of the mirrors is adjusted until the limiting numerical aperture free from spherical aberration is obtained.

The greater the ratio of radii the smaller will be the central obstruction inherent in the construction.

The spherical surfaces employed may be of small radius. Thus the radius of curvature of the larger of the two spherical surfaces may be usually between 3 inches and one-quarter inch. Preferably it is in the neighbourhood of 0.5 inches. Thus, it is conveniently about 0.6 inches.

Preferably the ratio of the radii is between 5 : 1 and 30 : 1.

The centres of curvature of the two surfaces may be separated in an axial direction, that is to say, in the direction of the axis of the objective or condenser.

Thus, where the ratio of the radii is 3.5:1 the separation may be about 0.035 inches, the centre of curvature of the convex and smaller reflecting surface being positioned further from the object to be viewed than the centre of curvature of the larger and concave surface.

With the radii of the reflecting surfaces in the proportions given and the reflecting surfaces positioned as specifically set out in the examples which follow, the central obstruction of the numerical aperture is about 40 per cent. Further, the use of reflecting surfaces having small radii gives a relatively greater numerical aperture which may equal 0.6 or above.

In the accompanying drawings:—

Figure 1 shows the diagrammatic layout of the arrangements according to the invention and the references thereon will be understood from the following Table:—

ρ = radius curvature concave mirror (inches)
R = radius curvature convex mirror (inches)
d = diameter convex mirror (mm)
ξ = separation of components (mm)
η = separation of object point and pole of convex mirror (mm)
D = diameter of hole in concave mirror (mm)
$\sin\theta$ = numerical aperture

$$\frac{\sin\theta^1}{\sin\theta} = \text{central obstruction}$$

T = tube length (mm)

Figures 2 and 3 show empirically derived graphs used for preparing specific examples of structures according to the invention.

Briefly the procedure for preparing a structure according to the invention is as follows:—

1. Select a suitable radius of curvature for the concave mirror (say 0.641 inches) and determine the central obstruction which can be tolerated.

2. From the graph of Figure 2 curve A, for which the right hand ordinates apply giving the percentage central obstruction for a concave mirror of radius 0.641 inch, read off the radius of curvature of the convex mirror for which the abscissæ are given in inches (the central obstruction being a function of the ratio of the radii of the concave and convex mirrors).

3. The focal length is then given from curve B of Figure 2 for which the ordinates are given at the left hand side in millimeters.

4. Then from curve C of Figure 3 for which the abscissæ are the radii of curvature of the convex mirror in inches, the working distance (separation of the object point and pole of the convex mirror) is determined and from curve D the separation of the mirrors. The ordinates of Figure 3 are in millimeters and are for the concave mirror radius of curvature of 0.641 inches. For other values of the radius of curvature of the concave mirror the ordinates are simply scaled up in exact proportion.

5. The diameter of the convex mirror is determined from the formula

$d_{mm} = 2 \times \text{focal length}_{mm} \times \text{numerical aperture}$. Thus if the numerical aperture is set at 0.65 then d_{mm} is determined.

6. Having determined d_{mm}, the dimensions of the concave mirror must be obtained by ray tracing so that all rays can leave the system.

Specific examples of constructions according to the invention are as follows:—

Example I.

Central obstruction 35%
Ratio of Radii = 4.45
ρ = 0.641″
R = 0.144″
F = 2.56 mm.
ξ = 12.0 mm.
η = 7.5 mm.

Example II.

Central obstruction 25%
Ratio of Radii = 8.90
ρ = 1.739″
R = 0.195″
F = 3.13 mm.
ξ = 36.4 mm.
η = 12.9 mm.

Example III.

Central obstruction 19%
Ratio of Radii = 17.5
ρ = 1.739″
R = 0.0991″
F = 1.55 mm.
ξ = 39.8 mm.
η = 8.0 mm.

In the above three examples a numerical aperture of about 0.65 is obtained free from spherical aberration. When some aberration can be tolerated e.g. when infra-red radiation is used the numerical aperture may usefully be increased to about 0.85.

We have found that with objectives of the kind which the invention is concerned with, the position of the reflecting surfaces with respect to one another should be extremely accurately adjusted both in an axial direction with respect to the tube of the microscope or the body of the objective and also laterally.

Generally it may be stated that the desired degree of accuracy cannot be secured or, if secured, only with considerable difficulty, by adopting the technique in positioning the several components of an objective of the refractive type.

Preferably, in accordance with the invention, the objective is furnished with means permitting axial and lateral adjustment of the reflecting surfaces by the user.

Suitable means are shown in the accompanying drawings:—

Figure 4 is a side elevation with outer dust casing removed;

Figure 5 an inverted plan with outer dust casing removed, and

Figure 6 a section on the line 6—6 of Figure 5 with outer dust cover in place.

Thus as shown the concave spherical surfaced reflector 1*a* is engaged in a hollow semi-cylinder or approximate semi-cylinder 1 furnished with means to be described later, whereby it may be moved axially with respect to a complementary semi-cylindrical member 2 secured to the tube of the microscope, by a R.M.S. (Royal Microscopic Society) Thread 2*a*.

The two opposite extremities of member 2 are grooved, and between them and the adjacent surfaces of the semi-cylinder 1 (one of which is grooved) are interposed hardened steel balls 3, one at one end and two at the other; and there is provided a spring strip 4 at one end of which is connected with an annular cap 2^1 while the other end is connected to an annular member 2*a*. The cap 2^1 and member 2*a* are integral with the supporting member 2. The spring strip 4 operates to hold the member 1 in the member 2 but to allow axial movement of the former within the latter. A hardened steel ball 4*a* operating in a groove in the semi-cylinder 1 is interposed between the spring 4 and the semi-cylinder 1 to reduce friction in the relative axial movement of the members 1 and 2.

The axial movement of the member 1 within the member 2 is effected by a screw 2*b* mounted on the member 2*a*, the movement of the screw being transmitted to the semi-cylinder 1 by means of a double-ended needle 2*c* engaging at one end in a recess in the screw and at the other end in a recess in the semi-cylinder 1.

The member supporting the convex reflecting surface 5*a* is furnished with means for imparting motion to it in two directions approximately perpendicular one to the other and to the axis of the microscope tube or objective axis.

Thus it may be secured by an arm 5*b* to an annular member 5 which is held in contact with the annular member 2*a* by means of the springs 8. Hardened steel balls 6 providing a three-point support are located between the members 2*a* and 5.

An adjusting screw 7 is provided for securing relative rotational movement between the members 2*a* and 5 and about one of the spherical balls 6 as centre, the displacement being in opposition to springs 8 which are secured at one end to the supporting member 2 and at the other end to the annular member 5 and which, as previously mentioned, hold the member 5 against the member 2*a*. A double ended needle 7*a* fits at one end in a recess in the screw 7 and at the other end in a recess in the member 5 to transmit the movement of the screw. A second adjusting screw 9 provides for radial movement between the annular members 5 and 2*a* which are radially grooved to hold the ball bearing 6 adjacent to the screw 9 and allow of this readial movement and provide a pivot for the previously-mentioned rotational movement.

The dust case 10 is shown secured in place in Figure 6.

What we claim is:—

1. A reflecting microscope objective in which the optical elements which determine the numerical aperture of the objective consist solely of a concave and a convex spherical mirror, coaxial therewith, the concave mirror being the larger and a central aperture being provided in the concave mirror to allow transmission of the light rays, the ratio of the radii of curvature of said mirrors being in the range 3.5 : 1 to 30 : 1 inclusive.

2. A microscope objective as claimed in Claim 1, in which the ratio of radii is between 5 : 1 and 30 : 1.

3. A microscope objective as claimed in Claim 1, in which the ratio of radii is between 3.5 : 1 and 5 : 1.

4. A microscope objective as claimed in Claim 1, in which the numerical aperture is in the range 0.5 to 0.85 inclusive.

5. A microscope objective as claimed in Claim 3, substantially as described with reference to Example I.

6. A microscope objective as claimed in Claim 2, substantially as described with reference to Example II.

7. A microscope objective as claimed in Claim 2, substantially as described with reference to Example III.

8. A microscope having an objective as claimed in any of the preceding claims, in which the concave mirror is secured in a member which can be axially moved with respect to a fixed element secured to the tube of the microscope.

9. A microscope as claimed in Claim 8, in which the convex mirror is furnished with means for imparting motion to it in two directions approximately perpendicular to each other and to the axis of the microscope tube.

10. A microscope as claimed in Claim 8 or 9 in which the concave mirror is secured in a hollow semi-cylinder or approximate semi-cylinder which slides on a co-operating supporting element of hollow semi-cylindrical or substantially semi-cylindrical form.

11. A microscope as claimed in Claim 9 in which the convex mirror is supported on an annular member supported by means of springs on a second annular member between which annular members are located three circumferentially spaced hard steel balls providing a

three point support.

12. A microscope as claimed in Claim 10, in which between the two opposite extremities of the semi-cylinders are interposed spaced hardened steel balls.

13. A microscope as claimed in Claims 10 and 11, in which said supporting element and said second annular member form an integral structure.

14. A microscope having an objective as claimed in Claim 1, the components of said objective being mounted substantially as described with reference to and as shown in Figures 4 and 6 of the accompanying drawings.

MARKS & CLERK.

PROVISIONAL SPECIFICATION.

Improvements in and relating to Microscopes and Microscope Objectives

We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, a British Company, of 1, Tilney Street, London, W.1, do hereby declare the nature of this invention to be as follows:—

This invention relates to microscope objectives in which magnification is effected by means of reflecting surfaces.

Various proposals have been made from the days of Newton onwards in connection with microscopes in which magnification is effected by reflecting surfaces.

The object of the present invention is to provide microscopes and microscope objectives in which magnification is secured by means of spherical reflecting surfaces and in particular to provide objectives of this kind adapted for use with tubes of the length and diameter customarily employed with objectives of the refractive kind or tubes not materially greater in diameter or length, and condensers.

One feature of the invention is the employment of spherical surfaces of small radius. Thus the radius of curvature of the larger of the two spherical surfaces may usefully be between 3 inches and one-quarter inch.

Preferably it is in the neighbourhood of 0.5 inches. Thus, it is conveniently about 0.6 inches.

A further feature of the invention is the employment of spherical surfaces the ratio of the radii of which is between 2:1 and 5:1, and preferably 3.5:1 for visible light.

The centres of curvature of the two surfaces may be displaced in an axial direction, that is to say in the direction of the axis of the objective or condenser.

Thus where the ratio of the radii is 3.5:1 the displacement may be 0.035 inches, the centre of curvature of the convex and smaller reflecting surface being positioned closer to the object to be viewed than the centre of curvature of the larger and concave reflecting surface.

With reflecting surfaces proportioned and positioned as specifically set out, the central obstruction of the numerical aperture is about 40 per cent. Further the use of reflecting surfaces having small radii gives a relatively great NA which may equal 0.6 inches or above.

We have found that with objectives of the kind which the invention is concerned with, the position of the reflecting surfaces with respect to one another should be extremely accurately adjusted both in an axial direction with respect to the tube of the microscope or the body of the objective and also laterally.

Generally it may be stated that the desired degree of accuracy cannot be secured or, if secured, only with considerable difficulty, by adopting the technique in positioning the several components of an objective of the refractive type.

Preferably, in accordance with the invention, the objective is furnished with means permitting axial and lateral adjustment of the reflecting surfaces by the user.

For instance, in accordance with the invention, the smaller but preferably the larger of the two spherical surfaced reflectors is engaged in a hollow cylinder furnished with means whereby it may be moved axially with respect to a fixed element secured to the tube of the microscope.

Thus the cylinder may be partly embraced by a member which is of substantially semi-cylindrical form between the two opposite extremities of which and the adjacent surfaces on the cylinder are interposed balls and between the cylinder and the member there may be located two helical springs one end of each of which is connected with the embracing member, while the other end of each of them is connected to the cylinder, the springs operating to draw the two members together and to provide a measure of axial constraint.

The member providing the larger but preferably the smaller of the refracting surfaces is furnished with means for imparting motion to it in two directions approximately perpendicular one to the other and to the axis of the tube or objective.

Thus it may be secured to an annular member which is freely supported by a second annular member between which are located hardened steel balls providing a three point support and the provision of an adjusting screw for securing relative motion between them, displaced in opposition to the springs in imparting motion to the immovable annular member in one direction for imparting motion in a direction at right angles thereto.

A further though optional feature of the invention and which without exceeding the scope of the present invention may be applied to microscopes employing refracting objectives, consists in the provision of focussing means by which the stage is moved while the objective and condenser remain fixed in position.

At this point it may be mentioned that focussing by moving the stage of a microscope is not uncommonly provided for in microscope stands but in such cases movement of the stage alters the position of the condenser with respect to the objective for the reason that the condenser is fixed to the stage although its position with respect to the stage may be varied.

Preferably in accordance with the invention, the movement of the stage in focussing is effected by tilting it about an axis perpendicular to the line of sight and displaced from such line to a degree, for instance, three inches, that the face of the object by such tilting motion moves only through a restricted angle.

For imparting tilting motion to the stage a simple screw may be used, the end of which forms one point of a three point support for the stage, the other two points being provided by the hinged connection of the stage with the stand.

Dated this 9th day of May, 1949.

MARKS & CLERK.

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Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained.

695,352 AMENDED SPECIFICATION
3 SHEETS

This drawing is a reproduction of the Original on a reduced scale.

SHEET 1

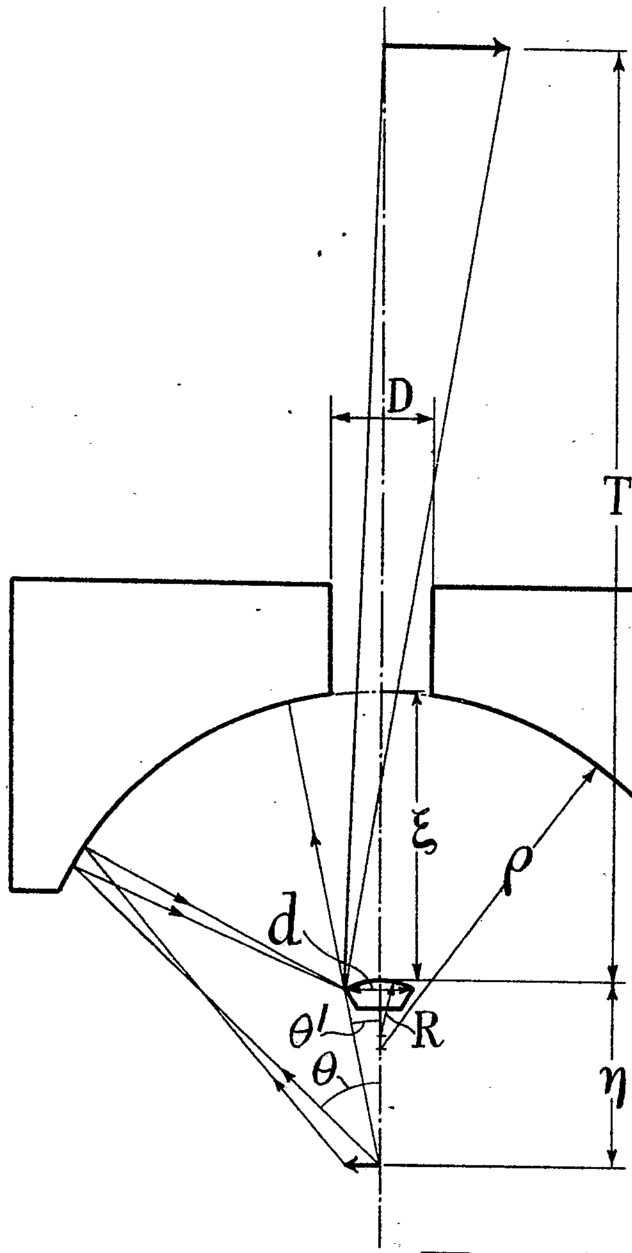
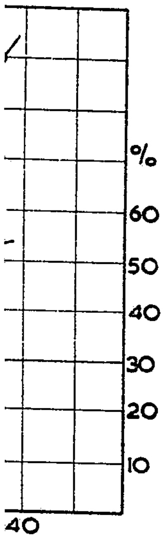


Fig. 1.



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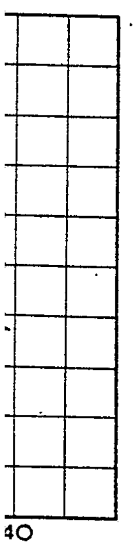


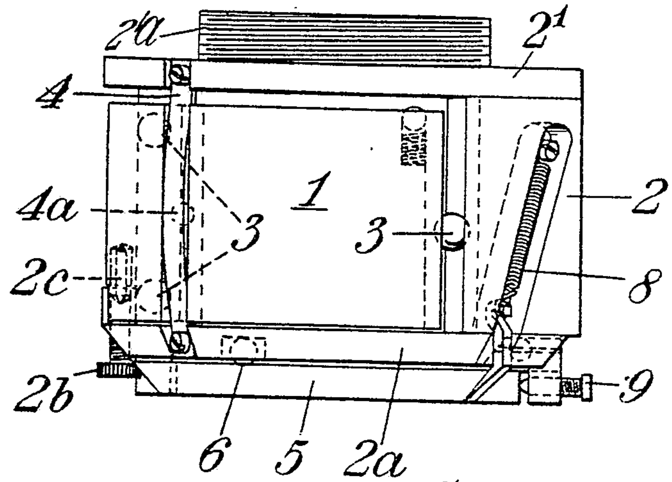
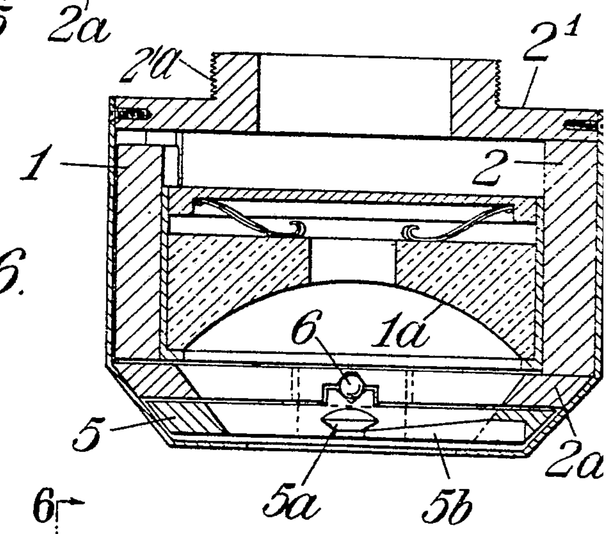


Fig. 4.

Fig. 6.



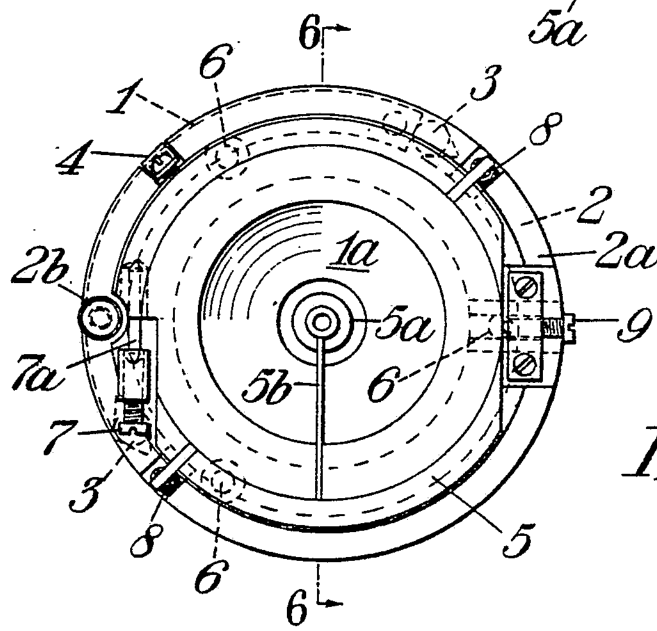


Fig. 5.

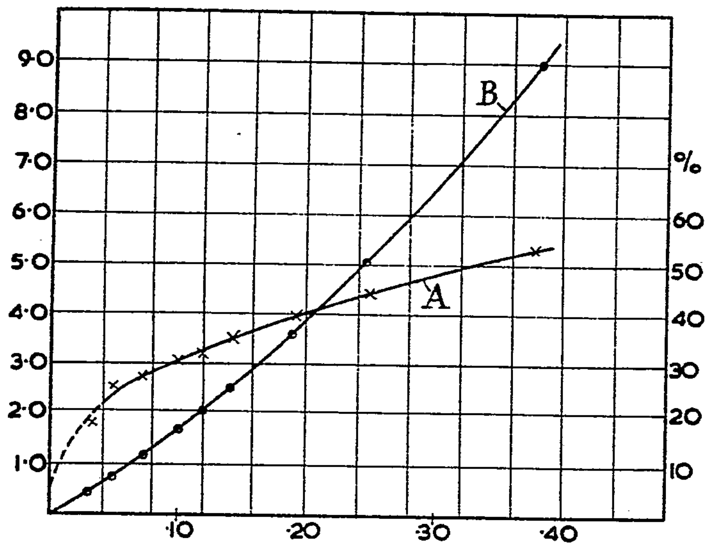

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Fig. 2.

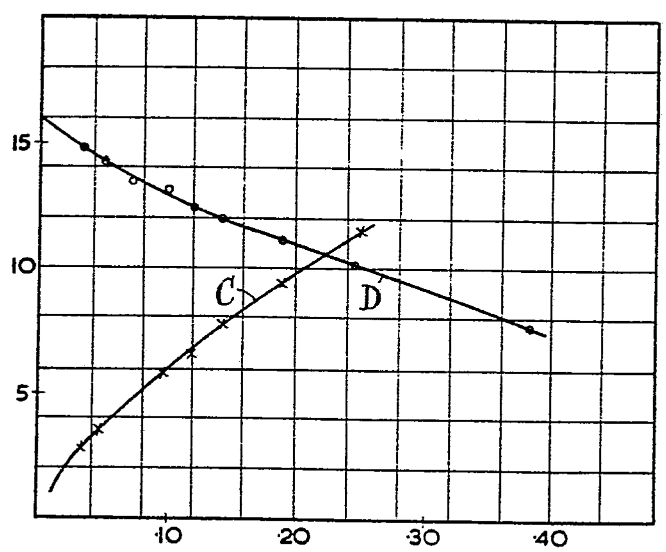
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Fig. 3.

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the Original on a reduced scale
SHEETS 2 & 3

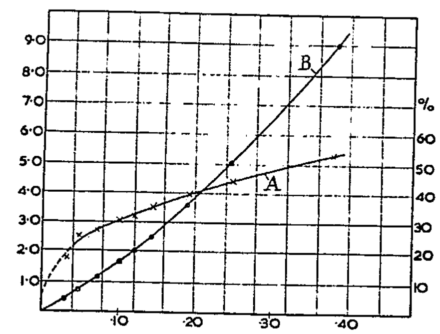

Fig. 2.

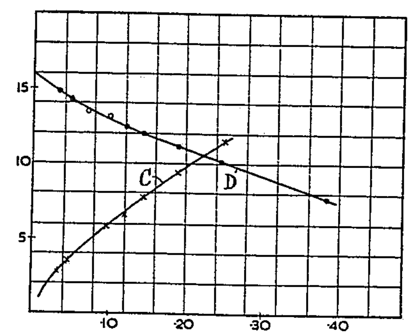

Fig. 3.

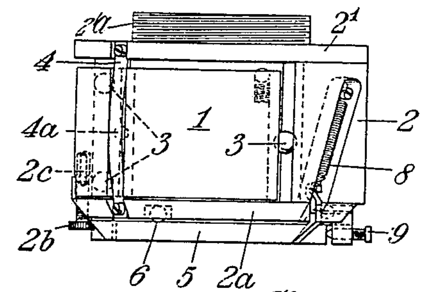

Fig. 4.

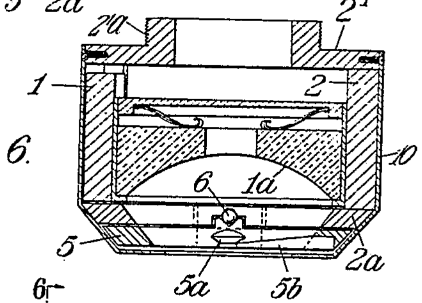

Fig. 6.

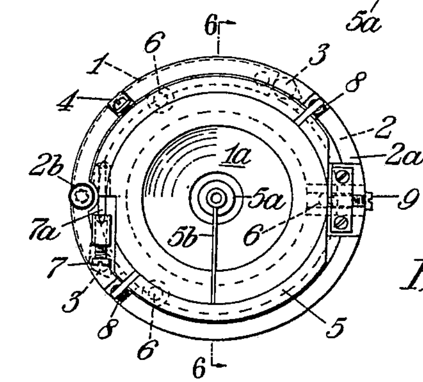

Fig. 5.