ZEISS

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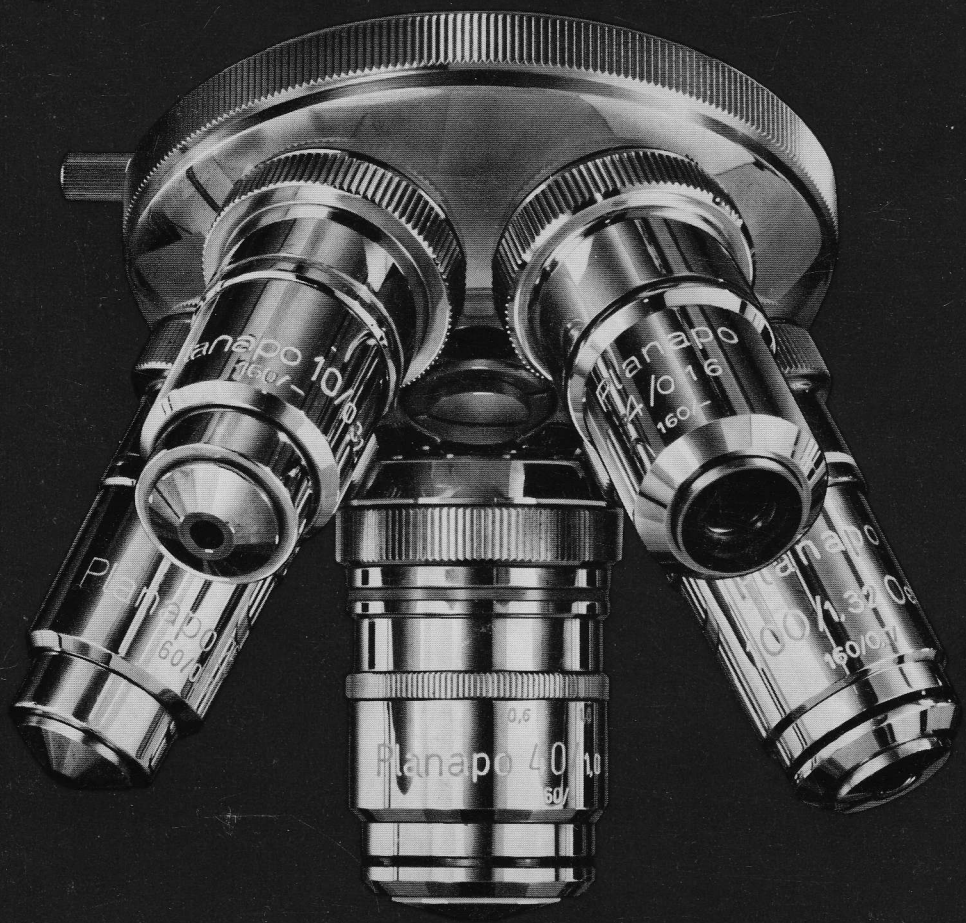
Optical Systems for the Microscope



General remarks

Survey of optical systems

General remarks 4

A few words on the working principle of the microscope

If objects or details are to be seen clearly, a sufficiently large image must be formed on the retina of the eye. A measure of the size of this image—which cannot be measured directly— is the so-called angle of view. In many cases this is so small that the desired clarity can no longer be achieved. To obtain greater clearness, means must therefore be used to increase the viewing angle and thus the image formed on the retina.

The simplest solution consists in approaching the eye as closely to the object as possible. This, however, is feasible only to a certain extent because of the limited ability of the eye to accommodate. To overcome this difficulty we have to avail ourselves of lenses or lens systems. The effect of such an auxiliary means is, in each case, that the object located a short distance in front of the eye—or even an image of such an object—is imaged at a greater viewing angle and a sufficient distance from the eye to allow observation without any particular stress on our mechanism of accommodation.

The aid usually employed for this purpose is an ordinary converging lens of sufficiently short focal length, which will form a magnified image of an object located in its focal plane at a distance far enough for the eye looking through the lens to view it without difficulty. The eye will then see the object under a wider viewing angle as if it were viewed from a normal distance. Such a lens is called a **magnifier.** Its **magnification** is defined as the relationship between the tangent functions of the two viewing angles, a certain value having been adopted as the normal viewing distance, viz. 250 mm. This is the so-called **distance of distinct vision.** Using this value, we obtain for the numerical value V_L of the magnification of a magnifier of focal length f_L:

$$V_L = \frac{250}{f_L}$$

If higher magnifications are required, simple lenses are no longer sufficient. In this case, the requirements to be made of image quality can only be satisfied by lens combinations. However, the magnification which can be achieved in a single magnification stage, as in a magnifier, is limited because technical problems only allow the focal length to be reduced to a certain degree: the lenses have to be curved ever more steeply and their diameters thus become smaller and smaller. This results in difficulties not only in manufacturing, but primarily in using them: the viewing distance is greatly reduced, the image brightness is low and the visual field small.

These disadvantages can be overcome if two successive image-forming systems are used as is the case in the **compound microscope:**

The first stage of image formation consists of a lens system, the microscope **objective,** located close to the object, which forms a real and magnified **aerial image** of the object, usually at a certain distance from the latter. The relationship between image size and object size, the scale of the image M_{obj}, is governed by optical laws and is represented by the relationship of the separation between the image and the primary focal point of the objective, which is called the "optical tube length t", and the objective focal length f_{obj}, viz.

$$M_{obj} = \frac{t}{f_{obj}}$$

The content of this aerial image formed by the objective, i. e. the detail of fine object structures it contains, however, has nothing to do with the scale at which the objective reproduces the object. On the contrary—as Abbe[1] was the first to prove—it depends not

only on the wavelength of the light used for observation, but primarily on the light-admitting properties of the objective. These are determined by the aperture angle of the cone of rays from the pencil originating at the object, which is able to enter the instrument through the aperture of the objective. The measure of this angle is—likewise since Abbe—the numerical value of the sine function of half the aperture angle. If the pencil originating at the object does not pass through air before it reaches the objective, but through another medium of different refractive index, the angle must be multiplied by this index. Because of its importance for image formation in the microscope, Abbe coined the term **numerical aperture** for the product of the sine of half the aperture angle and refractive index. Thus if this term is abbreviated N.A., as is customary in microscopy, and σ inserted for half the aperture angle, then we have

$$\text{N.A.} = n \cdot \sin \sigma$$

With regard to the magnified image formed by a microscope objective it must be noted that two adjacent object details will only be separated, or **resolved** as it is called in optical language, if the expression

$$\frac{\lambda}{\text{N.A.}} \geqq d \geqq \frac{\lambda}{2\,\text{N.A.}}$$

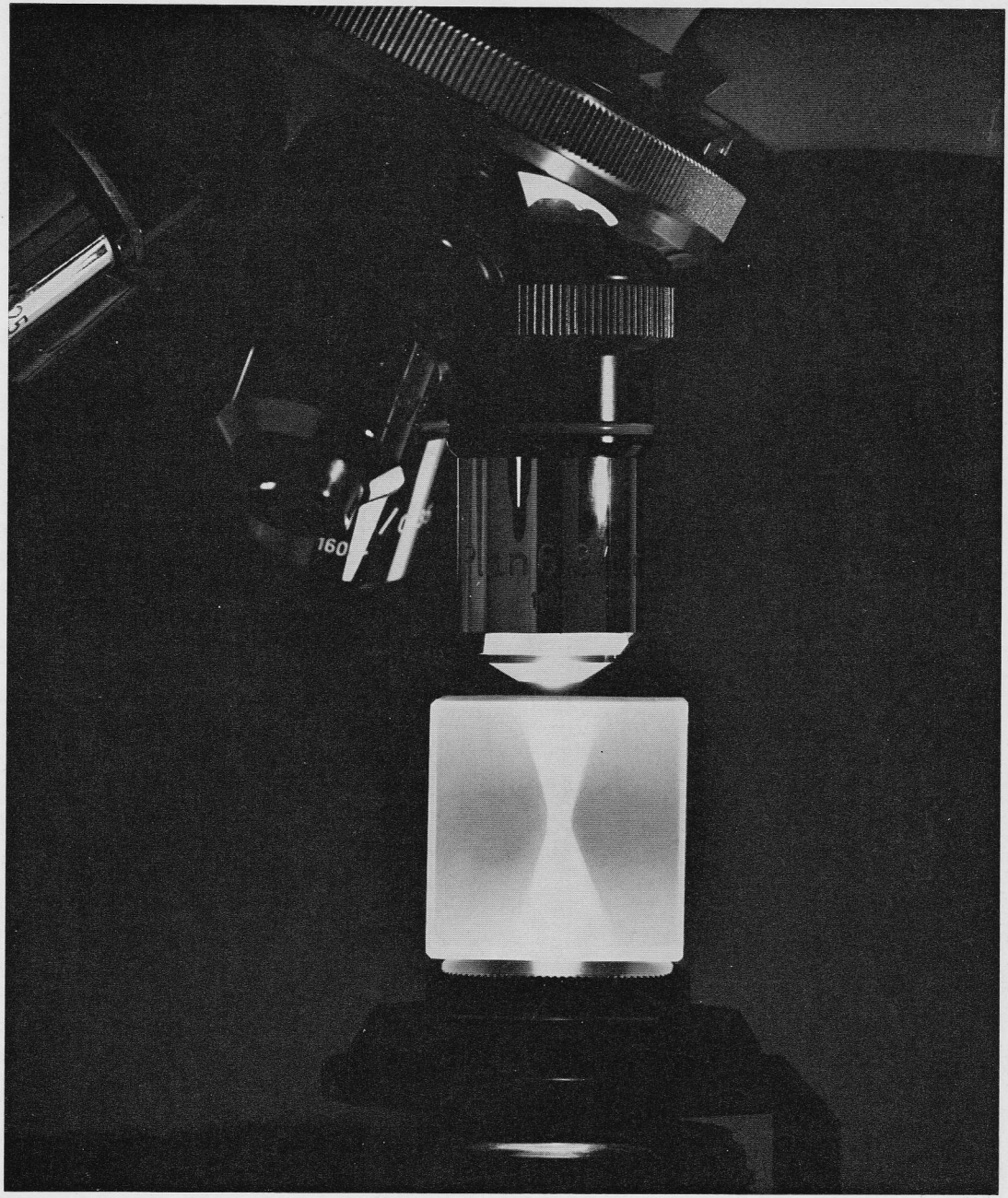
applies with regard to their separation d.

Consequently, the magnitude of the separation d to be resolved is always between the limits

$$\frac{\lambda}{\text{N.A.}} \text{ and } \frac{\lambda}{2\,\text{N.A.}}$$

Illustration:
Illuminating cone made visible.
The cone of light varies as a function of the numerical aperture.

[1] Ernst Abbe (1840–1905), physicist and professor at Jena. From 1867 worked for the ZEISS Optical Works. Became a partner in the company in 1875. Pioneer of microscope construction. Established the ZEISS Foundation.


160

Resolving power at $\lambda = 550$ nm Table 1

Objective aperture	Separation **d** (μ)		
	$\frac{\lambda}{\text{N.A.}}$		$\frac{\lambda}{2\ \text{N.A.}}$
0.10	5.5	. . .	2.75
0.30	1.83	. . .	0.92
0.65	0.84	. . .	0.42
0.95	0.58	. . .	0.29
1.25	0.44	. . .	0.22
1.40	0.39	. . .	0.20

An important fact which is frequently overlooked is that near the **limit of resolution** given by the above formula it is exclusively the **distance between the object details** which is reproduced correctly. Nothing can be said about their shape. To reproduce object configurations with a reasonable degree of similarity, we must remain considerably—by a factor of about 5 to 10—above the limit of resolution for the detail in question.

The second stage of image formation in the compound microscope is exclusively designed to spread the image produced by the first stage so that all details can be conveniently recognized by the eye. For this purpose the aerial image formed by the objective is viewed through a lens system acting like a magnifier and called the **eyepiece.**

It is natural that even the highest eyepiece magnification cannot show the eye more than the aerial image in accordance with the resolving power of the objective. There is thus no point using a higher eyepiece magnification than is required to make the resolved detail of the aerial image visible. Abbe realized that it was sufficient to use a total magnification of the objective-eyepiece system of 500 to 1000× the objective aperture. He coined the term **useful magnification**

for this range.

The total magnification V_{micr} is just the product of the scale of the aerial image M_{obj} produced by the objective and the eyepiece magnification V_{ocl}, namely

$$V_{micr} = \frac{t}{f_{obj}} \cdot \frac{250}{f_{ocl}}$$

On the basis of this formula we obtain for the total **focal length** of a compound microscope

$$V_{micr} = \frac{250}{\frac{f_{obj} \cdot f_{ocl}}{t}} = \frac{250}{f_{micr}}$$

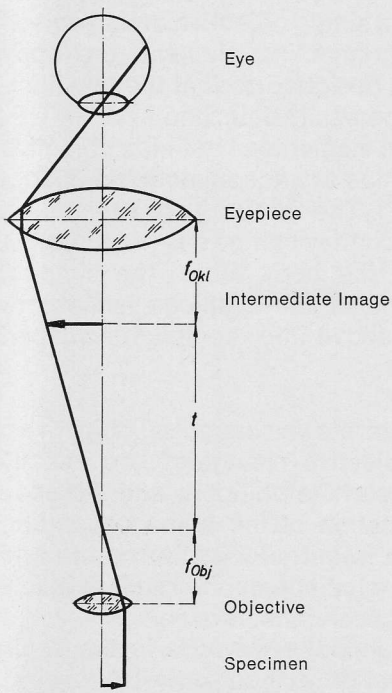
$$f_{micr} = \frac{f_{obj} \cdot f_{ocl}}{t}$$

A closer look at this formula clearly shows the advantages which the compound system has over the simple magnifying system:

Due to the possibility of combination, a multitude of total focal lengths can be achieved with only a few elements of different focal length.

Since the focal lengths of the different components remain large as compared to the focal length of the overall system, it is possible by appropriate selection of the former to obtain practically any desired short overall focal length. This means no less than that the magnifying power of a microscope is actually unlimited. That this unlimited magnifying power cannot be fully utilized in the compound microscope is due to the limited resolving power of the objective, which is determined by the wavelength of the light used and the numerical aperture.

However, sufficiently high resolving power and a magnifying power high enough to make the resolved image detail clearly visible still do not enable a compound system to present the eye with an undistorted image of this



Schematic drawing of the light path in the microscope

detail. In addition, the errors inherent to a greater or lesser degree in any image formed by the lenses have to be eliminated to such an extent that the overall system guarantees a largely unaberrated reproduction of resolved image detail.

While—as we have seen—the resolving power at a given wavelength of light depends exclusively on the objective, the **image-forming properties** are determined jointly by the objective and the eyepiece, although the primary influence is the type of objective.

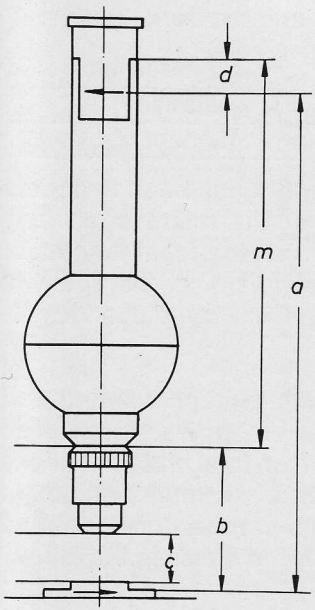
The **magnifying power** is determined on the one hand by the objective and the eyepiece, but on the other also by the mechanical system of the microscope connecting the two, because its length determines the optical tube length. Since the demands made with regard to resolving power, magnifying power and image-forming properties cannot be satisfied with a single objective and eyepiece system, the connecting element, the **body tube,** must be designed so that the two components can be easily detached from it. This is why the lens elements of both the objective and the eyepiece are accommodated in special "mounts". The former have a standard thread by which they can be screwed into the lower end of the body tube. The simpler, tubular mounts of the eyepiece lenses are slipped from above into the suitably shaped eyepiece tube.

Parfocalization of objectives and eyepieces

To facilitate the exchange of objectives, so-called "objective changers" are usually inserted between the objective and the body tube. The location of the plane separating the body tube from the objective on the one hand and the eyepiece on the other is determined by practical considerations:

The tube should always be in the same position in relation to the specimen.

The image must remain in focus when



m = mechanical tube length
a = object-to-image distance
b = object distance of objective
d = intermediate image distance of eyepiece
c = working distance of the objective

objectives or eyepieces are changed. In microscope language, this is called "parfocalization of objectives and eyepieces".

To satisfy the latter requirement, which is essential for undisturbed work with the microscope, the optical tube length cannot be the same for all types of objectives. It is the distance between the specimen and the aerial image that must be kept constant. With a given mechanical tube length this can only be achieved by appropriate design of the objective mount. The length of this must be chosen so that the separation between the object plane and the underside of the body tube against which the objective rests when it is screwed in is the same, and the lens system is positioned so that the aerial image will always be formed in the same plane in the tube, regardless of the objective focal length. The measure of the distance between objective plane and objective screw flange is the so-called object distance of the objective.

In order that the image will remain in focus when the eyepieces are exchanged, the eyepiece focal plane must always coincide with the real aerial image. In other words, the eyepiece flange must also be located at a fixed distance (intermediate image distance of the eyepiece) from the plane of the aerial image in the tube, and the eyepiece mounts must be so designed that their focal plane is always at a fixed distance from their seating.

Several points have to be taken into account when fixing the three mechanical dimensions: the object distance of the objective, the mechanical tube length and the intermediate image distance of the eyepiece.

The object distance of the objective is preferably chosen so that the objective of lowest power that is used frequently as well as objectives of particularly long construction can still be parfocalized. On the other hand, however, the objectives must not be made

excessively long or centering will become too difficult. A reasonable value has been found to be 45 mm, which we have been using for all our transmitted-light objectives since 1950.

The intermediate image distance of the eyepiece should be chosen as short as possible to allow eyepieces of short focal length also to be parfocalized without difficulty. With our eyepieces it is 10 mm.

The mechanical tube length should above all be chosen so that the microscope can be dimensioned to suit its purpose without becoming unwieldy. The mechanical tube length of our microscopes is 160 mm.

For the normal transmitted-light microscope, the combination of these three magnitudes results in a distance of 195 mm between the specimen and the aerial image.

Object distance		mechanical		intermediate image		object-to-image
of objective	+	tube length	−	plane of eyepiece	=	distance
45 mm	+	160 mm	−	10 mm	=	195 mm

Once the tube length has been fixed, the total magnification of the microscope only depends, in addition, on the focal lengths of objectives and eyepieces, i. e. the scale of the aerial image and the eyepiece magnification.

Appropriate selection of initial magnifications of objectives and eyepieces

The user of the microscope will find it of advantage if these two factors are chosen so that a large number of total magnifications can be achieved with a minimum equipment outlay. Such a series can be considered as well coordinated only if it satisfies the following conditions:

The relationship of every component in the series with the one preceding it and the one following it should be of equal magnitude.

It should be possible to obtain series with larger increments by leaving components with smaller increments out of a basic series.

The values of the different components should be round figures or should at least be close enough to round figures to be expressed by them with sufficient accuracy.

The series should be so established that once fixed for a power of ten it can be extended as desired by multiplying by 10, 100, etc.

These conditions are well satisfied by the decimal geometric series on which the German Industrial Standard DIN 323 is based. The working group on microscopy in the standards committee of the German Precision Engineering and Optical Industry has therefore proposed that the R 10 standard series from this standard be adopted as the basis for a microscope magnification series. It is contained in the draft standard on microscope magnifications, DIN 58,886, and is composed as follows:

Standard Series

1	1.25	1.6	2	2.5	3.2	4	5	6.3	8
10	12.5	16	20	25	32	40	50	63	80
100	125	160	200	250	320	400	500	630	800
1000	1250	1600	2000	2500	3200	4000	etc.		

When deciding on the characteristic values of objectives and eyepieces on the basis of such a series, the following points must be taken into consideration:

There should be 4 to 5 **main objectives** with the aid of which the range of total magnifications required for practical work can be covered, since only this number of objectives can be mounted on the conventional type of objective changer (revolving nosepieces).

The values for the initial magnification of the objectives and eyepieces must also be taken from the above series. Only then is the advantage of the standard series fully utilized, viz. that the product of any two figures is again a standard figure.

In view of these considerations we have chosen the following magnification increments for our objectives . Only in rare cases and in the case of special-purpose objectives have important reasons prompted certain deviations.

Series of initial magnifications of objectives

Basic series	2.5	4	6.3	10	16	25	40	63	100
Main series	2.5	–	6.3	–	16	–	40	–	100
Simplified series	2.5	–	–	10	–	–	40	–	(100)
	(2.5)	–	–	10	–	–	40	–	100

Series of initial magnifications of eyepieces

4×	5×	6.3×	8×	10×	12.5×	16×	20×	25×

The numerical aperture chosen for the different objective magnifications depends largely on the quality of correction. In general, the largest aperture is used that is possible and justified under the circumstances. The numerical apertures applying to our objectives may be taken from the different objective tables.

Field of view and viewing angle

In the compound microscope, the image is sharply limited by a diaphragm in the eyepiece which is called the **eyepiece field stop.** Its diameter depends on the focal length and type of the eyepiece and is limited by the inside diameter of the tube accepting the eyepiece. This diaphragm allows only a certain portion of the real intermediate image to be viewed. The diameter of this field is called the **field-of-view number.** In the tables included in this booklet it is indicated for each of the eyepieces. This number makes it possible to determine the diameter of the object portion which can be covered with the eyepiece field of view. This so-called **object field** is determined by dividing the field-of-view number by the initial magnification of

the objective used—if necessary making allowance for a factor due to body magnification or an intermediate optical system.

The field-of-view number and the eyepiece focal length also serve to determine the viewing angle under which the eye sees the entire image. If S is the field-of-view number, then the viewing angle w results from the expression

$$\text{tg}\frac{w}{2} = \frac{S}{2 \cdot f_{ocl}}$$

This viewing angle is also indicated in the different eyepiece tables.

All factors determining the magnifying power of the compound microscope and its relationship to the resolving power given by the aperture of the objective (range of useful magnification) can be represented diagrammatically as is shown by the following example of a typical series of objectives and eyepieces.

The horizontal lines in the diagram represent the steps by which the total magnification increases in accordance with the standard series, page 13. The solid lines from the lower right-hand corner to the upper left-hand corner are guide lines for the objectives, the magnification and numerical aperture of which are indicated beside the lower end of the guide line. The guide lines for the eyepieces are the dash-dotted ones running from the lower left-hand corner to the upper right-hand corner. The eyepiece magnification and the field-of-view number are indicated beside their lower end. The guide lines for the eyepieces intersect those of the objectives at the steps which indicate the total magnification of the corresponding combination. The colored frame limits the range of useful magnification as defined by Abbe.

Correction of aberrations

According to the laws of geometric optics, there is a considerable number of errors inherent in the image formed by an optical lens. Of these, the following affect image points even near the optical axis:
spherical aberration
sine coma
longitudinal chromatic aberration
chromatic difference of spherical aberration.

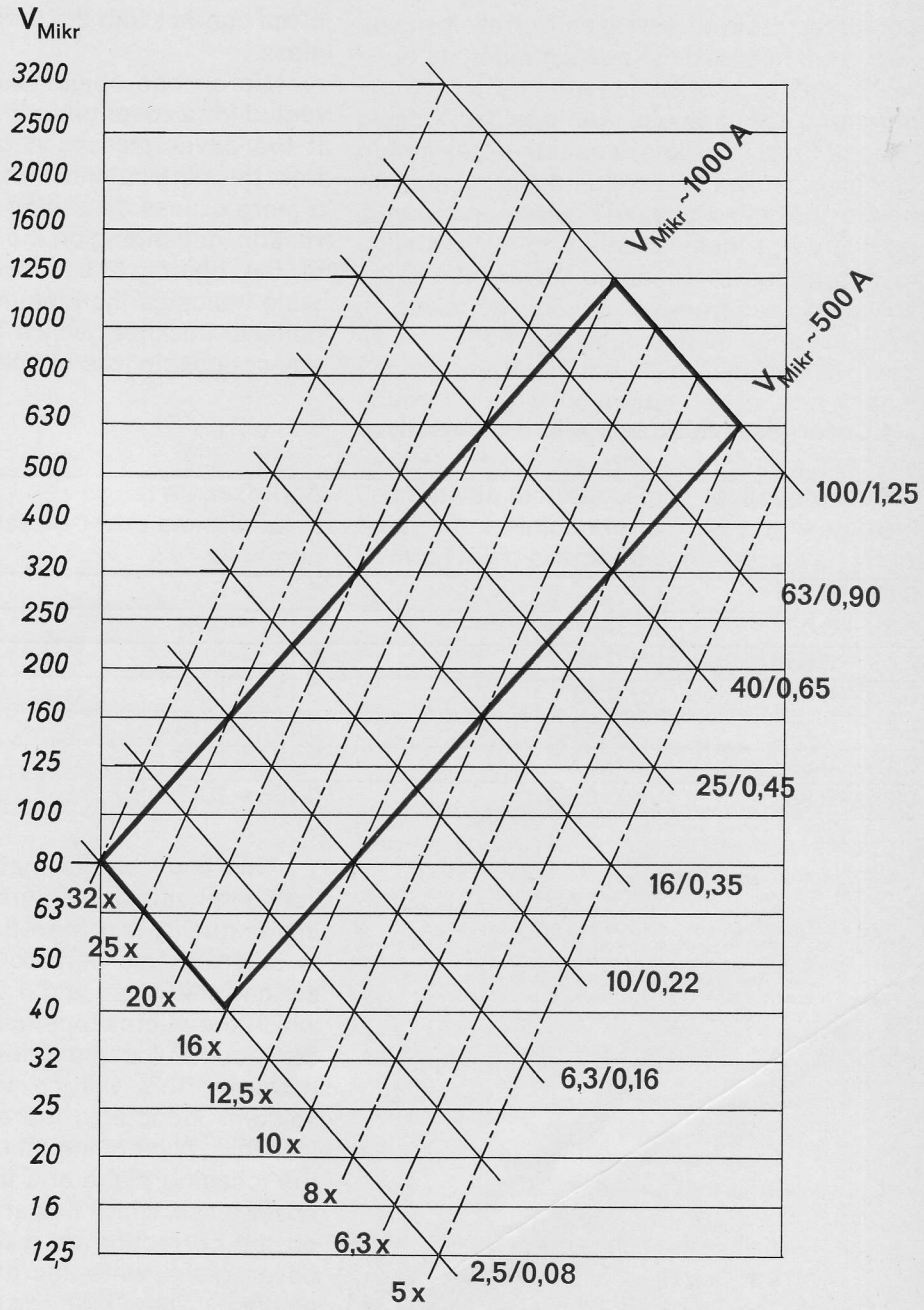
Towards the edge of the field, the following aberrations are increasingly evident:
coma
astigmatism
curvature of field
distortion
chromatic difference of magnification.

It is impossible to correct all these aberrations at once and completely. They can only be more or less reduced, greater emphasis being placed on the reduction of some than others depending on the intended use of the optical system.

The technical means required for the satisfactory correction of optical aberrations depend primarily on the degree of perfection desired; in addition, they depend on the desired numerical aperture.

The cover glass and its importance for image quality in the microscope

Special attention must be paid to the effect which the cover glass generally used for examining specimens by transmitted light has on image quality. This influence is clearly noticeable with objectives of larger numerical aperture than 0.3 to 0.35. It takes the form of spherical overcorrection and must be compensated by an appropriate residue of undercorrection in the objective if the latter is designed for examining covered specimens. This is, of course, possible only if the overcorrection introduced by the cover glass is always identical, and this is only the case if the cover glass has a certain thickness and refractive index, and the specimen is in very


V_{Mikr}
3200
2500
2000
1600
1250
1000
800
630
500
400
320
250
200
160
125
100
80
63
50
40
32
25
20
16
12,5
V_{Mikr} ~ 1000 A
V_{Mikr} ~ 500 A
100/1,25
63/0,90
40/0,65
25/0,45
16/0,35
10/0,22
6,3/0,16
2,5/0,08
32 x
25 x
20 x
16 x
12,5 x
10 x
8 x
6,3 x
5 x

close contact with the underside of the cover glass.

Microscope objectives are normally corrected for a cover glass thickness of 0.17 mm. If the cover glasses actually used deviate from this nominal thickness, they will produce a more or less disturbing over- or undercorrection, depending on the numerical aperture of the objective employed. The following table indicates the amount of deviation from nominal thickness which is tolerable without any noticeable loss of image quality.

Cover-glass thickness with dry objectives Table 2

N.A. of objective	Admissible deviation from nominal thickness of 0.17 mm	Approximate range of admissible cover-glass thickness (mm)
0.08 – 0.3	–	0 – 0.3
0.3 – 0.45	±0.07	0.1 – 0.24
0.45 – 0.55	±0.05	0.12 – 0.22
0.55 – 0.65	±0.03	0.14 – 0.20
0.65 – 0.75	±0.02	0.15 – 0.19
0.75 – 0.85	±0.01	0.16 – 0.18
0.85 – 0.95	±0.005	0.165 – 0.175

This table shows that with objectives of very high numerical aperture the optimum image quality is achieved only if special care is taken to use only cover glasses of prescribed thickness and if the object detail on which the microscope is focused is in direct contact with the underside of the cover glass. However, this will be the case only very seldom. Generally, there will be a more or less thick layer of mounting medium between the focusing plane and the underside of the cover glass, which has about the same effect on the correction as if the thickness of the cover glass were increased by the same amount. The "effective cover-glass thickness" is therefore composed of the actual

cover-glass thickness and the aforementioned layer of mounting medium between the focusing plane and the underside of the cover glass. The resulting inaccuracy has prompted objective manufacturers to use special mounts for all objectives with which such fine differences matter. These so-called **correction collars** allow one lens element to be shifted so that the over- or undercorrection due to a deviation of the cover-glass thickness from the nominal value can be compensated. For this purpose, the correction collar has a knurled ring with a graduation and index. The figures of the graduation (12 . . . 17 . . . 22) indicate the cover-glass thickness in hundredths of a millimeter. Optimum image quality is obtained when the figure corresponding to the thickness of the cover glass used is opposite the index.

In general microscopic practice it will not be possible to measure the effective cover-glass thickness directly. It is therefore necessary to use indirect methods to determine the correct setting of the correction collar.

1. The only method which can be used in all circumstances and at the same time ensures the most accurate setting of the correction collar, consists in measuring the effective cover-glass thickness with the aid of the microscope:

Using a 40×, N.A. 0.65, 40×, N.A. 0.75 or 40×, N.A. 0.85 objective, the condenser is stopped down to half the objective aperture and the microscope successively focused on the surface of the cover glass and the focusing plane with the aid of the fine adjustment. The corresponding readings of the fine adjustment are noted down. The difference between the two settings gives the optical thickness of the cover glass, which has to be converted to the mechanically "effective thickness" by multiplying it by a factor K. The latter is preferably determined once and for all by means of an experiment. For this purpose, the thickness D_1 of a few ordinary cover glasses is accurately determined by means of a measuring aid (micrometer, dial gage), whereupon their optical thickness D_2 is measured with the microscope as described above. The desired factor K results from the two measurements:

$$K = \frac{D_1}{D_2}.$$

It is not, as one might assume, identical with the refractive index of the cover glass.

Example: K is to be determined with two cover glasses of different thickness. Measurements show the following thicknesses.

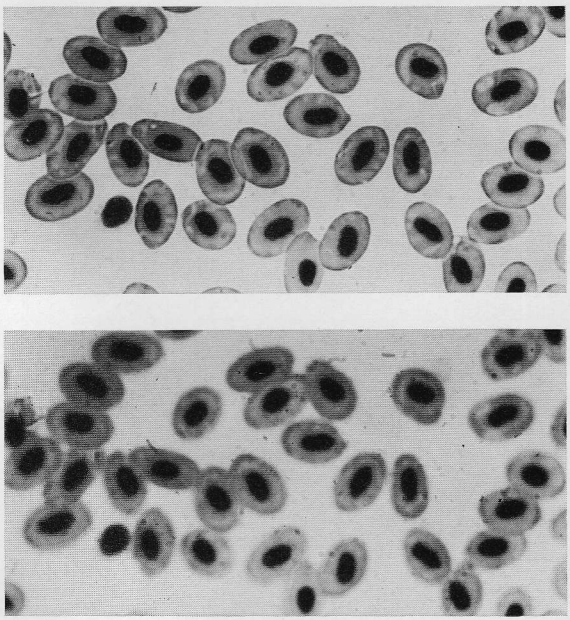
Cover glass No. 1	No. 2 ($n_D = 1.5288$)
D_1 mm 0.161	0.240
D_2 mm 0.102	0.152
We thus obtain for	
$D_1/D_2 = K$ 1.579	1.572

2. With less, but still sufficient accuracy the experienced microscopist will be able to adjust the correction collar by turning it until a fine, dark object detail is imaged with optimum contrast.

It follows from the aforesaid that objectives designed for use with cover-glass specimens cannot be employed for examining uncovered specimens. For use with uncovered specimens specially corrected objectives are available.

Illustration:
Rana, frog, blood smear.
NEOFLUAR, 63×, 0.90 N.A., corr.
Magnification 500×

In the upper micrograph
the correction collar has been accurately set
for cover-glass thickness,
in the lower the setting deviates
by 0.01 mm from the correct value.



The immersion method

An extremely efficient means of improving the image quality with objectives of high numerical aperture is the principle of immersion. It consists in using a liquid between the specimen and the front surface of the objective, which if possible should have the same optical properties as the glass of the front lens **(homogeneous immersion).** In accordance with the formula

$$d = \frac{\lambda}{N.A.} = \frac{\lambda}{n \cdot \sin \sigma}$$

this will also increase the resolving power by

the factor n, an advantage which today is frequently considered as the primary purpose of immersion.

Since an objective can be far better corrected for homogeneous immersion than a dry system of identical focal length and numerical aperture, it may also be of advantage to use the immersion method with systems of longer focal length. This gives objectives permitting a higher empty magnification and thus making it possible to cover a wide range of resultant magnifications by simple exchange of eyepieces.

Another advantage of the immersion method is that neither the cover-glass surface nor the front lens of the objective reflect any light so that for critical work the image is of considerably higher contrast than with an otherwise equivalent dry objective.

Since the optical characteristics of the immersion liquids have to be taken into account in the computation of the objectives, similar to those of the cover glass, it is essential to use only the prescribed immersion oil. This is all the more important as the principle of rigorous homogeneity has been abandoned with many of the highly developed immersion objectives presently in use.

Instead of the usual oil (refractive index n_D [20° C] = 1.515), water (n_D = 1.333) or glycerin (n_D = 1.455) are occasionally used as immersion media for special purposes. Water immersion is used for examining objects in water. Glycerin is used if for some reason the objective front lens and the cover glass are made of amorphous quartz and approximate homogeneity is desired.

Objectives designed for **homogeneous** immersion may be used with covered or uncovered specimens. The cover-glass thickness is naturally of no importance with these systems. It is different with present-day immersion objectives, in which the principle of

homogeneity has been abandoned. This point should be remembered if immersion objectives computed for covered specimens are also employed for viewing smears which are left uncovered to save trouble. This is normally the case in the examination of blood and bacteria smears. While the slight degradation of the image thus produced may still be tolerable for routine work, the trouble of covering the specimen should definitely not be shunned in critical work where full use is made of the high performance of the objective. It is true that the lack of a cover glass can be made up by other means, such as the use of immersion oil of higher refractive index—n_D 20 °C = 1.52 instead of 1.515—or by increasing the tube length, but who wants to use two different types of immersion oil and where can a microscope be found today in which the tube length can be increased up to 25 mm! Finally, objectives specially corrected for uncovered specimens, as normally employed for reflected-light work, may also be used for this purpose.

Classification of objectives

The different types of objectives are generally classified in accordance with the degree to which their aberrations have been corrected, their designation indicating chromatic correction first. This also automatically constitutes a classification according to the technical means required for achieving their respective degrees of correction and hence their price categories.

We distinguish between the following correction categories:
achromatic objectives,
semi-apochromatic objectives,
apochromatic objectives.

In their original form, all objectives in these three categories exhibit field curvature which increases considerably with decreasing focal length. As long as they were primarily used for visual observation, this was not felt as a serious drawback, because any desired point in the field of view could easily be focused with the aid of the fine adjustment. However, since the techniques of photomicrography have assumed such importance, new types of objectives have had to be developed in which the curvature of the field is eliminated to a sufficient degree, in addition to the other aberrations. Years of computation were required to solve this extraordinarily difficult problem in a satisfactory manner. In 1938 our firm introduced the first objectives giving a flat field, under the designation **Planachromats.** In the meantime, countless improvements have been made in these objectives.

As a result of this untiring work, a state has now been reached which permits not only achromats but also apochromats to be made as **flat-field objectives.** Thus the aforementioned three categories of objectives are supplemented by those of the
Planachromats and the
Planapochromats.

These can be supplied both as dry objectives and immersion objectives. There are objectives corrected for the observation of cover-glass specimens and others for use with uncovered specimens. While the objectives corrected for covered specimens are mounted and parfocalized so that they may be used for transmitted-light work, the objectives for uncovered specimens are—with few exceptions—designed for use in conjunction with vertical illuminators.

To satisfy the special requirements which have to be made for observation by polarized light (strain-free components, provision for accurate centering of objectives), objectives in centering mounts are supplied, the optical components of which are manufactured and mounted with special precautions to guarantee complete freedom from strain (POL objectives).

In principle, practically all objectives can be equipped with phase plates for use of the Zernike phase-contrast method. Our manufacturing program includes a wide choice of such objectives.

Our optical designers are today using the most advanced techniques and the latest glass types. They are constantly striving to find the best for the microscope optics we manufacture, the best that can be achieved with the means presently at our disposal. The use of highly perfected glass types may, however, occasionally have the disadvantage that a greater sensitivity to acids and water vapor is unavoidable. It is obvious that this applies above all to the most highly corrected and therefore most expensive types of objective—if only in a few cases. Allowance for this fact can be made by using only the less costly objectives for work with acids.

A lens error which has a very important influence on the satisfactory imaging of a visual field of a certain extension is the chro-

matic difference of magnification. Ever since Abbe's time, this error has generally not been corrected in the objective but by means of an eyepiece having an error of identical magnitude but opposite direction. Such eyepieces are called **compensating eyepieces.** In order that a single series of eyepieces may be sufficient—a fact which is today considered indispensable in the interests of easy operation of the microscope by less experienced personnel—all our objectives have the same lateral chromatic aberration. The fact that this is the case with all our objectives ensures that the user of our microscopes need not bother about which type of eyepiece to use for a certain objective. Any of our eyepieces will do. However, our objectives should never be combined with eyepieces of another make if a more or less serious loss of image quality is to be avoided.

The different categories of objectives are distinguished by the following characteristics:

Achromats

Achromats are lens combinations in which, to keep the price down, only the back focal distances for the colors blue and red of the spectrum have been made equal. This gives the most favorable correction for the brightest region of the spectrum. In this region, spherical aberration and sine coma as well as astigmatism have, of course, been eliminated as far as necessary or feasible with the means available at this price level. The residual chromatic aberration in this type of objective can be seen under oblique illumination as violet and yellowish-green color fringes around dark object details. Under straight illumination and with the specimen out of focus, it appears as a weak violet cast above the plane of sharp focus and as a weak yellowish-green cast below that plane. These secondary colors are all the more pronounced, the better the other aberrations

have been corrected. Altogether, however, they are generally not bad enough to disturb visual observation.

The focal lengths of achromatic objectives are chosen so that the upper limit of useful magnification can be reached with eyepieces of relatively low power. Eyepieces of higher magnification than 12.5× should therefore not be used, or only in exceptional cases, e. g. for measuring and counting.

Achromatic objectives are employed for routine work, for equipping teaching microscopes and for all applications in which critical observation is not required. If due allowance is made for their characteristics, these objectives may also be used for photomicrography, even for color photography. We now only manufacture achromats in simple mounts and exclusively for transmitted light.

Planachromats

Planachromats are objectives of improved chromatic correction, in which the curvature of field has been eliminated practically entirely even for the largest field of view encountered in the microscope. This, of course, requires a much greater outlay which results in a correspondingly higher price. Due to the importance of field flattening for viewing polished specimens under vertical illumination, almost all our objectives for this type of work are Planachromats. They are then called **EPIPLAN** objectives and should be used together with Kpl eyepieces.

For reflected-light microscopy we have

1. EPIPLAN objectives for bright-field illumination, by which the illuminating light is transmitted to the specimen via a reflecting means (plane glass or prism) through the objective. The objective acts as its own condenser.
2. EPIPLAN HD objectives for bright-field and dark-field illumination. Bright-field illumination is attained as described above. In

dark-field illumination the light is guided past the objective and concentrated in the specimen plane by means of concentric mirrors or concentric lens systems. The concentric mirrors or lens systems are combined with the objective to form one unit.

NEOFLUARS

Using fluorite instead of crown glass, microscope objectives can be built which are distinguished by considerably improved correction of aberrations although they have the same number of lens elements as achromatic objectives. The design we use for our "NEOFLUARS" and which can be traced back to R. Winkel comes very close to the correction of apochromatic objectives. Only secondary color has not been completely eliminated although it is far less noticeable than with the achromats. It is obvious that the limited number of lens elements used in the NEOFLUARS does not allow a correction for field curvature. However, the low number of glass-to-air surfaces in these objectives ensures a minimum of flare so that they produce images of surprisingly high contrast. The excellent correction of NEOFLUARS makes it possible to achieve considerably higher numerical apertures than in achromatic objectives. Thus the N.A. of NEOFLUAR objectives—insofar as they are dry systems—is 15 to 30 % above that of normal achromats of identical focal length (tables 8–10). NEOFLUARS may therefore be combined with higher-power eyepieces (which should always be of the Kpl type). They are particularly well suited for phase-contrast work.

Planapochromats

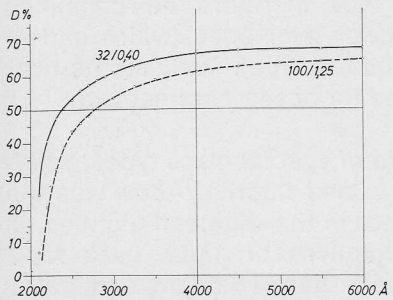
With the aid of special glass types, which were then new, and fluorite, Abbe was the first to succeed, in the eighteen-eighties, in computing objectives of equal back focal distance for more than two colors and, at the same time, far-reaching correction of the

other aberrations as well. Abbe announced this new type of objective, which he called **apochromat,** on July 7, 1886. Ever since, it has been continually improved and today it is so highly developed that further improvement appears hardly possible, all the more so as it now gives a perfectly flat field without sacrificing any of its other characteristics. Since this has become possible we only manufacture flat-field apochromats, which we call "Planapochromats". Owing to the apochromatic correction of these objectives, residual chromatic aberration can no longer be recognized in the image. It is, of course, necessary to use suitable eyepieces which compensate for the chromatic difference of magnification.

The numerical aperture of our Planapochromats has been increased to a few per cent above that of the NEOFLUAR objectives. They thus represent the ultimate in performance that is possible today—and probably that is possible at all. As a result, these objectives are used whenever maximum resolution is required for extremely critical work. It is obvious that they are superior to all other types of objective in color photomicrography. Planapochromats should always be combined with Kpl eyepieces.

ULTRAFLUARS

ULTRAFLUARS are special-purpose objectives designed so that the ultraviolet light is also used for image formation in the microscope. They must therefore contain only material the transmission of which is sufficient for the desired range from 400 mμ down to about 200 mμ. Glass cannot be used for this purpose. Only amorphous quartz and fluorite are suitable. Since for many years it seemed impossible to achieve chromatic correction—even just for a small region of the spectrum—with the aid of these two materials alone, so-called "Monochromats" were at first intro-



Transmission of ULTRAFLUARS

duced, which were corrected for only one wavelength. Only recently have our optical designers accomplished the feat of computing a series of objectives of excellent chromatic correction over the very large spectral region from 230 mμ to 700 mμ. Since then we have been making only one series of objectives for ultraviolet microscopy. We call them ULTRAFLUARS. We do not manufacture any monochromats or even reflecting objectives, because these offer no advantages over ULTRAFLUARS, but only have disadvantages.

Objective mounts

Transillumination objectives have the standard W 0.8″ × 1/36″ thread for screwing into the revolving nosepiece or single nosepiece. The high-power systems, which may touch the cover glass, are equipped with resilient mounts which give way if they knock against the specimen. This guarantees adequate protection of both the specimen and the objective front lens. The mount of the immersion objectives—except the achromats—can be locked in retracted position so as to facilitate application of the immersion liquid.

In view of the large number of objectives with different characteristics which we manufacture it has been found convenient to make them differ externally as well, so that the user will recognize at a glance what type of objective he has before him. They are therefore identified by the color and finish of the mount, as well as its engraving (see table 3).

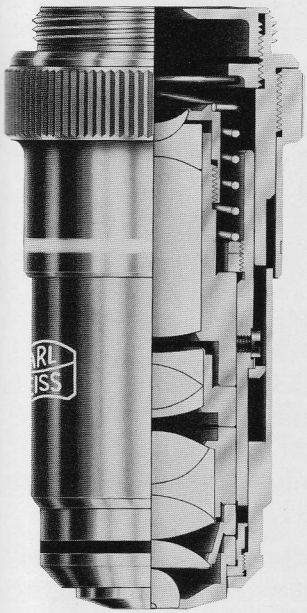


Figure:
Cross-section diagram of Planapochromat, 100×, 1.3 N.A., oil, with object and front lens protection.

Objective mounts

Table 3

Objective type	Upper part of mount	Chromium-plated lower part of mount	Color of engraving	Engraved designation
Achromats	chromium-plated, belt-polished		black	–
Planachromats	black	glossy	white	Plan, EPIPLAN
NEOFLUARS	chromium-plated, belt-polished	belt-polished	black	NEOFLUAR
Planapochromats	chromium-plated, glossy	glossy	white	Planapo
ULTRAFLUARS			black	ULTRAFLUAR

Immersion systems are distinguished from dry objectives by a black or colored ring at the lower end of the mount. In addition, the immersion medium indicated by the color of the ring is also identified by an abbreviation after the objective data. The following colors and abbreviated designations are used on immersion objectives:

Immersion objectives

Table 4

Immersion medium	Color of ring	Designation
Oil	black	Oel
Water	white	W
Glycerin	orange	Glyz
Methylene iodide	yellow	Methylenjodid

Apart from the trade mark, our objectives are engraved first of all with a figure indicating the scale at which the real intermediate image is reproduced at the object-to-image distance fixed for our microscopes, i. e. the initial magnification (e. g. 25), then—after a stroke—the value of the numerical aperture (e. g. 45). Below these two figures there may be additional data indicating the mechanical tube length or the cover-glass thickness for which

the objectives are corrected, as well as the serial number.

The mechanical tube length in all our microscopes is 160 mm. On objectives sensitive to deviations from the prescribed cover-glass thickness, the cover-glass thickness for which they are corrected follows the figure 160 after a stroke.

Indications referring to cover-glass thickness have the following meaning:

"0.17" the objective is sensitive to deviations from a cover-glass thickness of 0.17 mm.

"–" the objective may be used with or without cover glass.

"0" the objective should only be used without a cover glass.

Special objectives, e. g. those containing strain-free lenses for polarized-light microscopy, phase-contrast objectives, etc., are identified by the abbreviations listed in the following table:

Table 5

Abbreviation	Meaning
o D	Objective for transmitted-light work, corrected for use with **uncovered** specimens
	Phase-contrast objectives
Ph 1	Use annular diaphragm 1 } of phase-contrast condenser
Ph 2 (red)	Use annular diaphragm 2 } of phase-contrast condenser
Ph 3	Use annular diaphragm 3 } of phase-contrast condenser
Pol (red)	Objective for polarized-light microscopy
HD	Objective for reflected-light work using bright-field or dark-field illumination
Epi	Objective for reflected-light microscopy

Since the engraving on the objectives is often in a position where it cannot be seen once these have been screwed into the microscope, our objectives have colored rings at the lower end of the funnel, which are visible in any position and indicate the initial

magnification of the objective. This color code, which is independent of the type of objective, is explained in the following table.

Color code for initial magnification Table 6

Initial magnification	1×	2.5×	4×	6.3×	8/10×	16×	25×	40×	63×	80/100×
Color of ring	black	brown	red	orange	yellow	bright green	dark green	bright blue	dark blue	white

ZEISS objectives for photomicrography
LUMINARS

In the compound microscope, the object fields that can be recorded photomicrographically for low-power work are of limited size, in the case of our instruments a maximum 7...8 mm. This is due to the fact that it is possible neither to achieve a sufficiently small scale of reproduction in a compound microscope, nor to magnify the portion of the aerial image covered by the eyepiece beyond the limit imposed by the clear diameter of the tube. If larger object fields are to be photographed at small scales and with a flat field, we may only use a **single magnification stage,** i. e. an image of the specimen must be formed directly on a light-sensitive emulsion by means of an objective of suitable focal length. Where high image quality is required, specially developed systems are used the design of which is similar to that of photographic lenses. In addition, it is advisable to employ a camera of variable extension. To cover a wide range of image scales, we need a series of such "photomicrographic objectives" with carefully selected focal-length increments. These increments depend on the degree to which the camera extension can be varied. Of course the extension is always limited.

We manufacture such photomicrographic objectives under the designation LUMINARS.

Accessories are available which allow these objectives to be used on our large camera microscope ULTRAPHOT, which can be equipped for any type of microscopic and photomicrographic work, as well as on our PHOTOMICROSCOPE and the UNIVERSAL research microscope. For further details, see the operating instructions for these instruments.

LUMINARS are always used without eyepieces. The shorter focal lengths (16, 25 and 40 mm) may occasionally also be combined with eyepieces and used like ordinary microscope objectives. In this case, however, eyepieces must be chosen to match the correction of the LUMINARS. Suitable types are the eyepieces of our stereomicroscopes and C-type eyepieces.

Types of eyepiece

As was mentioned in the introduction (page 8), the eyepiece is designed to present to the eye the object detail resolved by the objective and contained in the real intermediate image under a viewing angle which is sufficiently large for easy recognition. This alone could be achieved with a simple converging lens, but no influence could be exerted on aberrations. If this is desired, such single-element eyepieces will have to be replaced by more complex systems.

In practice, however, these can be made only with relatively short focal lengths, because on the one hand their diameter increases sharply with growing focal length, while on the other the exit pupil of the microscope—i. e. the image of the objective aperture formed by the eyepiece, which represents the plane where the observer's eye pupil must be located—is moved to an inconveniently long distance away from the eyepiece lens. Both these drawbacks are eliminated by constructing the eyepieces from two more or less widely spaced components. one of which is located near the aerial image. Here it affects primarily the imaging of the pupil, while the second component takes over the eyepiece function proper, viz. that of magnifying. The first component is called the "collective or field lens", the second the "eye lens". The field lens may be located before, in or behind the real intermediate image. If it lies before the aerial image, it will reduce the latter by a certain degree and shift it towards the objective. Eyepieces of this type are called Huygenian eyepieces. If the field lens is located behind the real intermediate image, then, of course, it does not modify the latter. This is particularly favorable for the purpose of measurement with the aid of micrometer disks arranged in the image plane. Eyepieces of this type are called Ramsden eyepieces.

Huygenian eyepieces result in a shorter overall length of the microscope than eyepieces of the Ramsden type. With short focal lengths, however, the latter type allows the exit pupil to be located further away from the eye lens. This is why eyepieces of long focal length are usually designed on the Huygens principle, those of short focal length on the Ramsden principle. The two components consist of single elements only in the simplest types of eyepiece. Several elements are invariably required per component if any influence is to be exerted on the aberrations of the eyepiece itself or the residual errors in the image produced by the objective. Thus it has been general practice ever since the time of Abbe to compensate for a rather troublesome error frequently exhibited by the objective image and difficult as well as costly to correct in the objective—the chromatic difference of magnification—by using eyepieces which exhibit the same but opposite aberration. In addition, attempts have occasionally been made to reduce field curvature by means of the eyepiece. Eyepieces compensating for lateral chromatic aberration are known as **compensating eyepieces.**

To facilitate the use of our microscopes, we have computed all our objectives so that the chromatic difference of magnification in the real intermediate image they produce is always the same. We can therefore be content to supply compensating eyepieces which make up for this degree of lateral chromatic aberration. This matching of objective and eyepiece correction, introduced in the interests of our customers, is the reason why we have to warn our customers against using eyepieces of other manufacture with our objectives.

The eyepieces for our stereomicroscopes, however, are not designed on the principle explained above. They have no compensat-

ing effect, because in stereomicroscopes the optical systems of the first magnification stage are also free from lateral chromatic aberration. These eyepieces therefore cannot be combined with the usual microscope objectives.

Intermediate systems changing the magnification

During practical use of the microscope, a change of magnification by means of changing eyepieces is frequently considered inconvenient and troublesome, because the eyepieces not being used at the moment are detached parts which may get lost or damaged. To counter this disadvantage, magnification-changing systems have been inserted between the objective and the eyepiece of the microscope. These may either be designed for a stepwise change of magnification—which would correspond to a change of eyepieces—or as continuously variable systems. In the latter, however, a more or less noticeable loss of image quality is unavoidable. We have therefore adopted the system of changing the magnification by steps.

If only two alternative magnifications are required—which is generally considered sufficient for teaching and laboratory microscopes used for routine work, for instance—then the **magnification changer** may be used. This is a two-component system mounted so that it can be inserted into the limb top of our STANDARD microscopes (STANDARD K, R or WL). For this purpose the limb top is equipped with a spindle which can be rotated through 90° and on which the magnification changer is secured by means of a coaxial screw. This arrangement offers the advantage that the magnification changer is normally firmly attached to the microscope, but can be removed if necessary.

The following magnification changers are available:

0.8× ⇆ 1×, 1× ⇆ 1.6×, 1× ⇄ 2× (see Section on field-of-view number and size of object field).

When the magnification changer is set in the proper position, the total magnification computed from the initial magnifications of objective and eyepiece will be changed by the corresponding factor.

If a rapid change of magnification in more than two steps is desired, it is necessary to employ a more complicated optical system such as that contained in our **OPTOVAR.** Here the aerial image produced by the objective is first shifted to infinity by means of a lower Telan lens of negative power. This image is then viewed through a telescope system mounted above it. In the present case, the telescope system consists of an upper Telan lens of positive power mounted at the lower end of the tube and representing the telescope objective, and the usual microscope eyepiece. The two Telan lenses are held by the upper and lower walls of a cylindrical housing. The latter is designed so that small Galilean telescopes can be inserted in the space between the two Telan lenses. For this purpose, the telescopes are mounted on a revolving disk which can be controlled from the outside. The magnifying factors to be achieved are identical with the magnification of the telescope systems. Apart from the factor 1, which is effective if no telescope is in the light path, the OPTOVAR can be set for 1.25×, 1.6× and 2× or 0.8×, 1.25× and 1.6× magnification with the aid of telescopes. In addition, another system can be moved into the light path, which has the effect of a Bertrand lens and permits the exit pupil of the objective to be viewed, for instance for observing interference patterns, for centering the annular diaphragm in relation to the phase plate annulus in phase work, or for checking the stopping down of the objective.

This image-forming system for pupil observation may also be used to advantage for producing an only slightly magnified image of the specimen, if it is desired to scan the specimen for general orientation. In this case its magnification factor is approx. 1.25.

Intermediate magnification-changing systems are listed in table 36 on page 88.

Field-of-view number and size of object field

Magnification-changing systems are a convenient means of varying the size of the object field covered for a certain field-of-view number of the eyepiece without changing any mechanical dimensions of the microscope. If the scale of the real intermediate image is increased by means of such an intermediate system, a smaller object field will be covered. On the other hand, if the scale of the real intermediate image is reduced, the object field will, of course, be larger. The latter is undoubtedly an advantage in all cases where many specimens have to be scanned. The only drawback is that the total magnification is reduced by the same factor by which the scale of the intermediate image is changed. This disadvantage, though, can easily be offset by a higher-power eyepiece which should, however, have the same field-of-view number as the one originally used.

An example may serve to illustrate this:

Combining a 10× objective and a 10× eyepiece with a field-of-view number of 16, an object field S of 16:10 = 1.6 mm will be covered under a total magnification of 100×.

Inserting an intermediate system with a factor of 0.8 will increase the object field by the reciprocal factor, since we have

$$S = \frac{16}{10 \cdot 0.8} = \frac{16}{8} = 2 \text{ mm}.$$

If we wish the total magnification to remain unchanged, instead of the 10× eyepiece we

shall have to use an eyepiece $\frac{10}{0.8} = 12.5\times$ which also has a field-of-view number of 16. Further magnification of the object field is possible if eyepieces with increased field-of-view numbers, so-called wide-angle eyepieces, are employed. Substituting 10× or 12.5× wide-angle eyepieces with a field-of-view number of 20 for the ordinary eyepieces, the above example can be written as follows:

Without intermediate system

$$S = \frac{20}{10} = 2 \text{ mm.}$$

With 0.8× intermediate system

$$S = \frac{20}{10 \cdot 0.8} = \frac{20}{8} = 2.5 \text{ mm.}$$

In other words, the same object field is covered under 100× total magnification as if a 10× eyepiece with a field-of-view number of 25 were used.

Wide-angle eyepieces have been developed for the observation of larger fields-of-view. The following table lists the eyepieces and their field-of-view numbers. The *image diameter given in the third column is based on the conventional object distance of 250 mm. It is the product of the field-of-view number and the eyepiece magnification.

Table 7

Kpl Wide-angle eyepiece	Field-of-view number	Image diameter*
10×	20	200 mm
12.5×	20	250 mm
16×	16	256 mm

Mounts and identification of eyepieces

As is usual, the lenses of the eyepiece systems are housed in relatively simple mounts. These in turn are contained in a tube fitting into the upper end of the microscope tube with the eye lens at the top and the field

lens at the bottom. The mount of the eye lens is designed so that its projecting edge may be gripped. The field lens is either located right in the eyepiece tube or likewise contained in a special mounting ring. The eyepiece tube or mounting ring has a female thread of M 22×0.5 into which light filters or other accessories may be screwed, as required.

The outside diameter of the eyepieces is standardized. This standard diameter is traditional in the normal microscope. It is 23.2 mm. In our stereomicroscopes a standard diameter of 30 mm has been adopted. In addition, the diameter of the eye-lens mount of all our eyepieces conforms to the German DIN Standard 58,881 to facilitate the attachment of accessories. Consequently, the eye-lens mount diameter of all our eyepieces is 28 mm.

As is the general practice today, the magnification of the eyepieces is indicated by a figure followed by "×". Letters before the magnification mark the type of eyepiece. Since we manufacture only compensating eyepieces, such an identification would normally be superfluous. However, our eyepieces of higher power are so designed that they produce a flat field, which is not necessary for the low-power systems. The latter are therefore marked C (compensating eyepieces) to distinguish them from the former marked Kpl (compensating flat-field eyepieces).

The fact that the eyepieces are used to view a real image may be utilized to make a sharp image of a reticule, graduation and other figures or pointers visible together with this object image. These figures are engraved on glass plates (micrometer disks) which are inserted in the diaphragm plane of the eyepieces. However, since they will not necessarily be seen sharply with normal eye-

pieces, above all if the eye of the observer is not free from visual defects, eyepieces with a focusing eye lens are used for this purpose. In addition, these eyepieces are designed so that the micrometer disk can be easily inserted and will be centered once it is in position. The micrometer disks normally supplied by us are listed on page 75.

For polarized-light microscopy the crosshairs marking the center of rotation of the stage must be very accurately centered. Since this cannot be achieved by the mere insertion of crosshair disks, we manufacture special eyepieces with accurately adjusted crosshairs or crosshair micrometer disks for this purpose.

For critical work, partly for very special measuring or counting problems, we also manufacture a great variety of special-purpose eyepieces which are listed after the ordinary eyepieces.

In microscopy self-luminous objects are rarely encountered, in fact only in fluorescent work. In general, the objects to be examined under the microscope must be suitably illuminated to allow their details to be imaged and viewed. Either incident or transmitted light may be used for illumination, and in both cases either the bright-field or the dark-field method may be employed. In the former, an image of the light source is formed in the objective aperture, while in the latter this is not the case.

With a perfect bright-field illuminator the aforementioned source image should fill the objective aperture completely, because only then can the full aperture of the objective be utilized, if necessary. In addition, the object field reproduced should, of course, be completely and evenly illuminated.

When using high-aperture objectives, a source image of sufficient size can be achieved only with very large light sources. However, since the size of the light sources generally used today is limited, it must be magnified by optical means. This is done with the aid of a lens system located near the specimen, the so-called condenser.

The light source to be magnified must be brought as close to the focal plane of the condenser as possible so that its magnified image will be produced at a sufficient distance from the specimen. Otherwise the angle of incidence of the pencils of rays illuminating the object points will vary greatly in the center and the outer field, thus producing increasingly oblique illumination towards the edge of the image so that the image character will no longer be homogeneous. Since it is not normally possible to locate a light source in the condenser focal plane due to the heat it generates, the source is arranged at an appropriate distance from the microscope and a source image filling the con-

denser aperture is formed in the condenser focal plane with the aid of another lens system, the lamp condenser. This offers the following additional advantages:

The effective area of this image can be reduced by means of an iris diaphragm, which is a convenient means of controlling the illuminating aperture. Such an aperture iris is practically always permanently attached to the condenser.

It is easy to achieve a very homogeneous illumination of the object field reproduced by adjusting the condenser so that it forms a sharp image of the homogeneous illuminated aperture of the lamp condenser on the specimen. An iris diaphragm in this plane **(lamp field stop)** makes it possible to match the size of the illuminated field with that of the field imaged **(Köhler's method of illumination).**

In accordance with these general observations, a condenser has two functions in an economic bright-field illuminating setup:

1. The condenser must be capable of producing cones of rays for illuminating the object points, the axes (principal rays) of which should as far as possible be parallel and perpendicular to the specimen plane and whose aperture can in certain cases be as large as the aperture of the objective employed.
2. The condenser should form a high-quality image of the lamp field stop in the specimen plane.

To satisfy the first condition, a universally applicable condenser would have to have the highest numerical aperture occurring with the objectives used (1.3–1.4). However, such a high illuminating aperture is actually used only in rare cases in microscopic practice. In fact, to increase image contrast the illuminating aperture should be smaller than the objective aperture. Experience has shown that even in the case of immersion objectives with the extremely high aperture of N.A. $\leqq$ 1.4 an

illuminating aperture of less than 1.0 is generally sufficient so that an N.A. 0.9 condenser will do in the great majority of cases. This offers the following advantages:

The correction of the condenser can be improved without increasing its cost.

The **focal length and object distance of the condenser can be increased.**

As a result, the condenser diaphragm can more easily be arranged in the correct position, in the focal plane. The front lens need not be connected to the specimen slide by means of an immersion liquid.

For reasons of price, condensers are generally corrected only as far as is possible at minimum expense. Especially when used with higher apertures, it is therefore very difficult to achieve a satisfactory image of the lamp field stop with most condensers due to their spherical and chromatic aberrations. In order to obtain a homogeneously illuminated object field the lamp field stop must be opened further than would normally be necessary. However, this is of no importance as long as image contrast is not impaired.

For critical work and in conjunction with high-performance objectives we recommend that corrected condensers be used, which are available in the form of **achromatic-aplanatic condensers.**

With a lamp field stop of given diameter, a condenser of a certain focal length will only illuminate an object field of a certain size. It is impossible to design condensers suited for illuminating all the apertures and fields of view used in practice. This can be achieved only if—as with the objectives—condensers of different focal length are employed. Many condensers are therefore designed so that a relatively short-focus condenser can be converted into a condenser of longer focal length and lower maximum aperture by removing its front lens or a front

component.

For this purpose the front lens is either unscrewed or, where this is technically feasible, swung out of the light path.

All condensers are provided with the mechanical fittings required for their use. The extent and design of these are indicated in the following tables.

The type of mount used to attach the condenser to the microscope depends on the type of illuminator employed.

If the light of a separate illuminator is reflected into the condenser by means of a mirror or if an integral illuminator with a sufficiently large radiant field is available (e. g. low-voltage base illuminator or on-base illuminator), the condenser need not be centerable.

With our microscopes, the simplest design consists of a condenser sleeve mounted underneath the microscope stage, into which the condenser is inserted.

When the condenser must be movable in the axial direction, however, it is mounted on a rack-and-pinion condenser carrier.

In all our large microscopes (STANDARD, WL, UNIVERSAL, PHOTOMICROSCOPE and ULTRAPHOT) the low-voltage illuminator normally used as **light source is permanently attached to the microscope.**

To allow the aforementioned illuminating techniques to be employed with sufficient accuracy, a device had to be incorporated in the illuminating system with the aid of which the image of the lamp field stop formed in the specimen plane could be centered in relation to the field reproduced by the microscope. We thus provided for a displacement of the condenser by means of two **centering screws** on the condenser carrier, which act against the force of a spring. This device also serves to hold the condenser which is inserted into it with a heat-treated dovetail ring. The **con-**

denser can here in any case **be axially displaced with the aid of the condenser carrier to allow the image of the lamp field stop to be focused in the specimen plane.**

Z-type condensers are used with the condenser carriers.

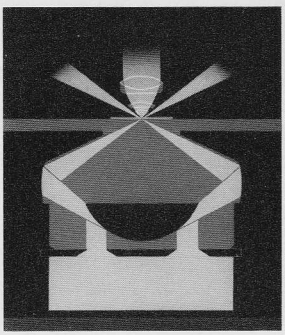
Dark-field illumination

If dark-field illumination is used, the light from the condenser does not enter the objective directly. Only the light diffracted by the specimen (in the case of incident illumination, the light reflected by the specimen) enters the objective and forms the image. As a result, the areas in the field of view which contain no object structures remain dark.

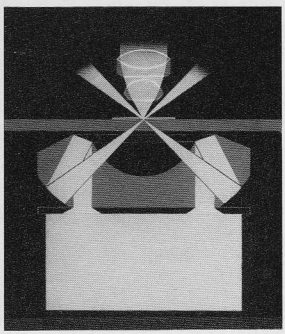
With dark-field illumination, the specimen is actually illuminated by a hollow cone of light, the lowest aperture (interior limit of aperture) of which is larger than the numerical aperture of the viewing objective.

Dark-field illumination requires powerful light sources and special condensers. Immersion objectives of higher numerical aperture than 1 must be equipped with an iris diaphragm to allow their aperture to be reduced. With fully open iris diaphragm these objectives are employed for bright-field illumination. Phase-contrast objectives are unsuitable for dark-field observation.

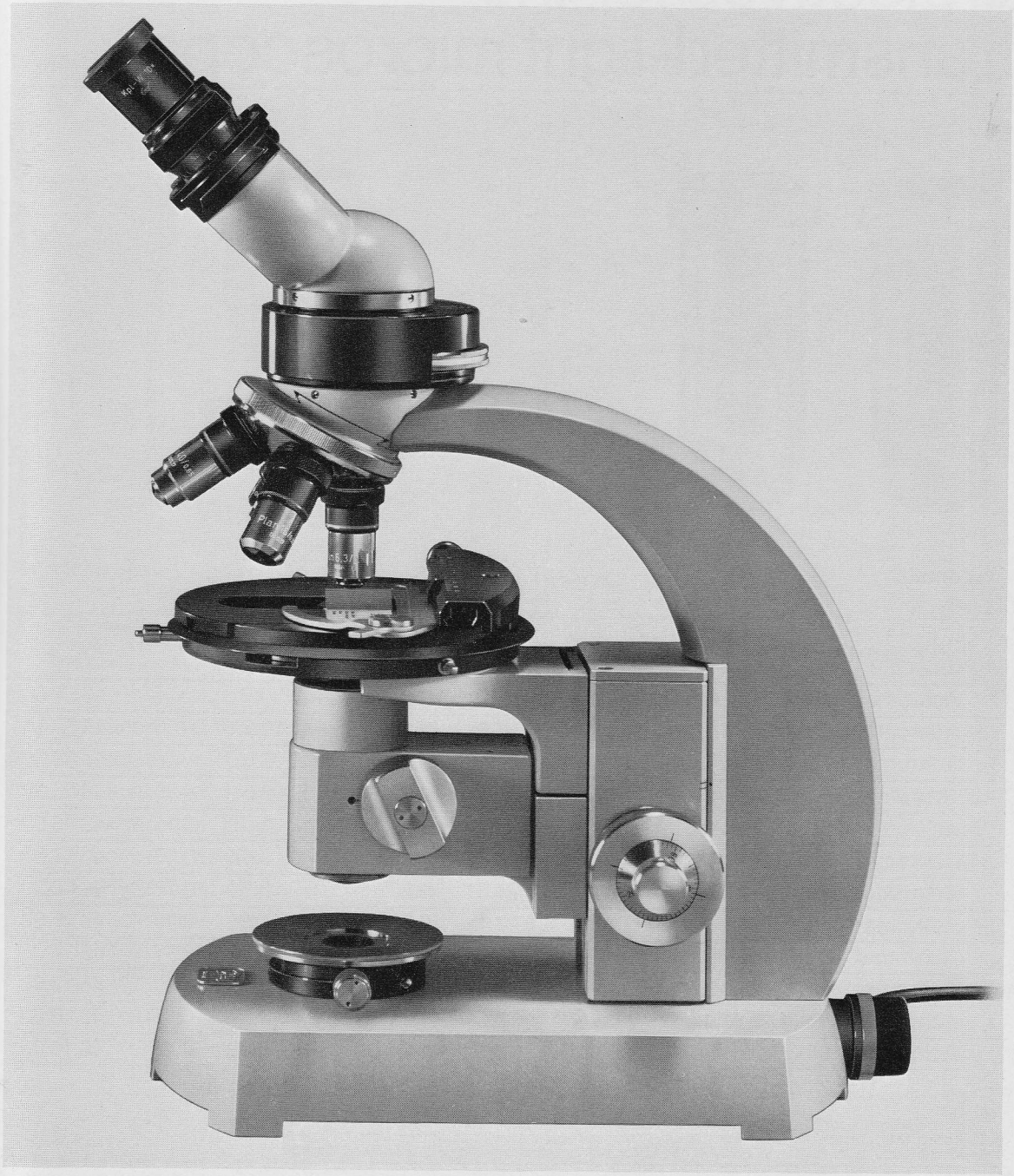
Dark-field Ultracondenser



Dry dark-field condenser



STANDARD WL research microscope with 6 v, 15 w integral illuminator,
pancratic condenser, Planachromats, OPTOVAR and Kpl wide-angle eyepieces.



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Objectives for the transmitted-light microscope

Achromats

Table 8

	Designation	Initial magni-fication	N.A.	Focal length mm	Working distance[2] mm	Cover-glass thickness mm	Catalog No.
○	Achromat, **3.2x,** 0.07 N.A.	3.2x	0.07	34.9	30	—	46 01 00
	Achromat, **6.3x,** 0.16 N.A.	6.5x	0.16	24.4	10.3	—	46 03 00
○	Achromat, **10x,** 0.22 N.A.	10.2x	0.22	16.7	5.0	—	46 04 00
	Achromat, **16x,** 0.32 N.A.	16.2x	0.32	10.8	3.5	—	46 05 00
	Achromat, **25x,** 0.45 N.A.	25.4x	0.45	7.0	1.0	0.17	46 06 00
○	Achromat, **40x,** 0.65 N.A.	40.8x	0.65	4.5	0.47	0.17	46 07 00
	Achromat, **63x,** 0.80 N.A.	63.3x	0.80	3.0	0.14	0.17	46 08 00
	Achromat, **40x,** 0.75 N.A., water[1]	40.4x	0.75	4.6	1.6	0.17	46 17 02
	Achromat, **40x,** 0.85 N.A., oil	40.0x	0.85	4.6	0.35	0.17	46 17 06
	Achromat, **40x,** 0.85 N.A., oil	39.2x	0.85	4.7	0.35	**1.5**	46 17 08
○	Achromat **100x,** 1.25 N.A., oil	98.8x	1.25	1.9	0.09	0.17	46 19 00
	Achromat, **100x,** 1.25 N.A., oil, with iris[3]	98.8x	1.25	1.9	0.09	0.17	46 19 06

[1] For Achromat, 40x, 0.75 N.A., water, a clip-on cap 46 17 90 is supplied.
[2] The working distance is the clear distance between the front lens of the objective used and the specimen (upper surface of cover glass).
[3] Objective with iris for stopping down the aperture in dark-field work.
[4] Objective with correction collar can be used for cover-glasses with thickness from 1.1 to 1.5 mm.
[5] Special objective, e. g., for STANDARD UPL, for work with specimen in thick-walled chambers.

Planachromats

Table 9

	Designation	Initial magnification	N.A.	Focal length mm	Working distance[2] mm	Cover-glass thickness mm	Catalog No.
O+	Planachromat, **2.5x,** 0.8 N.A.	2.6x	0.08	54.5	8.7	—	46 01 10
+	Planachromat **6.3x,** 0.16 N.A.	6.26x	0.16	27.1	4.9	—	46 03 10
O	Planachromat, **10x,** 0.22 N.A.	10.0x	0.22	15.8	4.8	—	46 04 10
+	Planachromat, **16x,** 0.35 N.A.	16.1x	0.35	10.4	2.7	—	46 05 10
	Planachromat, **25x,** 0.45 N.A.	25.2x	0.45	7.0	1.4	0.17	46 06 10
O+	Planachromat, **40x,** 0.65 N.A.	40.8x	0.65	4.13	0.7	0.17	46 07 10
	LD-Planachromat, **40x,** 0.60 N.A., corr.[4]	39.9x	0.60	4.1	**1.5**	1.1–1.5	46 07 15[5]
O+	Planachromat **100x,** 1.25 N.A., oil	100.6x	1.25	1.66	0.09	0.17	46 19 10
	Planachromat, **100x,** 1.25 N.A., oil, with iris[3]	100.6x	1.25	1.66	0.09	0.17	46 19 16

Generally recommended for a series of
O four objectives
+ five objectives

NEOFLUARS Table 10

Designation	Initial magnification	N.A.	Focal length mm	Working distance[2] mm	Cover-glass thickness mm	Catalog No.
+ NEOFLUAR, **6.3x,** 0.20 N.A.	6.4x	0.20	23.6	10.8	—	46 03 20
NEOFLUAR, **10x,** 0.30 N.A.	10.2x	0.30	16.4	4.0	—	46 04 20
+ NEOFLUAR, **16x,** 0.40 N.A.	16.1x	0.40	10.8	0.9	0.17	46 05 20
NEOFLUAR, **25x,** 0.60 N.A.	25.2x	0.60	7.1	0.54	0.17	46 06 20
+ NEOFLUAR, **40x,** 0.75 N.A.	40.5x	0.75	4.5	0.33	0.17	46 07 20
Plan-NEOFLUAR, **63x,** 0.90 N.A., corr.[4]	62.9x	0.90	2.7	0.09	0.11-0.23	46 08 12 - 9903
NEOFLUAR, **63x,** 1.25 N.A., oil	62.6x	1.25	2.8	0.65	0.17	46 18 20
+ NEOFLUAR, 100x, **1.30** N.A., oil	100.0x	1.25	1.92	0.24	0.17	46 19 20

Planapochromats

Table 11

Designation	Initial magnification	N.A.	Focal length mm	Working distance[2] mm	Cover-glass tickness mm	Catalog No.
Planapochromat, **4x,** 0.16 N.A.	4.1x	0.16	35.1	2.5	—	46 02 40
Planapochromat, **10x,** 0.32 N.A.	10.0x	0.32	14.6	0.35	0.17	46 04 40
Planapochromat, **25x,** 0.65 N.A.	25.3x	0.65	6.3	0.14	0.17	46 06 40
Planapochromat **40x,** 0.95 N.A., corr.[4]	40.4x	0.95	4.25	0.09	0.11-0.23	46 07 42
Planapochromat, **40x,** 1.0 N.A., oil, with iris[3]	100.2x	1.3	1.63	0.09	0.17	46 19 46
Planapochromat, **63x,** 1.4 N.A., oil	62.1x	1.4	2.57	0.09	0.17	46 18 40
Planapochromat, **100x,** 1.3 N.A., oil,	100.2x	1.3	1.63	0.09	0.17	46 19 40
Planapochromat, **100x,** 1.3 N.A., oil, with iris[3]	40.1x	1.0	4.05	0.22	0.17	46 17 46

[2]) The working distance is the clear distance between the front lens of the objective used and the specimen (upper surface of cover glass).
[3]) Objective with iris for stopping down the aperture in dark-field work.
[4]) Objective with correction collar can be used for cover-glasses with thickness from 0.11 to 0.23 mm.

Phase-contrast objectives

These objectives contain an annular phase plate in which phase shift and absorption are matched so that optimum images will be obtained with the majority of specimens for which the phase-contrast technique can be used to advantage. For special problems, objectives with specially matched absorption can be made to order. Details will be supplied on request.

If phase-contrast objectives are used for bright-field work, a more or less noticeable but generally hardly disturbing loss of contrast must be expected, depending on the objective type chosen. This effect will be least noticeable with the Ph NEOFLUARS and Planapochromats. For dark-field observation phase-contrast objectives are generally not to be recommended.

Phase-contrast objectives

Table 12

Designation		Initial-magnification	N.A.	Focal length mm	Working distance mm	Cover-glass thickness mm	Catalog No.
Achromat,	**10x,** 0.22 N.A., Ph1	10.2x	0.22	16.7	5.0	—	46 04 01
Achromat,	**40x,** 0.65 N.A., Ph2	40.8x	0.65	4.5	0.47	0.17	46 07 01
Achromat,	**40x,** 0.75 N.A., water, Ph2	40.4x	0.75	4.6	1.6	0.17	46 17 03
Achromat,	**40x,** 0.85 N.A., oil, Ph3	39.2x	0.85	4.7	0.35	**1.5**	46 17 09
Achromat,	**100x,** 1.25 N.A., oil, Ph3	98.8x	1.25	1.9	0.09	0.17	46 19 01
Planachromat,	**25x,** 0.45 N.A., Ph2	25.2x	0.45	7.0	1.4	0.17	46 06 11
LD-Planachromat,	**40x,** 0.60 N.A., corr., Ph2	39.9x	0.60	4.1	1.5	1.1-1.5	46 07 16*
Planachromat,	**40x,** 0.65 N.A., Ph2	40.8x	0.65	4.13	0.7	0.17	46 07 11
Planachromat,	**63x,** 0.90 N.A., corr., Ph3	63.4x	0.90	2.7	0.09	0.17	46 08 13
Planachromat,	**100x,** 1.25 N.A., oil, Ph3	100.6x	1.25	1.66	0.09	0.17	46 19 11
NEOFLUAR,	**16x,** 0.40 N.A., Ph2	16.1x	0.40	10.8	0.9	0.17	46 05 21
NEOFLUAR,	**25x,** 0.60 N.A., Ph2	25.2x	0.60	7.1	0.54	0.17	46 06 21
NEOFLUAR,	**40x,** 0.75 N.A., Ph2	40.5x	0.75	4.5	0.33	0.17	46 07 21
Plan-NEOFLUAR,	**63x,** 0.90 N.A., corr., Ph3	62.9x	0.90	2.7	0.09	0.11-0.23	46 08 13 - 9903
NEOFLUAR,	**63x,** 1.25 N.A., oil, Ph3	62.6x	1.25	2.8	0.65	0.17	46 18 21
NEOFLUAR,	**100x,** 1.30 N.A., oil, Ph3	100.2x	1.25	1.92	0.24	0.17	46 19 21
Planapochromat,	**25x,** 0.65 N.A., Ph2	25.3x	0.65	6.3	0.14	0.17	46 06 41
Planapochromat,	**40x,** 0.95 N.A., corr., Ph3	40.4x	0.95	4.25	0.09	0.11-0.23	46 07 43
Planapochromat,	**40x,** 1.0 N.A., oil, with iris, Ph3	40.1x	1.0	4.05	0.22	0.17	46 17 47
Planapochromat,	**63x,** 1.4 N.A., oil, Ph3	62.1x	1.4	2.57	0.09	0.17	46 18 41
Planapochromat,	**100x,** 1.30 N.A., oil, Ph3	100.2x	1.3	1.63	0.09	0.17	46 19 41

* Special objective, e. g., for STANDARD UPL, for work with specimens in thick-walled chambers.

POL Z objectives for polarized-light microscopy

The objectives listed below are strain-free and have centering mounts.

Table 13

Designation		Initial magnification	N.A.	Focal length mm	Working distance mm	Cover-glass thickness mm	Catalog No.
O + Planachromat,	**2.5x,** 0.08 N.A., POL Z	2.6x	0.08	54.5	8.7	—	46 01 18
O + Achromat,	**10x,** 0.22 N.A., POL Z	10.2x	0.22	16.7	5.0	—	46 04 08
+ NEOFLUAR,	**25x,** 0.60 N.A., POL Z	25.2x	0.60	7.1	0.54	0.17	46 06 28
O + Achromat,	**40x,** 0.85 N.A., POL Z	39.4x	0.85	4.7	0.36	0.17	46 07 08
NEOFLUAR,	**63x,** 0.90 N.A., POL Z	63.3x	0.90	3.0	0.12	0.17	46 08 28
O + Achromat,	**100x,** 1.25 N.A., oil, POL Z	98.8x	1.25	1.9	0.09	0.17	46 19 08

Generally recommended for a series of
O four objectives
\+ five objectives

UD Achromats

UD achromats are objectives specially designed for use with the universal rotary stage. This aid for spatial orientation of the specimen is primarily used in polarized-light microscopy. The objectives are attached to the polarizing microscope with the aid of a centerable objective changer.

The initial magnification and numerical aperture indicated on the UD achromats hold for use in conjunction with hemispheres with a refractive index of 1.555. If the objectives are suited for "conoscopic" observation, they are marked "C". Under orthoscopic observation, the extinction position of a crystal can be recognized if the aperture of the objective is reduced. This is why two funnel stops are supplied with every UD achromat of higher magnification than 16x.

Used without hemisphere, the UD achromats offer a particularly long working distance. Due to their overall length of 33 mm they must be attached to the microscope by means of the adapter ring 46 29 91.

Table 14

UD Achromats
for universal rotary stage, without specimen protection, parfocalized for 33 mm

Designation	Technical data for using the objectives with and without hemisphere: Initial magnification	N.A.	Focal length mm	Working distance mm	Catalog No. of objective	Refractive index n_D*	Radius	Catalog No. of hemisphere
Achromat UD,	3.7	0.07	30.4	19.0	46 20 42	—	—	—
6.3x, 0.12 N.A.						1.517	5.52	47 38 24
	5.8	0.12	41.8	13.5		1.517	5.52	47 38 25
	6.1	0.13	44.6	13.5		1.648	5.52	47 38 26
						1.517	12.56	47 38 27
	5.8	0.12	25.5	6.5		1.517	12.56	47 38 28
	6.1	0.13	24.8	6.5		1.648	12.56	47 38 29
Achromat UD,	9.6	0.11	15.6	13.5	46 20 44	—	—	—
16x, 0.17 N.A.						1.517	5.52	47 38 24
	14.9	0.17	11.2	10		1.557	5.52	47 38 25
	15.8	0.18	10.7	10		1.648	5.52	47 38 26
						1.517	12.56	47 38 27
	14.9	0.17	10.5	3		1.517	12.56	47 38 28
	15.8	0.18	10.0	3		1.648	12.56	47 38 29
Achromat UD,	12.7	0.38	12.6	4.2	46 20 45	—	—	—
20x, 0.57 N.A. C**						1.517	5.52	47 38 24
	19.7	0.57	8.5	0.8		1.517	5.52	47 38 25
	21.0	0.61	8.2	0.8		1.648	5.52	47 38 26
Achromat UD,	25.8	0.41	6.9	6.8	46 20 46	—	—	—
40x, 0.65 N.A. C**						1.517	5.52	47 38 24
	40.2	0.64	3.9	1.5		1.517	5.52	47 38 25
	42.7	0.68	3.7	1.5		1.648	5.52	47 38 26

* Maximum permissible deviation 0.002.
** Suitable for conoscopic observation.

The 1x Planachromat is the objective with the lowest initial magnification and built-in field lens. It is not parfocalized with the other objectives. For polarized-light microscopy we select the most strain-free objectives.

The 1.6x—5x Planachromat is particularly suitable for measuring purposes, because the magnification of the aerial image can be accurately adapted to the graduation of the micrometer disk. The objective is used with a condenser whose front lens is swung out of the light path. Refocusing is required if the magnification of the objective is changed.

The 32x Planachromat is an objective specially designed for our Revolver Microprojector. Its front-lens mount is finished in black to avoid stray light. If necessary, it may be used on any other microscope.

Special-purpose objectives
for the normal transmitted-light microscope Table 15

Designation	Initial magnification	N.A.	Focal length mm	Working distance mm	Cover-glass thickness mm	Catalog No.
Planachromat,						
1x, 0.04 N.A.	1.08x	0.04	134.7	4.4	—	46 20 10
1x, 0.04 N.A., POL	1.08x	0.04	134.7	4.4	—	46 20 11
1.6x—5x, 0.03—0.1 N.A.	1.6x—5x	0.03—0.1	41.2—20.8	32—1.5	—	46 20 13
32x, 0.65 N.A.	32.2x	0.65	5.6	0.3	0.17	46 20 16
63x, 0.90 N.A., oD						
(for uncovered specimens)	63.0x	0.90	3.0	0.09	0	46 08 60

ULTRAFLUARS

These are special-purpose objectives equally suited for observation by ultraviolet and visible light. They are achromatic for a range from 230 to 700 mμ. Thus there is practically no shift in focus when changing from one wavelength to another. The objectives are corrected for 0.35 mm thick quartz (Homosil) cover glasses and designed for glycerin immersion, except the ULTRAFLUAR, 10x, 0.20 N.A., 46 20 59.

These objectives are very sensitive to fluctuations of temperature.

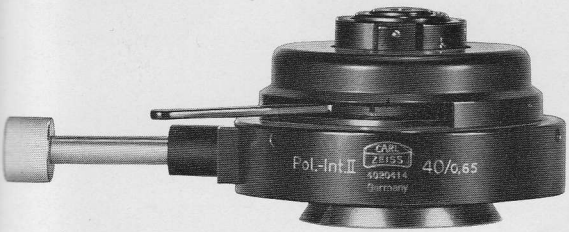
Table 16

Designation	For wavelength 280 mμ Initial magnification	N.A.	Focal length mm	Working distance mm	Coverglass thickness mm	For wavelength 546 mμ Initial magnification	N.A.	Focal length mm	Catalog No.
ULTRAFLUAR, **10x,** 0.20 N.A.	10.0x	0.20	16.4	7.4	—	9.4	0.19	17.5	46 20 58
32x, 0.40 N.A., glyc.	32.0x	0.40	6.0	0.45	0.35	30.0	0.38	6.4	46 20 60
100x, 0.85 N.A., glyc.	103.5x	0.85	1.79	0.12	0.35	98.0	0.81	1.93	46 20 63
100x, 1.25 N.A., glyc.	100.9x	1.25	1.77	0.07	0.35	87.8	1.15	2.00	46 20 64
32x, 0.40 N.A., glyc., **Ph**	32.0x	0.40	6.0	0.45	0.35	30.0	0.38	6.4	46 20 70
100x, 0.85 N.A., glyc., **Ph**	103.5x	0.85	1.79	0.12	0.35	98.0	0.80	1.93	46 20 73
10x, 0.20 N.A., **POL**	10.0x	0.20	16.4	7.4	—	9.4	0.19	17.5	46 20 59
32x, 0.40 N.A., glyc., **POL**	32.0x	0.40	6.0	0.46	0.35	30.0	0.38	6.4	46 20 61
100x, 1.25 N.A., glyc., **POL**	100.9x	1.25	1.77	0.07	0.35	87.8	1.15	2.00	46 20 65

For achromatic-aplanatic ULTRAFLUAR-condenser 46 55 57, see page 93.

Jamin-Lebedeff transmitted-light interference-equipment

Three objectives of the Achromat POL Int type and a specially selected condenser convert any of our large polarizing microscopes into an interference microscope. This allows the refractive index, thickness and dry mass of discrete objects (i. e. objects which do not cover a continuous area) to be determined. The beam splitter in the condenser separates the measuring and comparison beams. The beam combiner in the objective causes the two beams to interfere. For further details see booklet 41-560.



Interference attachments

Table 17

Interference attachment	with Achromat POL Int	Working distance mm	Distance between measuring and comparison beams mm	Catalog No. for STANDARD microscopes	Catalog No. for UNIVERSAL, PHOTOMICROSCOPE, ULTRAPHOT
I	**10x,** 0.22 N.A.	2.26	0.5	47 44 03	47 44 13
II	**40x,** 0.65 N.A.	0.2	0.17	47 44 06	47 44 16
III	**100x,** 1.0 N.A., oil	0.08	0.05	47 44 08	47 44 18

Objectives for reflected-light microscopy

All our microscopes for opaque work are computed for uncovered specimens. In view of the height of the vertical illuminator to be inserted between the tube and the objective they have a relatively short parfocal distance of 33 mm. Their initial magnifications partly deviate from our usual standard values in view of the standard magnifications of 50x, 100x, 200x, 500x and 1000x used in metallurgical work.

With few exceptions, all our reflected-light objectives are designed as flat-field objectives. In the systems supplied since 1965 special care has been taken to eliminate reflections at glass-to-air surfaces by suitable shaping and coating of the lenses. This has been surprisingly successful in the new series of EPIPLAN objectives.

EPIPLAN HD objectives
for bright-field and dark-field observation by incident light

For dark-field observation the objective proper is built into a concentric mirror or lens system. This reduces the free working distance of the three low-power systems. These objectives do not have the Whitworth thread 0.8″ x 1/36″ but the M 24 x 0.75 screw thread.

Table 18

Designation	Initial magnification	N.A.	Focal length mm	Working distance mm	Coverglass thickness mm	Catalog No. Objective for nosepiece	Catalog No. Objective with change ring (46 62 55)
EPIPLAN **4x,** 0.10 N.A., HD	4.07x	0.1	36.3	1	—	46 02 69	48 02 69
EPIPLAN **8x,** 0.20 N.A., HD	7.96x	0.2	18.7	1	—	46 03 69	48 03 69
EPIPLAN **16x,** 0.35 N.A., HD	16.06x	0.35	10.4	1	0	46 05 69	48 05 69
EPIPLAN **40x,** 0.85 N.A., HD	40.56x	0.85	4.6	0.23	0	46 07 69	48 07 69
EPIPLAN **80x,** 0.95 N.A., HD	80.7x	0.95	2.25	0.09	0	46 08 69	48 08 69
EPIPLAN **100x,** 1.25 N.A., oil, HD	100.6x	1.25	1.66	0.25	0	46 19 69	48 19 69

EPIPLAN objectives
for bright-field observation by incident light

To permit rapid change between the standard magnifications used in metallography, these objectives are mounted on the type III D vertical illuminator 46 62 47. On the UNIVERSAL microscope, the PHOTOMICROSCOPE and the ULTRAPHOT camera microscope magnifications of 50x, 100x, 200x, 500x and 1000x can be achieved with Kpl 10x eyepieces.

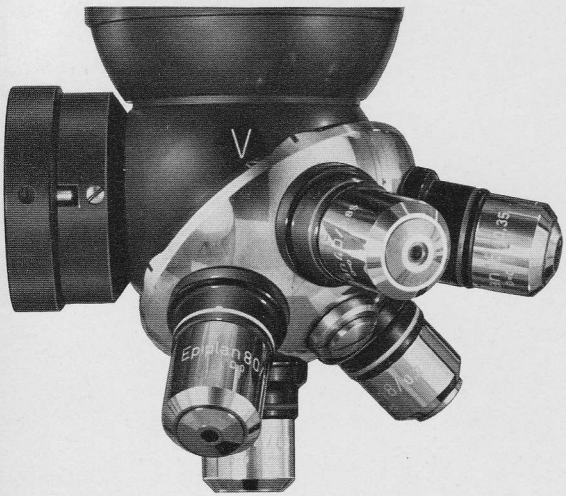


Table 19

Designation	Initial magnification	N.A.	Focal length mm	Working distance mm	Cover-glass thickness mm
EPIPLAN, **4x,** 0.1 N.A.	4.07x	0.1	36.3	9.0	—
EPIPLAN, **8x,** 0.2 N.A.	7.96x	0.2	18.8	7.2	—
EPIPLAN, **16x,** 0.35 N.A.	16.06x	0.35	10.4	2.8	0
EPIPLAN, **40x,** 0.85 N.A.	40.56x	0.85	4.6	0.23	0
EPIPLAN, **80x,** 0.95 N.A.	80.7x	0.95	2.25	0.09	0

LD-EPIPLAN objectives have an extra long working distance. They are required whenever the objective must be protected against the effects of heat, caustic vapors, etc., by means of a glass plate placed in the object field. LD-EPIPLAN objectives with the designation D = 1.5 mm are supplied with a 1.5 mm thick protective cap. If the specimen is covered by a quartz glass, e. g., as is usual in work with heating stages, then the quartz plate provides the necessary protection in place of the protective cap.

Due to their long working distance, the LD-EPIPLAN objectives are especially suitable as substage condensers. They are used for this purpose primarily in work with the Microscope Photometer.

Table 20

Designation	Initial magnification	N.A.	Focal length mm	Working distance (mm) with 1.5 mm cover-glass	Working distance (mm) with 1.5 mm protective cap	Cover-glass thickness mm	Objective Catalog No.	Protective cap, D 1.5 Catalog No.
LD-EPIPLAN, **4x,** 0.1 N.A.	4.06x	0.1	36.3	8	7.5	1.5	46 21 01	46 29 11
LD-EPIPLAN, **8x,** 0.2 N.A.	7.94x	0.2	18.7	6.2	5.7	1.5	46 21 02	46 29 12
LD-EPIPLAN, **16x,** 0.30 N.A.	16x	0.30	10.1	4.1	3.6	1.5	46 21 03	46 29 13
LD-EPIPLAN, **40x,** 0.60 N.A.	40.1x	0.60	4.1	3.4	2.3	1.5	46 21 04	46 29 14
LD-EPIPLAN, **40x,** 0.60 N.A.	40.1x	0.60	4.1	3.1	—	0	46 20 97	—
LD-EPIPLAN, **40x,** 0.60 N.A., Pol*	40.1x	0.60	4.1	3.4	2.3		46 21 24	46 29 16

* For the Nomarski interference-contrast method in reflected light use this objective, mounted almost strain-free, with protective cap D 1.5 (46 29 16) and interference-contrast attachment (47 44 64).

EPIPLAN POL objectives
for polarized-light microscopy and the Nomarski interference-contrast method with incident light (CNRS licence)

centering change ring

EPIPLAN POL objective with thread W 0.8″

Interference-contrast attachment with thread W 0.8″ for EPIPLAN POL objective

The completely strain-free bright-field objectives are designed for polarized-light work, e. g. in ore microscopy or in connection with optically anisotropic metal phases. They are attached to the type II A, II ST, II C and II E vertical illuminators by means of the change ring 46 62 56 in which they can be centered.

As compared with dry objectives, immersion objectives result in enhanced image contrast because reflections at the first surface of the front lens are made impossible and the differences between the reflectivity and the intrinsic color of certain objects stand out more clearly against oil than against air.

If a vertical illuminator is to be used for the Nomarski interference-contrast method, a special interference-contrast attachment is needed for each EPIPLAN POL objective.

Table 21

Designation	Initial magnification	N.A.	Focal length mm	Working distance mm	Coverglass thickness mm	Catalog No. objective	Catalog No. Interference-contrast attachment*
EPIPLAN, **4x,** 0.10 N.A., POL	4.07x	0.1	36.3	9.05	—	46 20 01	47 44 92
EPIPLAN, **8x,** 0.20 N.A., POL	7.96x	0.2	18.7	7.1	—	46 20 02	47 44 92
EPIPLAN, **16x,** 0.35 N.A., POL	16.06x	0.35	10.4	2.7	0	46 20 03	47 44 93
EPIPLAN, **40x,** 0.85 N.A., POL	40.56x	0.85	4.6	0.23	0	46 20 04	47 44 94
EPIPLAN, **80x,** 0.95 N.A., POL	80.7x	0.95	2.3	0.09	0	46 20 80	47 44 95
EPIPLAN, **4x,** 0.10 N.A., POL, oil	4.07x	0.1	36.3	0.3	—	46 20 06	—
EPIPLAN, **8x,** 0.20 N.A., POL, oil	7.96x	0.2	18.7	0.3	—	46 20 07	—
Epi-Achromat, **16x,** 0.40 N.A., POL, oil	16.0x	0.40	10.0	0.85	0	46 20 08	—
Epi-Achromat, **40x,** 0.85 N.A., POL, oil	40.0x	0.85	4.6	0.5	0	46 20 09	—
EPIPLAN, **100x,** 1.25 N.A., POL, oil	98.8x	1.25	1.94	0.28	0	46 20 05	47 44 96

* To be used on Type II vertical illuminators with change ring 46 62 58. On vertical illuminators with revolving nosepiece (Types I A, III A, III C) the interference-contrast attachments 47 44 93/94/95 and corresponding objectives are parfocalized. Adapter ring 46 29 96 serves as connection

EPIPLAN StM objectives

These are designed for the STANDARD UM inverted metallurgical microscope. Since they fit into the revolving nosepiece of the standard transmitted-light microscopes and are parfocalized with the transmitted-light objectives, they may also be used for examining uncovered transparent specimens in all cases where ordinary transmitted-light objectives would give unsatisfactory results due to the lack of a cover glass.

EPIPLAN StM Ph objectives can be used for phase work if the diaphragm insert 467059 is placed in the base of the inverted metallurgical microscope. Every EPIPLAN StM Ph objective is supplied with an annular diaphragm which can be centered in this insert.

Table 22

Designation	Initial magnification	N.A.	Focal length mm	Working distance mm	Cover-glass thickness mm	Catalog No.
EPIPLAN StM, **4x,** 0.10 N.A.	4.07x	0.10	36.3	9.0	—	46 20 31
EPIPLAN StM, **8x,** 0.20 N.A.	7.96x	0.20	18.8	7.2	—	46 20 32
EPIPLAN StM, **16x,** 0.35 N.A.	16.06x	0.35	10.4	2.8	0	46 20 33
EPIPLAN StM, **40x,** 0.85 N.A.	40.56x	0.85	4.6	0.23	0	46 20 34
EPIPLAN StM, **80x,** 0.95 N.A.	80.7x	0.95	2.25	0.09	0	46 20 35
EPIPLAN StM, **100x,** 1.25 N.A., oil	100.7x	1.25	1.7	0.25	0	46 20 36
EPIPLAN StM, **16x,** 0.35 N.A., Ph	16.06x	0.35	10.4	2.8	0	46 20 37
EPIPLAN StM, **40x,** 0.85 N.A., Ph	40.56x	0.85	4.6	0.23	0	46 20 38
EPIPLAN StM, **100x,** 1.25 N.A., oil, Ph	100.7x	1.25	1.7	0.25	0	46 20 39

EPIPLAN Ph objectives
for phase-contrast work
with vertical illuminators

These objectives contain annular phase plates specially adapted to the requirements of incident-light phase-contrast microscopy. They are used in conjunction with a phase-contrast diaphragm insert which among other things holds three suitable annular diaphragms on a change disk.

EPIPLAN Ph objectives have the same W 0.8″ x 1/36″ screw thread as the transmitted-light objectives. They are not suitable for combination with our phase-contrast condensers for transmitted light.

EPIPLAN Ph objectives Table 23

Designation	Initial magnification	N.A.	Focal length mm	Working distance mm	Cover-glass thickness mm	Catalog No.
EPIPLAN, **16x,** 0.35 N.A., Ph	16.04x	0.35	10.4	2.8	0	46 20 27
EPIPLAN, **40x,** 0.85 N.A., Ph	40.56x	0.85	4.6	0.23	0	46 20 28
EPIPLAN, **100x,** 1.25 N.A., oil, Ph	100.7x	1.25	1.62	0.25	0	46 20 29

Phase-contrast diaphragm insert 47 20 73 for vertical illuminator type II C with single objective changer,
Phase-contrast diaphragm insert 47 20 72 for vertical illuminator type III C with a revolving nosepiece
can be combined with the UNIVERSAL and ULTRAPHOT microscopes

Antiflex immersion objectives

In the case of reflected-light bright-field illumination, part of the illuminating light is always reflected back to the image plane from the glass-air surfaces of the objective before it has fully passed through the latter. The amount of light that is reflected depends on the type of objective and the adjustment of the light path. It may even happen that an image of the objective aperture becomes visible. This effect is particularly disturbing when viewing objects of low reflectivity. It can be eliminated by using polarized light for illumination, whose state of polarization is hardly changed by specular reflection. When an analyzer in the light path is oriented so that its plane of vibration is perpendicular to that of the light reflected from the lens surfaces, this light can be extinguished. The light diffusely reflected from the specimen surface, however, will pass through the analyzer practically unattenuated because it is depolarized in the course of diffuse reflection.

In the case of specular reflectors—which most polished specimens are—this method is possible only if a suitably oriented, circularly polarizing filter is inserted between the specimen and the objective. Some of our bright-field reflected-light objectives are provided with such filters. They are then called "Antiflex objectives". These are available in the form of EPIPLAN and achromatic objectives for incident-light work with oil and methylene iodide.

Antiflex immersion objectives give particular high contrast for bright-field incident-light observations, because the use of an immersion medium eliminates all reflections at the first surface of the front lens, while the Antiflex system eliminates all reflection from the surfaces of all other lens elements, and because the differences of reflectivity and intrinsic color of certain objects are more pronounced and more clearly visible in oil

than in air. These objectives are especially suitable for objects of low to medium reflectivity (coal petrography) and specimens of varying reflectivity (weak to strongly absorbing or refracting). Methylene iodide immersion objectives generally produce the same result as the corresponding objectives for oil immersion, but are even better suited for objects of extremely low reflectivity (coal petrography).

The circularly polarizing filter located in front of their lens elements makes these objectives unsuitable for certain measuring techniques, e. g. for the polarized-light analysis of the vibrational state of polarized reflected light.

Antiflex immersion objectives Table 24

Designation	Initial magnification	N.A.	Focal length mm	Working distance mm	Coverglass thickness mm	Catalog No. Objective for nosepiece	Catalog No. Objective with change ring
EPIPLAN-Antiflex, **8x,** 0.2 N.A., oil	7.9x	0.2	18.75	0.4	—	46 13 64	48 13 64
Antiflex-Epi-Achromat, **16x,** 0.40 N.A., oil	16.0x	0.4	10.0	0.45	—	46 15 54	48 15 54
Antiflex-Epi-Achromat, **40x,** 0.65 N.A., oil	40.0x	0.65	4.6	0.5	0	46 17 54	48 17 54
EPIPLAN-Antiflex, **2.5x,** 0.08 N.A., methylene iodide	2.9x	0.08	54.8	0.3	0	46 11 63	48 11 63
EPIPLAN-Antiflex, **4x,** 0.1 N.A., methylene iodide	4.1x	0.1	36.3	0.4	—	46 12 63	
EPIPLAN-Antiflex, **8x,** 0.2 N.A., methylene iodide	7.9x	0.2	18.75	0.4	—	46 13 63	48 13 63
Antiflex-Epi-Achromat, **16x,** 0.40 N.A., methylene iodide	16.2x	0.4	10.0	0.35	0	46 15 53	48 15 53
Antiflex-Epi-Achromat, **40x,** 0.65 N.A., methylene iodide	39.6x	0.65	4.6	0.25	0	46 17 53	48 17 53

Photomicrographic objectives

LUMINARS with iris diaphragm

for photography by transmitted or incident light, with dark-field illumination produced by stereomicroscope illuminators.

Table 25

Designation	Focal length mm	For infinite object distance N.A.	Relative aperture	Distance between focal plane and front lens vertex (mm) object-side	image-side	Magnifications obtainable with ULTRAPHOT*	with UNIVERSAL microscope, PHOTO-MICROSCOPE	Catalog No.
16 mm LUMINAR	16.1	0.2	1:2.5	10.1	11.5	50x–70x 40x–55x	14x–22x	46 25 11
25 mm LUMINAR	26.0	0.14	1:3.5	21.9	23.0	31x–43x 25x–34x	8x–14x	46 25 13
40 mm LUMINAR	39.9	0.11	1:4.5	34.9	27.9	20x–27x 16x–22x	4x–8x	46 25 15
63 mm LUMINAR	63.4	0.11	1:4.5	54.8	45.0	11.5x–16x 9.5x–12.5x	2x–4x	46 25 17
100 mm LUMINAR	102.3	0.08	1:6.3	76.2	91.8			46 25 19
100 mm LUMINAR for Luminar head	102.3	0.08	1:6.3	76.2	91.8	6.5x–9.5x 5.3x–7.5x	1.5x–28x	46 25 29
2.5x to 5x LUMINAR for ULTRAPHOT	vari-able	0.04/ 0.05	—	—	—	2.5x–3.6x 3.6x–5x		46 25 31

* A continuous series of magnifications can be achieved with the ULTRAPHOT if the 0.8x auxiliary system, Catalog No. 46 25 80, is employed. The magnifications corresponding to this combination appear in small print.

100 mm LUMINAR

The 100 mm LUMINAR, Cat. No. 46 25 19, has an M 44 x 0.75 screw thread at either end. Thus, when the protective ring in front has been removed, the objective may also be used in an inverted position to secure reduced scales.

100 mm LUMINAR

The 100 mm LUMINAR, Cat. No. 46 25 29, is basically the same objective as No. 46 25 19. With its special mount it can be attached to the Luminar head of the ULTRAPHOT.

2.5x to 5x LUMINAR

The 2.5x to 5x LUMINAR is a special-purpose objective designed for very small scales. It is exclusively intended for the ULTRAPHOT camera microscope and can only be used for transmitted light in conjunction with the macro-stage 47 25 61. When ordering the macro-stage, please indicate the serial number of your ULTRAPHOT.

Epi-LUMINARS
without iris diaphragm with field lens

These are intended for photography with our ULTRAPHOT camera microscope using reflected-light bright-field illumination. The objectives 46 25 42/43/45 can also be used on our UNIVERSAL microscope.

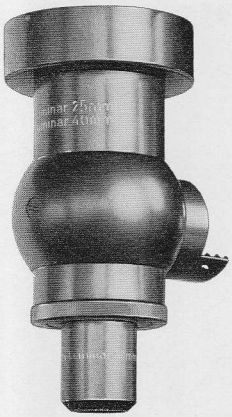


Table 26

Designation	Focal length mm	Catalog No. for objective	Magnifications to be achieved with ULTRAPHOT	Catalog No. for macro-illuminator
20 mm Epi-LUMINAR	18.7	46 25 42	44.5:1–61:1 35:1–49:1	47 25 75
25 mm Epi-LUMINAR	25.0	46 25 43	33:1–46:1 27:1–36:1	47 25 75
40 mm Epi-LUMINAR	40.0	46 25 45	22:1–29:1 17:1–23:1	47 25 75
63 mm Epi-LUMINAR	63.4	46 25 17	12:1–17.5:1 10:1–14:1	47 25 76
100 mm Epi-LUMINAR	102.3	46 25 29	8.5:1–12:1 6.5:1–9:1	47 25 77

The magnifications in small print can be achieved by using the 0.8x auxiliary system (46 25 80) with the Epi-LUMINARS.

ZEISS eyepieces

For tubes with an inside diameter of 23.2 mm; adapted to a location of the real intermediate image 10 mm below the tube edge; with compensating effect adapted to the correction of our objectives.

C-type eyepieces may be used in conjunction with simple types of objective. Objectives of higher correction should, if possible, always be combined with Kpl eyepieces. This applies above all to the Planachromats and Planapochromats.

Table 27

Designation	Eyepiece magnification	Eye relief mm	Focal length mm	Field-of-view number	Angle of view	Catalog No.
5x compensating eyepiece	5x	9	50.5	20	23°	46 37 10
6.3x compensating eyepiece	6.3x	9	39.9	18	26°	46 38 10
8x compensating eyepiece	8x	8	31.2	16	30°	46 39 10
10x compensating eyepiece	10x	6	24.9	16	36°	46 40 10
12.5x compensating eyepiece	12.5x	6	20.0	12.5	36°	46 41 10
8x Kpl eyepiece	8x	9	31.5	18	33°	46 39 20
10x Kpl eyepiece	10x	7	25.0	16	36°	46 40 20
16x Kpl eyepiece	16x	11	15.6	10	36°	46 42 20
20x Kpl eyepiece	20x	8.5	12.5	8	36°	46 43 20
25x Kpl eyepiece	25x	6.5	10.0	6.3	36°	46 44 20
16x Kpl wide-angle eyepiece	16x	12	15.6	16	55°	46 42 44

Eyepieces for spectacle wearers

These have a particularly long eye relief and are therefore suitable for wearers of eyeglasses. It should be noted, however, that the spectacle lens also has an influence on the height of the exit pupil. Minus lenses magnify, plus lenses reduce the image according to their power. A wearer of strong plus lenses may therefore be unable even with these eyepieces to approach the pupil of his eye close enough to the eyepiece for it to coincide with the exit pupil of the latter.

Table 28

Designation	Eyepiece magnification	Eye relief mm	Focal length mm	Field-of-view number	Angle of view	Catalog No.
8x Br Kpl eyepiece	8x	17	31.3	18	32°	46 39 22
12.5x Br Kpl eyepiece	12.5x	16	19.8	12.5	36°	46 41 20
10x Br Kpl wide-angle eyepiece	10x	20	25.1	18	41°	46 40 42*
12.5x Br Kpl wide-angle eyepiece	12.5x	15	20.3	18	50°	46 41 42*

* Eyepiece is supplied with foldable rubber eyecup.

Eyepieces for micrometer disks

In these eyepieces, the mount of the collective lens is designed to hold micrometer disks. The disk is pressed against the eyepiece diaphragm by means of a clip-on ring so that it rests in the image plane. The eyepiece may also be used, with or without a micrometer disk, combined with an ordinary eyepiece of the same specification (table 27) in a binocular body.

Table 29

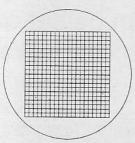
Designation	Eyepiece magnification	Eye relief mm	Focal length mm	Field-of-view number	Angle of view	Catalog No.
8x compensating eyepiece for 17 mm dia. micrometer disks	8x	8	31.2	16	30°	46 49 13
12.5x compensating eyepiece for 17 mm dia. micrometer disks	12.5x	6	20.0	12.5	36°	46 41 13
8x Kpl eyepiece for 17 mm dia. micrometer disks	8x	9	31.5	18	33°	46 39 23
12.5x Br Kpl eyepiece for 17 mm dia. micrometer disks	12.5x	16	19.8	12.5	36°	46 41 23
16x Kpl eyepiece for 17 mm dia. micrometer disks	16x	11	15.6	10	36°	46 42 23
20x Kpl eyepiece for 17 mm dia. micrometer disks	20x	8.5	12.5	8	36°	46 43 23
10x Br Kpl wide-angle eyepiece for 19 mm dia. micrometer disks	10x	20	25.1	18	41°	46 40 43*
10x Br Kpl wide-angle eyepiece for 19 mm dia. micrometer disks with orienting screw	10x	20	25.1	18	44°	46 40 46

* Eyepiece is supplied with foldable rubber eyecup.

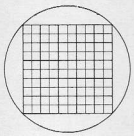
Micrometer disks

The following micrometer disks with diameter 17 or 19 mm to be used in the eyepieces listed on table 29.

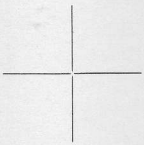
The eyepieces for the stereomicroscopes listed in table 32 require micrometer disks of 22.5 mm diameter.

		Catalog No.
	10 mm eyepiece micrometer, with 100 divisions, 17 mm dia.	47 40 11
	Same as above, but with 19 mm dia.	47 40 02
	Same as above for stereomicroscopes	47 40 61
	5 mm micrometer disk, with 100 divisions, 17 mm dia.	47 40 10
	10 mm contrast micrometer disk, with 100 or 200 divisions, 17 mm dia.	47 40 12
	10 mm line contrast micrometer disk, with 100 divisions, 17 mm dia. The shaded area transmits 5 to 10 % of the incident light.	47 40 13
	Net micrometer disk 10x10 mm, 20x20 squares, 17 mm dia.	47 40 14
	Same as above, but with 19 mm dia.	47 40 44
	Same as above for stereomicroscopes	47 40 62

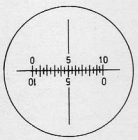
Catalog No.



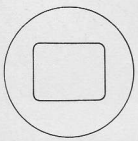
Net micrometer disk 5x5 mm, 10x10 squares, 17 mm dia. — 47 40 15



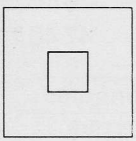
Crosshair disk, 17 mm dia. — 47 40 16
Same as above for stereomicroscopes — 47 40 60



10 mm crosshair micrometer disk, with 100 divisions, 19 mm dia. — 47 40 07



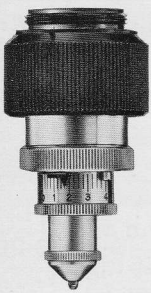
Reticule for color television microscope, 19 mm dia. — 47 40 09



Reticulocyte disk — 47 40 32

To simplify the counting of reticulocytes and thrombocytes*, this micrometer disk contains a small square within a large square (8x8 mm, 11.2 mm diagonal). The areas of the two squares are in a ratio of 10:1. The number of reticulocytes in the large square is determined in relation to that of the erythrocytes in the small square.

This disk is preferably used in the eyepieces with focusing eye lens, 8x Kpl (46 39 23) and 12.5x Br Kpl (46 41 23).



Object marker with diamond tip — 46 29 60

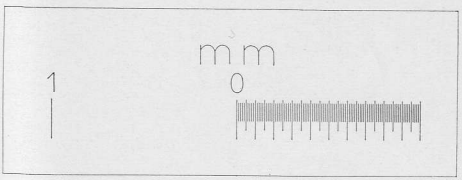
This is screwed into the microscope like an objective. The diameter of the circle to be made around the object can be set on a graduation. Then the diamond tip is lowered onto the cover glass and the circle engraved by turning a ring.

* Brecher and Schneidermann, The American Journal of Clinical Pathology, **20,** 1079–1083 (1950).

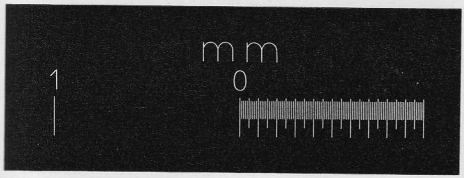
Catalog No.

Stage micrometers

A glass plate in a metal slide is provided with a 5 mm scale divided into 5 intervals. A further distance of 1 mm is divided into 100/100 mm = 10 μ.

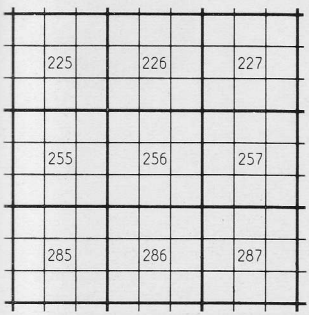


For transmitted light: positive stage micrometer 5 + 100/100 mm, in case 47 40 20
For reflected light: stage micrometer as above, but without cover glass 47 40 22
For ultraviolet microscopy: stage micrometer with slide and cover glass made of quartz glass 47 40 23



For transmitted light: negative stage micrometer 5 + 100/100 mm, in case 47 40 21

For stereomicroscopes: stage micrometer 25 + 50/10 mm, in case 47 40 25



Object finder

46 29 65

To allow the accurate relocation of object details, three squares marked ABC, each containing 30x30 smaller squares, are engraved on a 26x76 mm slide. The 0.75x0.75 mm squares are figured from 1 to 900 and further subdivided into 3x3 squares. The slide with the specimen need only be exchanged for the object finder to give an accurate reading of the position of the stage.

Pointer eyepieces

These eyepieces have a pointer in the image plane, the tip of which can be moved to any point in the field by turning a knob and rotating the eyepiece in the tube. For use in binocular bodies, the pointer eyepiece should be paired with an ordinary eyepiece of the same optical data, as listed in table 27.

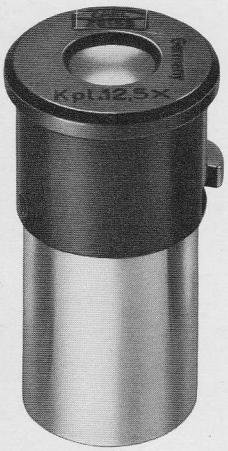


Table 30

Designation	Eyepiece magnification	Eye relief mm	Focal length mm	Field-of-view number	Angle of view	Catalog No.
8x compensating eyepiece with pointer	8x	8	31.2	16	30°	46 39 18
12.5x Br Kpl eyepiece with pointer	12.5x	16	19.8	12.5	36°	46 41 28

POL crosshair eyepieces
with focusing eye lens and orienting screw

This eyepiece is inserted into the tube correctly oriented. The crosshairs have been centered with high accuracy. They mark the optical axis of the polarizing microscope and the vibration direction of polarizer and analyzer in their zero positions. They serve as an index for measuring azimuth angles by rotation of the stage.

Crosshair micrometers are also suited for length measurements under orthoscopic and conoscopic observation.

Table 31

Designation	Eyepiece magnification	Eye relief mm	Focal length mm	Field-of-view number	Angle of view	Catalog No.
8x Kpl crosshair eyepiece POL	8x	9	31.5	18	33°	46 39 25
12.5x Br Kpl wide-angle eyepiece with crosshair micrometer	12.5x	15	20.3	18	50°	46 41 45

Eyepieces for stereomicroscopes

These are eyepieces specially designed for use with our stereomicroscopes, for an inside tube diameter of 30 mm. They are adapted for a real intermediate image located 10 mm below the tube edge and have no compensating effect.

Table 32

Designation	Eyepiece magnification	Eye relief mm	Focal length mm	Field-of-view number	Angle of view	Catalog No.
4x eyepiece	4x	10	62.6	30	27°	46 36 01*
10x eyepiece	10x	12	25	20	43°	46 40 01
Same for micrometer disks 25x eyepiece	25x	7.3	10	10	55°	46 40 04 46 44 01
Same for micrometer disks 10x Br wide-angle eyepiece	10x	18	25	25	55°	46 44 04 46 40 02*
16x Br wide-angle eyepiece	16x	15	15.6	16	55°	46 42 02

*) not for stereomicroscope IV

The 10x stereoscopic depth-measuring eyepiece

Catalog No. 46 40 05, with integral index for stereoscopic depth measurement is identical in design to the 10x eyepiece for micrometer disks.

Clamping ring 46 49 12 serves for orientation of the eyepiece.

Microprojection eyepieces
Eyepieces of long focal length for use in microprojection equipment

Table 33
Transfer factors

Focal length of microprojection eyepiece	Camera lens of focal length 100 mm	125 mm	160 mm
125 mm	0.8x	1x	1.25x
100 mm	1x	1.25x	1.6x
80 mm	1.25x	1.6x	2x
63 mm	1.6x	2x	2.5x

For the recommended projection distance, the scale factor of all projection eyepieces, i. e. the relationship between their field-of-view number and the diameter of the projected image, is identical. It is 100.

This means that all the eyepieces, which have a field-of-view number of 20, will produce an image of 2 m diameter at this distance.

In exceptional cases, these eyepieces may also be used for visual observation if eyepiece magnifications are required which are lower than those of the normal eyepieces. This is why the values corresponding to eyepiece magnification and eye relief are also indicated. The eyepieces may also be used to advantage if in cinemicrography on 16 mm or 8 mm film the aerial image produced by the camera lens is to be transferred to the film plane by the eyepiece with little or no magnification. In this case the camera, with a lens of suitable focal length, should be arranged above the eyepiece. The camera lens may be a simple achromatic lens (telescope objective). Table 33 gives the transfer factors which can be achieved, for example, with telescope objectives and the four microprojection eyepieces.

For details on microprojection equipment including projectives see brochure 41-480.

Microprojection eyepieces

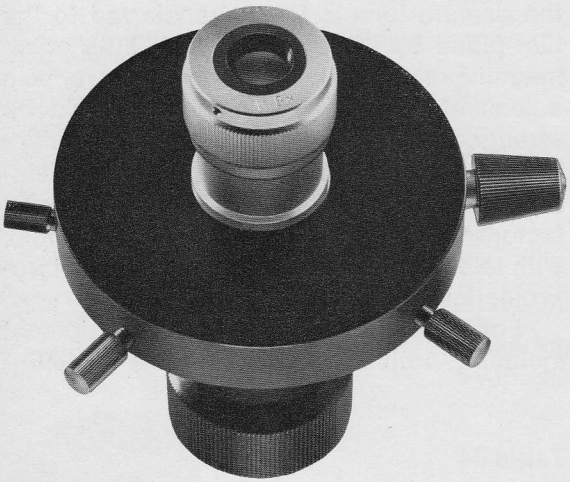
Table 34

Designation	Eyepiece magnification	Eye relief mm	Focal length mm	Field-of-view number	Recommended for projection distance of m	Catalog No.
125 mm microprojection eyepiece	2x	30	126.0	20	12.5	46 33 79
100 mm microprojection eyepiece	2.5x	30	100.0	20	10	46 34 79
80 mm microprojection eyepiece	3.2x	30	79.3	20	8	46 35 79
63 mm microprojection eyepiece	4x	30	63.1	20	6.3	46 36 79

Special-purpose eyepieces 82

Screw micrometer eyepieces with inner reading

Screw micrometer eyepieces are used for measuring object lengths. The microscopist may now read the measured value off the micrometer, measurements with an accuracy eyepiece. Thus, inner reading of measured values avoids mistakes caused by accommodation. After calibrating with the stage micrometer, measurements with an accuracy of $^{1}/_{1000}$ of a millimeter can be made.



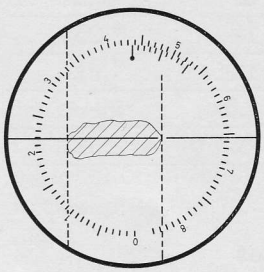
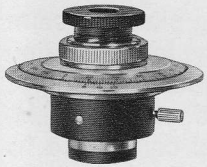


Table 35

Screw micrometer eyepieces with inner reading	with Kpl 8x Catalog No.	with Kpl 16x Catalog No.
for standard monocular tube with 25 mm outside diameter and for polarizing tube	46 39 73	46 42 73
for tubes with 33 mm diameter, for stereomicroscopes	46 39 83	46 42 83

Catalog No.



K 8x goniometer eyepiece

for standard monocular tube with 25 mm outside diameter	46 39 74
for tube with 33 mm diameter, for stereomicroscopes	46 39 84
for polarizing tube	46 39 94

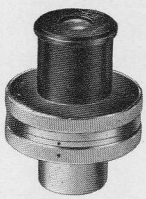
This eyepiece is provided with crosshairs which can be rotated through 360° about the intersection of the two hairs. The angle of rotation can be read off a graduation with vernier to within $^1/_{10}$°. The eyepiece is intended for measuring angles in the microscope field of view.

K 8x and K 16x eyepieces for Microhardness Tester with focusing eye lens 46 39 77

This is a special eyepiece for evaluating the Vickers indentations produced by means of a Microhardness Tester. It contains two micrometer disks with rectangular patterns of dashed lines which combine to form a crosshair in zero position. The two disks can be symmetrically shifted in relation to the vertical center line by means of a knob. The diagonal of the indentation is measured by this shift. The eyepiece is of the interior reading type.

K 10x UV projective 46 40 82

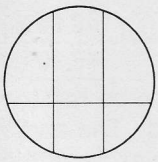
This system is designed to produce a second real image e. g. on a light-sensitive emulsion (photomicrography) or in a photometer system (Type 05 UV-microscope photometer).



8x Kpl counting eyepiece 46 39 71

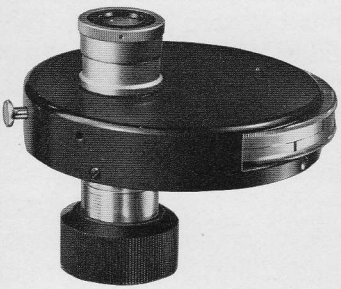
This eyepiece can be clamped in the monocular tube. It contains two diaphragm blades with rectangular cutouts, which can be shifted symmetrically in relation to the vertical center line, thus making it possible to select square sections from the field of view. When using an object chamber of known depth, volumes can thus be easily limited for counting purposes. In other words, the eyepiece is intended for counting particles within a certain volume.

Catalog No.



8x Kpl eyepiece with adjustable counting lines 46 39 70

This has primarily been developed for counting plankton samples. However, it may also be used to advantage for evaluating other samples. It is clamped in a monocular tube and contains a fixed horizontal hair and two vertical hairs which can be shifted symmetrically in relation to the vertical center line by means of a knurled ring. The two adjustable hairs serve to delimit counting areas of any desired size.

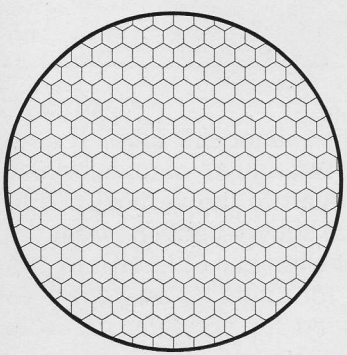


10x Br K eyepiece for spectacle wearers, for micrometer-disk turret

for standard monocular tube with 25 mm outside diameter	46 40 75
for polarizing tube	46 40 95

This eyepiece accepts revolving disks which serve for the convenient disposition and rapid exchange of several micrometer disks in the intermediate image plane. This may be of advantage for evaluating clusters of particles in connection with standard series, for measuring particle size and determining volume.

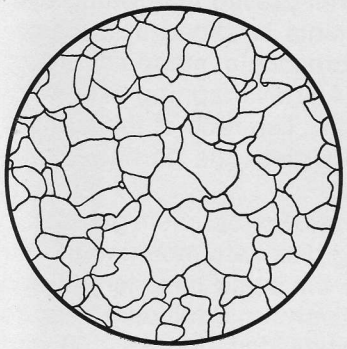
Each turret contains either one revolving disk or two, arranged one above the other, with 6 or 12 reticules, respectively. In another position, the light passes freely through the disks.



Type 'a' "honeycomb net" micrometer-disk turret 47 41 20

The micrometer disks built into this double turret conform to ASTM E 19–46. The 11 disks correspond to the ASTM numbers 0 to 10. With the aid of the appropriate objectives, the ASTM numbers $\overline{2}$ to 12 can thus be covered. The honeycomb nets are extremely convenient for estimating particle sizes with relative radii of $\sqrt{2}:1$ and 2:1. One opening contains a micrometer disk with 10 mm/100 mm and 4 inch/128 graduations.

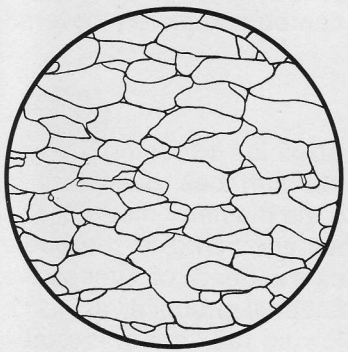
Catalog No.



Type 'b' "austenite-ferrite" micrometer-disk turret 47 41 21

Each of the two revolving disks holds six micrometer disks with austenite-ferrite grain sizes in a ratio of 1:1 conforming to the Steel and Iron Standard 1510-61. The disks bear the data for the Steel and Iron Test Nos. 2 to 7. In conjunction with our EPIPLAN objectives it is thus possible to cover the numbers 0 to 9.

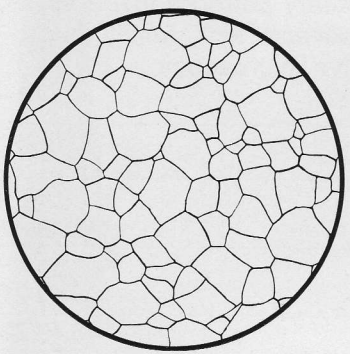
The micrometer-disk turrets 47 41 21 and 47 41 22 together give the overall requirements of the Steel and Iron Standard 1510-61 and should therefore be ordered and treated as one unit.



Type 'c' micrometer-disk turret, 47 41 22
"ferrite grain sizes 2:1 and 4:1"

This double turret is identical in design to the turret 47 41 21, with the only difference that it covers the grain size ratios 2:1 and 4:1.

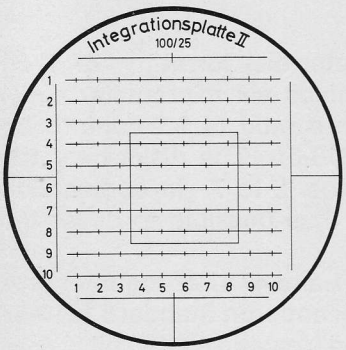
This micrometer-disk turret reflects all the different conditions of the Steel and Iron Standard 1510-61 in conjunction with the turret 47 41 21. The two should therefore be ordered and treated as one unit.



Type 'd' micrometer-disk turret, 47 41 23
"ASTM-E 112 untwinned grains"

On this turret the grain-size samples are arranged according to ASTM-E 112 with the whole numbers 0—4 or, respectively, 7 and 8 as well as the half numbers 4.5—5.5. Variation of the initial magnifications of the objectives thus allows the ASTM numbers 2 to 10 to be covered. The distribution of grain sizes has been particularly adapted for the assessment of austenite grain sizes, but it may also be used in conjunction with isometric grain-size systems.

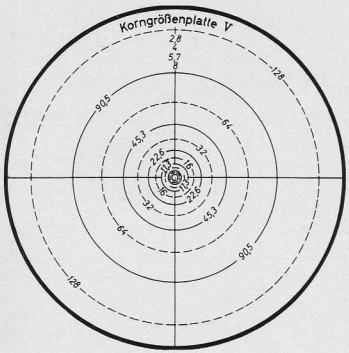
Catalog No.



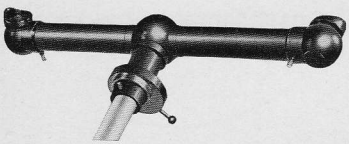
Integrating micrometer-disk turret 47 41 30

This turret takes the place of the well-proved integrating eyepiece I. With this turret, sets of points arranged in a square are superimposed on the aerial microscopic image according to the principle of point analysis. Any overlapping of a point with a component is counted as a hit. The ratio of the number of hits to the total number of points gives the partial volume or the percentage by volume.

The revolving disk has seven openings. For optimum geometric adaptation to the object, integrating disks are mounted in four of these openings. The disks have the same base length and 25, 100, 400 and 900 points, respectively. In addition, the large clusters of points are centrally subdivided into 25, 100 and 400 points so that small object fields can be uniformly counted with these partial nets. If the coordinate motions of the attachable mechanical stages are made parallel to the sides of the counting nets, then the specimens can be completely covered with the point nets.



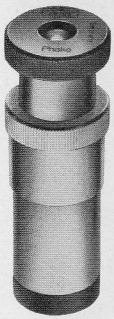
Disks 5 and 6 of the turret are intended for the determination of grain sizes, shape factors, specific surfaces, diameters of medium-sized particles according to the diameter method, and determination of medium-sized areas according to the circle method. With the disk 5, the radius quotients of successive circles behave, according to international practice, as $\sqrt{2}$:1, i. e. the quotients of the second following radii are in the ratio 2:1. The radii of the grain-size disk 6 are selected in linear, decimal order in steps of ten. In addition, the radii of the Aterberg division customary in sedimentary petrography, 2—6.3—20—63, have been included. The seventh disk, finally, is provided with crosshairs for quantitative microscopy.



K 8x double eyepiece with pointer	Catalog No.
for standard monocular tube with 25 mm outside diameter	46 49 20
for tube with 33 mm diameter, for stereomicroscopes	46 49 21
for polarizing tube	46 49 22

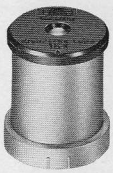
This unit has two separate eyepieces spaced approx. 380 mm.

Bestell-Nr.

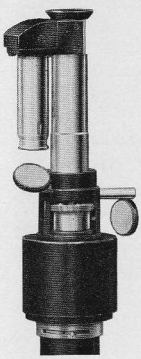


Centering telescope 46 48 20
This is a small telescope inserted into the tube instead of the eyepiece and serving for observation of the magnified exit pupil of the microscope objective as well as the aperture stop image appearing in it. This allows accurate checking of the objective aperture. It serves instead of a Bertrand lens to adjust the phase-contrast annular diaphragm of the condenser in relation to the phase annulus in the objective, or to observe interference figures.
The centering telescope is focused by shifting its eyepiece.

Centering telescope 46 48 21
with built-in 5:100 micrometer disk
e. g. for the measurement of interference angles.



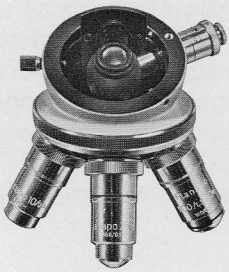
Klein magnifier 46 48 30
Clip-on eyepiece magnifier designed to magnify the exit pupil of the entire microscope. It serves the same purpose as the centering telescope.



Pupillary spectroscope 47 43 00
This low-power eyepiece with focusing eye lens and an iris diaphragm for limiting the field of view is combined with a hand spectroscope. The slit of the spectroscope is located in the plane of the eyepiece exit pupil. With the aid of the iris diaphragm the detail to be investigated spectroscopically can be singled out and its characteristic absorption or emission spectrum viewed in the spectroscope. The hand spectroscope permits a wavelength scale and, if desired, a comparison spectrum, to be projected into the image. With the aid of a special-purpose camera the spectra can be photographically recorded.

Intermediate magnification-changing systems

The total magnification power of a microscope, calculated from the initial magnification of the objective and of the eyepiece, can be varied by means of an optical lens system.



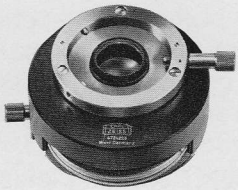
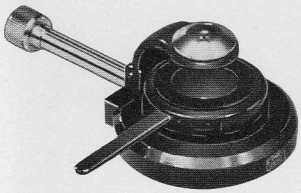


Table 36

Designation	Factor	for microscope	Catalog No.
Wide-field system	0.8x	To be screwed into the body tube, used primarily with the STANDARD K and R	47 30 67
Wide-field changer	0.8x – 1x	STANDARD K and R, with holder screw in limb top	47 30 68
Magnification changer	1.6x – 1x	Same as for the wide-field changer	47 30 60
Magnification changer	2x – 1x	Same as for the wide-field changer	47 30 65
OPTOVAR	1x – 1.25x – 1.6x – 2x	STANDARD R, WL, among others	47 30 50
Wide-field OPTOVAR	0.8x – 1x – 1.25x – 1.6x	STANDARD R, WL, among others	47 30 70
OPTOVAR on tube head	1.25x – 1.6x – 2x	UNIVERSAL	47 16 45*
		PHOTOMICROSCOPE, part of stand	47 21 89*
OPTOVAR on tube head	1.25x – 1.6x – 2x	ULTRAPHOT	47 26 45*
* Wide-field OPTOVAR on tube head is obtained if the standard revolving nosepiece is replaced by the nosepiece with wide-field system (47 31 55).	0.8x – 1x – 1.25x	PHOTOMICROSCOPE, UNIVERSAL ULTRAPHOT	

Z-type condensers

For the condenser carrier of our routine and research microscopes, parfocalized for a distance of 38.2 mm, with built-in aperture iris diaphragm for bright field.



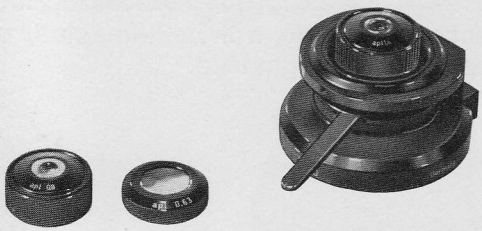
Simple condensers

Table 37

Designation	Front lens	N.A.	Focal length mm	Object distance* mm	Catalog No.
Condenser, 0.6 N.A.,SZ	fixed	0.6	24.8		46 52 00
Condenser, 0.9 N.A., Z with swing-out lens	swinging out	0.9	13.1	2.0 – 2.2	46 52 52
Condenser, 1.3 N.A., Z with swing-out lens	swinging out	1.3	8.4	1.6 – 1.8	46 52 53
Condenser, 0.9 N.A., Z, **POL**	swinging out	0.9	13.1	2.0 – 2.2	46 52 62
Condenser, 1.3 N.A., Z, **POL** with swing-out lens	swinging out	1.3	8.4	1.6 – 1.8	46 52 63
Phase-contrast condenser II Z with swing-out lens	swinging out	0.9	13.1	2.0 – 2.2	46 52 70
Phase-contrast condenser II Z, **POL** with swing-out lens	swinging out	0.9	13.1	2.0 – 2.2	46 52 82

* The object distance indicates the position of the image of an infinitely distant lamp field stop above the stage surface in glass for a medium aperture and a condenser racked up to its upper stop. This measure is an indication of the thickness of the objects which can still be properly illuminated with the condenser following Köhler's method.

N.A. 1.4 achromatic-aplanatic condenser Z



Universal variable-focus condenser for bright-field illumination, if used together with the two auxiliary front lenses of N.A. 0.6 and N.A. 0.9.

Table 38

Front lens	N.A.	Focal length mm	Object distance mm	Catalog No.
Immersed	1.4	6.8	1.3–1.5	46 52 57
Without front lens	0.32	30.7	37	–
Auxiliary front lens				
0.63	0.64	15.3	6.6	46 52 55
0.9	0.9	10.4	1.8	46 52 56

Achromatic-aplanatic phase-contrast condenser IV Z/7

Dry condenser of long objective distances with aperture iris diaphragm for bright field and three annular diaphragms on a revolving disk, matched with our phase-contrast objectives, for phase-contrast observations of living objects in sample chambers.

Table 39

N.A.	Focal length mm	Object distance in glass mm	Catalog No.
0.63	15.3	11	46 52 72

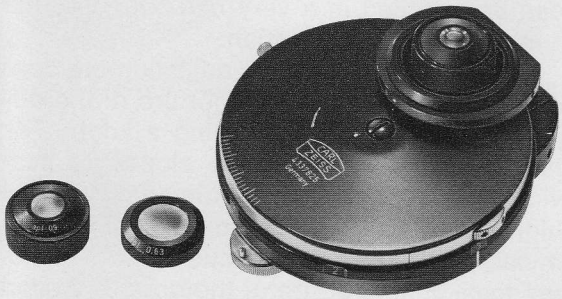
Achromatic-aplanatic bright-field dark-field phase-contrast condenser V Z 46 52 77

For bright-field this is a variable condenser like the N.A. 1.4 condenser Z, 46 52 57.

For the phase-contrast technique it may be used with the N.A. 1.4 front lens in conjunction with our Ph objectives of 16x or higher power.

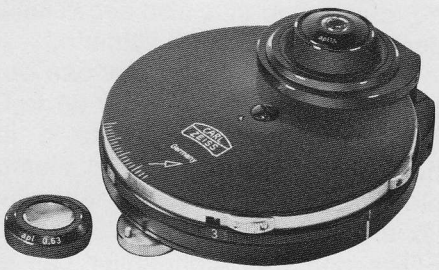
For dark-field work, the N.A. 1.4 front lens of the condenser is immersed (object distance in glass 1.1—1.3 mm). Its aperture is then 1.1—1.4, and it is suited for use in conjunction with N.A. 0.65 to 1.0 objectives. High-power oil immersion objectives must be equipped with an iris diaphragm.

Achromatic-aplanatic phase-contrast fluorescence condenser 46 52 78



This is the same condenser as 46 52 77. However, in positions 2 and 3 of the revolving disk, which are marked in blue, it contains two additional annular diaphragms for polarized light. In conjunction with the light regulator 47 72 20 these permit a phase-contrast image to be continuously converted into a fluorescent image.

Achromatic-aplanatic phase-contrast and interference-contrast condenser 46 52 84

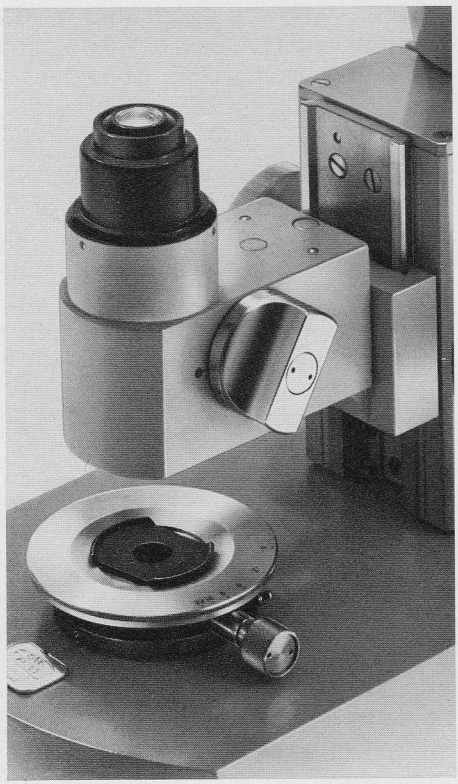


For phase-contrast illumination this condenser with strain-free mounted lenses is similar to the condenser IV Z, 46 52 77. In the positions I, II, III and IV the revolving disk contains a double-prism quartz wedge and an aperture diaphragm. Used together with Planachromats 6.3x, 16x, 40x and 100x, a polarizer and an interference-contrast slide 47 44 31 or 47 44 33, this condenser will give NOMARSKI differential interference contrast. A rotary specimen stage will be found helpful for this type of work (booklet 41-210).

Pancratic

condensor, 0.13 . . . 0.90 N.A. 46 52 90

Condenser head, 1.3 N.A. 46 52 91



The pancratic condenser is based on the idea that an additional optical system of continuously variable focal length should be located between the condenser system and the condenser diaphragm to image the diaphragm in the focal plane of the condenser system at a continuously variable scale and thus to cause a continuous change of aperture. Since such a system at the same time makes it possible to image the aperture of the lamp condenser in the specimen plane in the sense opposed to that of the change in image scale, the product of the field-of-view diameter and the aperture remains constant. If all elements are suitably matched, the basic requirement of the Köhler illumination method can be satisfied in a very neat manner with a minimum of manipulation.

Operation is limited to adjusting the condenser for the maximum aperture of the objective used simply by turning a knob. For further simplification, three stops are provided for low-power, medium-power and high-power objectives. Reduction of the illuminating aperture to a value below that of the maximum aperture of the objective used for observation is achieved as usual by varying the aperture diaphragm located in a special insert in the microscope base. It is mounted so that it can be shifted laterally and rotated and thus also allows oblique illumination of any desired azimuth.

The pancratic condenser can be used as dry condenser for apertures up to 0.9 or as immersion condenser up to a maximum aperture of 1.3. It serves to illuminate the fields and apertures of all objectives from 2.5x to 100x.

The pancratic condenser can easily be used for phase contrast. For this purpose, an annular diaphragm supplied with the unit is inserted at the plane of the aperture diaphragm. By varying the adjustment of the

pancratic system, the image of the annular diaphragm in the focal plane of the phase-contrast objective can be perfectly matched to the size of the phase annulus there and centered with the aid of the diaphragm adjustment.

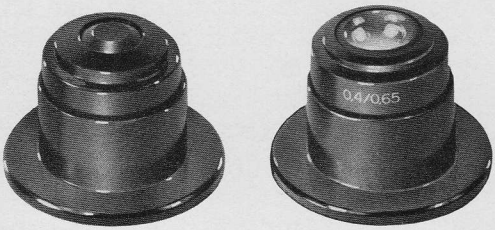
N.A. 0.6 conoscopic condenser UD 46 55 50

This condenser is specially adapted to the position of the object on the universal stage and serves for optimum illumination of the conoscopic interference pattern. In conjunction with hemispheres with a refractive index of 1.555 it acts with an aperture of 0.6. In air its object distance is 17 mm. Its working distance from 1 mm thick specimen slides is then 15 mm.

N.A. 0.8 achromatic ULTRAFLUAR-condenser with iris diaphragm 46 55 57

This condenser for work by ultraviolet light is corrected and parfocalized like an ULTRAFLUAR objective (see page 58). At a wavelength of 280 mμ its focal length is 6.2 mm and its initial magnification 29.5x. Although it is a dry condenser, it may also be immersed in the usual glycerin used in UV microscopy.

This condenser is inserted into the condenser carrier of our microscopes in conjunction with change ring 46 62 58, intermediate ring 46 29 90 and carrier Z for microscope objectives, 46 55 45.



Dark-field condensers Table 40

Designation	N.A.	Focal length mm	Object distance mm	For objectives of N.A.	Catalog No.
Ultracondenser, 1.2 . . . 1.4 N.A., oil	1.2—1.4	5.9	1.1—1.3	0.75—1.0	46 55 00
Dry dark-field condenser, 0.8 . . . 0.95 N.A.	0.8—0.95	8.2	6	0.6 —0.75	46 55 05
Dry dark-field condenser, 0.7 . . . 0.85 N.A.	0.7—0.85	8.5	6.5	0.4 —0.6	46 55 06

For our microscopes with centering carrier, each of these condensers must be equipped with a condenser holder Z, 46 55 42.

For insertion into a condenser sleeve,
the ultracondenser must be equipped with the centerable condenser holder S 46 55 41,
the other condensers with the condenser holder S 46 55 40.

Spectacle-lens condensers

For photomacrography with LUMINARS (table 25), for photography by polarized light as POL models.

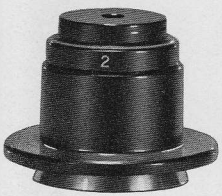
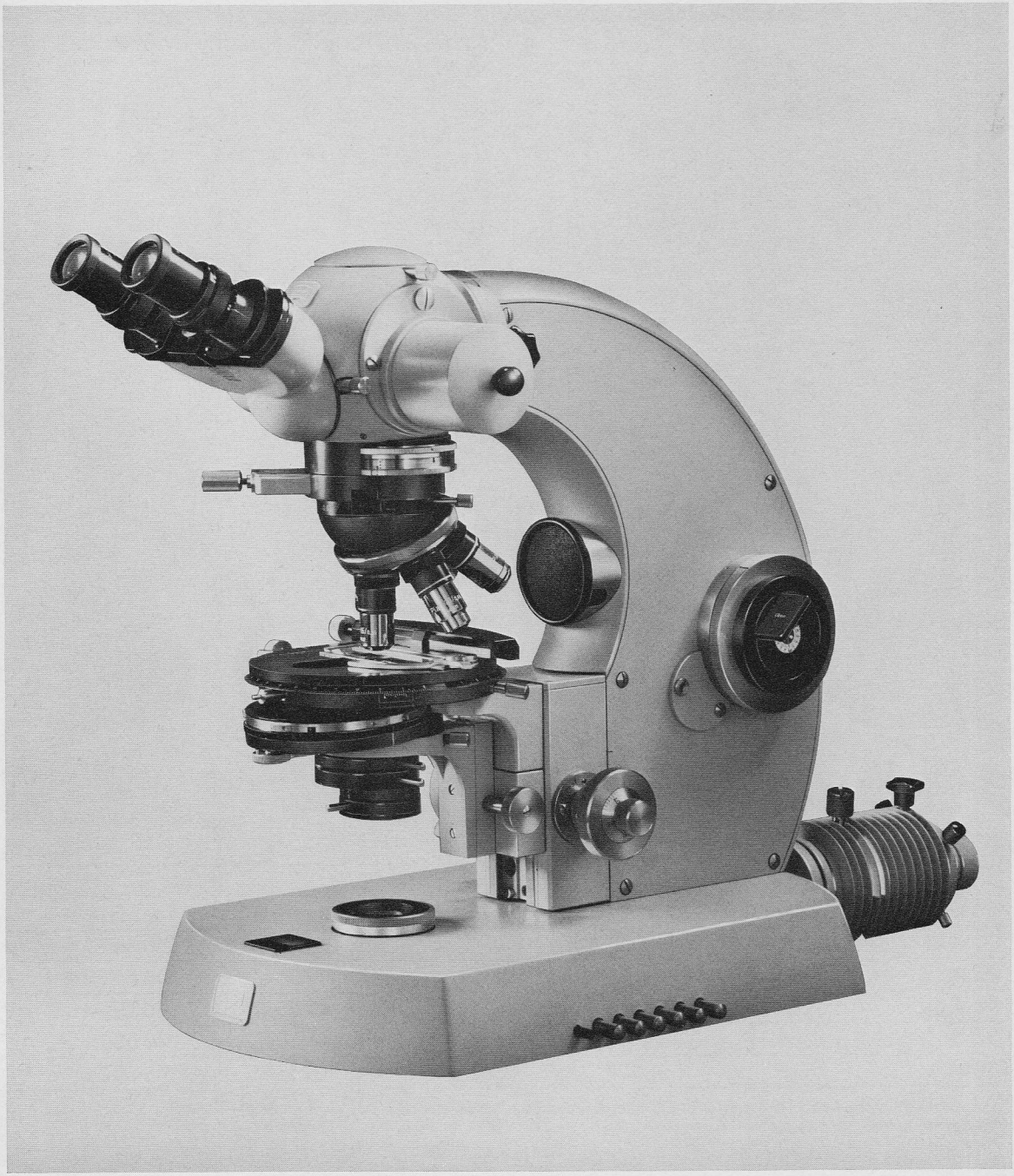


Table 41

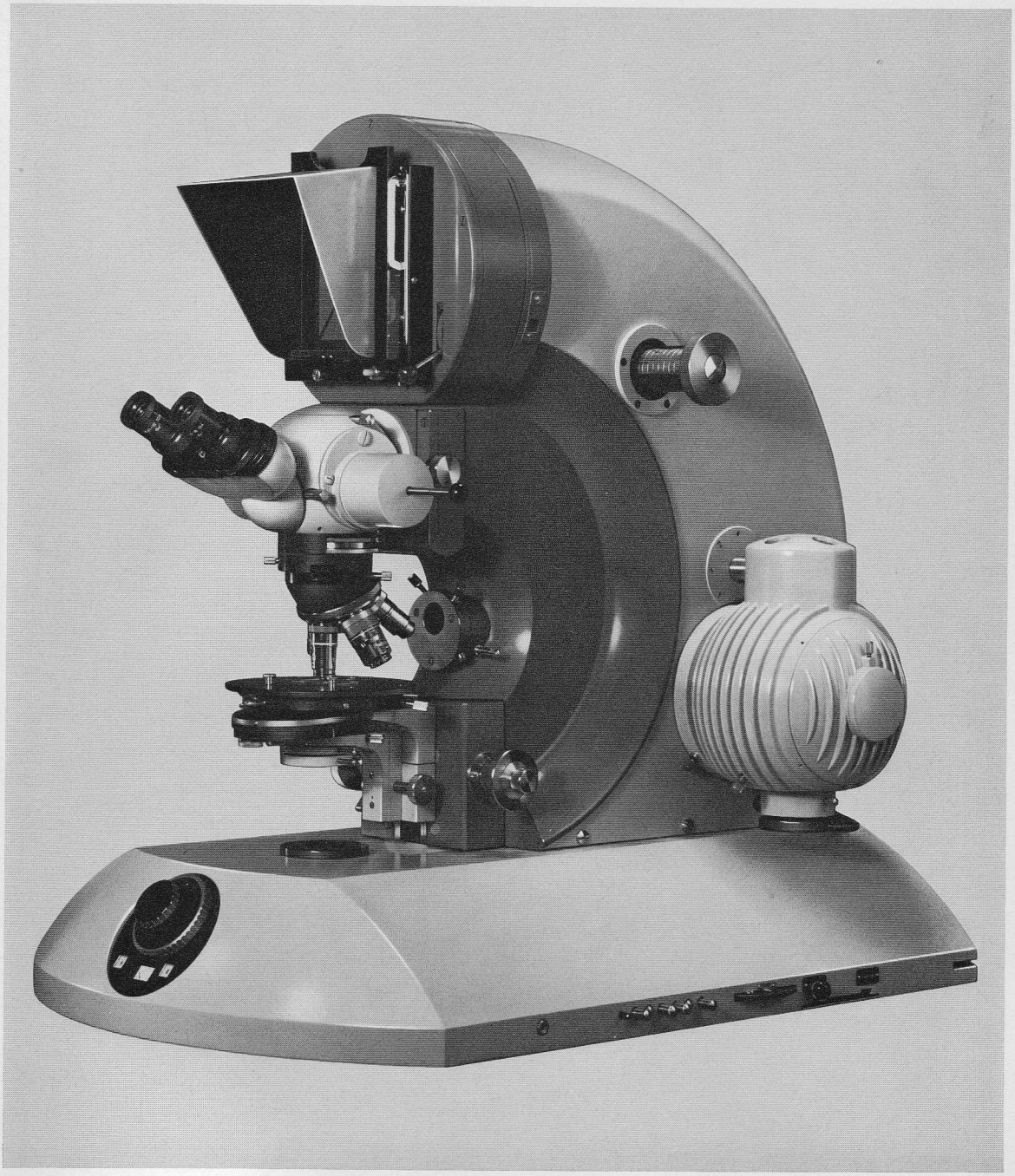
For LUMINAR	Spectacle-lens condenser	Focal length mm	Diameter of clip-on diaphragm (mm)	Catalog No.	POL model Catalog No.
16 mm	**1***	21	3.5	46 55 61	46 55 71
25 mm	**2***	36	6	46 55 62	46 55 72
40 mm	**3***	47	9	46 55 63	46 55 73
63 or 100 mm	**4**	82	15	46 55 64	46 55 74
100 mm	**5**	137	27	46 55 65	46 55 75

* For insertion into the centering carrier of our microscopes each of these condensers must be equipped with condenser holder Z, 46 55 42.

PHOTOMICROSCOPE II with integral, fully automatic 35 mm camera including photomultiplier;
equipped for differential interference-contrast in transmitted light, phase contrast and bright field.



ULTRAPHOT III Camera Microscope for 4″×5″ or 35 mm photography with fully automatic, integral camera including photomultiplier. This instrument can be used for all techniques applied in microscopy.



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