CARL ZEISS

OPTICAL WORKS

JENA

OPTICAL
MEASURING INSTRUMENTS

1893

Timothy P. Epps

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The following two separate catalogues, German, English and French editions, may be had on application, free of charge:

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Jena, 1893.

Carl Zeiss,
Optical Works.

Telegraphic address: **"Zeiss Werkstaette Jena".**

We shall be pleased to place blocks of illustrations contained in this catalogue at the disposal of authors of scientific publications.

The whole of the instruments and apparatus described in this catalogue have, both in principle and construction, originated in our works and took their existence from problems arising from our own requirements. They were constructed in the course of years by the scientists attached to the firm, either for immediate assistance in the manufacture of our leading optical instruments or for experimental research suggested by the work of the firm. Accordingly, the instruments have been tested throughout by our own use, which in several cases has been continued for many years, and those among these which have already been previously described, constitute in their present form the definite result of experiment and experience.

Until recently these instruments have only occasionally been supplied for the use of others. But as they appear to commend themselves to the interest of many engaged in scientific research and technical work or of teachers of physical sciences, we have now formed in our works a special department in which instruments of this class are regularly manufactured. This department is under the care of Dr. C. Pulfrich, a physicist of practical experience on the subject of philosophical instruments. Beside the instruments described in this catalogue we undertake to construct other appliances of the same class according to special designs.

Jena, December 1892.

Carl Zeiss,
Optical Works.

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Apparatus

for determining

the Refractive and Dispersive Powers

of solid and fluid bodies.

No. I. Abbe Spectrometer (Fig. 1 on following page).

This spectrometer has, during the last few years, only received a few minor improvements, otherwise it is essentially the same as described by Prof. ABBE in his paper on "Neue Apparate zur Bestimmung des Brechungs- und Zerstreuungsvermögens fester und flüssiger Körper", Jena 1874. It is the same instrument which has been used in our own laboratory for several thousands of determinations of optical data and which in all these cases has proved perfectly satisfactory.

In constructing the spectrometer it has been our aim to embody the following conditions: To simplify the instrument as much as possible by removing all such parts that were at all dispensable; to so arrange its mechanism that the instrument might be adjusted with ease and precision and that all the necessary readings for a complete determination might be taken without the necessity of in the least altering and readjusting the instrument, and, finally, to provide the instrument with a simple and convenient micrometer arrangement so as to render it possible to find the data required for the determination of the dispersion independently of the goniometric reading by means of the divided circle, in order that the graduation of the circle need not be finer nor the construction of the instrument and its manipulation any more delicate than is required for the exact determination of the absolute value of the refractive index.

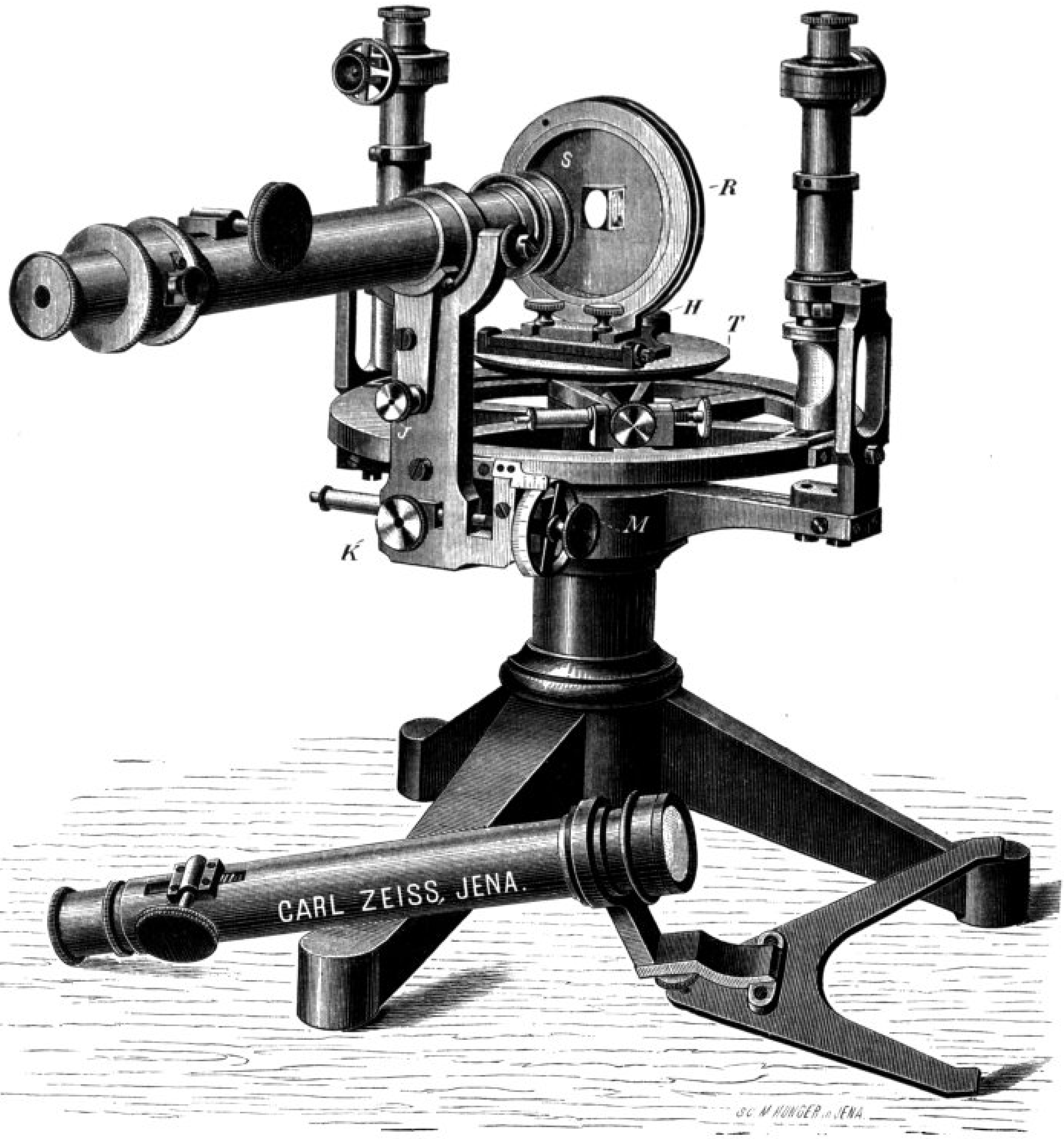

Fig. 1.
Abbe Spectrometer (No. 1).
$^1/_3$ Full Size.

The principle upon which the construction of the apparatus is based is that of autocollimation (method of a ray returning along its own path). The same telescope serves for observation and illumination. In the focal plane of the telescope objective is placed a vertical slit which is illuminated by means of a small reflecting prism, which covers it and reflects upon it the light from the source of light placed at the left hand side. Monochromatic flames or GEISSLER tubes, the latter being placed longitudinally (vid. Nos. 2 and 3, p. 5) form suitable illuminants. The parallel pencil of rays emerging from the telescope objective is reflected either directly by the surface of the prism, or it is first refracted and then reflected by the posterior surface. In the case of normal reflection the pencil of rays returns along its own path and forms an image of the slit which is coincident with the latter itself. The path of the light is identical with that due to minimum deviation of a prism having double the refracting angle (Fig. 2). Both methods, therefore, agree as regards the similarity of the object and its image; the taking of the reading is, however, in our case, greatly simplified in as much as the determination of the minimum deviation is entirely dispensed with, it being only necessary to make coincide the image of the slit with the latter itself. The slit being covered by the reflecting prism, a web is stretched across the free half of the focal plane in a direction parallel to the slit, and this web has to coincide with the image of the slit, which appears as a bright line upon a dark ground[1]). The width of the slit may be regulated externally. The perpendicular position of the telescope with respect to the axis of rotation of the divided circle is obtained by means of the adjusting screw *J*.

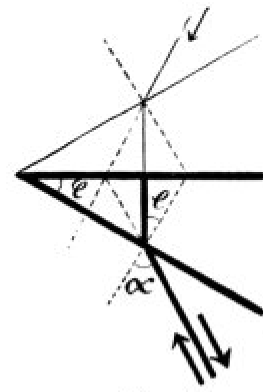

Fig. 2.

The prism which is to be examined is, as a rule, not placed upon a stage but is affixed with wax to a circular disc with central opening (*S*, Fig. 1), which, by means of spring-clips, may be connected to a ring *R* fixed with screws upon the spectrometer stage *T*. The ring rotates on its horizontal axis. Thereby one of the prism surfaces is placed very approximately in the axis of the spectrometer. The exact adjustment of this surface in a direction parallel to the same axis is effected by means of the screw *H*. Subsequently, the other surface of the prism is, by rotation of the ring, also placed parallel to the axis of the spectrometer. This mode of attaching the prism requires, therefore, no special preparation of the prism; consequently, particularly also on account of the small prism angle (about 30° instead of the usual angle of 60°) the material to be examined may be economised in the most welcome manner.

1) The intensity of the spectrum thus formed may be made nearly equal to that obtained with transmitted light by covering the back of the prism with mercury (rub a few globules of mercury upon a piece of tin-foil and apply the latter to the back of the prism).

In the case of prisms of large dimensions, particulary of fluid prisms, this mode of attachment is not sufficiently secure. For this reason all the parts connected with the ring *R* above the stage *T* are made to readily remove so as to be replaced by a small stage with three levelling screws, which is supplied with the apparatus; this levelling-stage is adjusted in the usual manner.

The angles are, by means of two micrometer-microscopes, read off a circle of 20 cm diameter divided into $^{1}/_{6}$ degrees; the reading taken being exact within a few seconds. The stage of the spectrometer is made to rotate by itself and to repeat the angular positions previously determined. This is effected by means of the arrangement shown in the figure below *T*, which consists of a clamp acting in a radial and an adjustment-screw acting in a tangential direction.

The determination of the dispersion is not proceeded, as is the case with the usual methods, by a determination of the refractive indices for various lines of the spectrum but is found by differential measurement with the aid of a micrometer arrangement.

This method has over that of direct determination of each individual refractive index the advantage of being not only much simpler and easier to perform but also of being much more accurate in its results under equal conditions. The micrometer arrangement (***M***, Fig. 1) is composed of the screw effecting the fine adjustment of the divided circle and a drum divided in 100 parts fitted with scale, indicating complete revolutions. The angular equivalent of each complete revolution is exactly 10 minutes, therefore that of each division on the drum 0',1 or 6''. The angles read off the micrometer screw are, of course, capable of repetition in the same way as are those read off the divided circle.

For measurements with reflection-gratings the spectrometer may be used without being altered. The coincidence of the incident and diffracted rays enhances, in fact, greatly the accuracy of the readings, in the same sens as in the case of the minimum of deviation in prisms.

In order, however, that the spectrometer may also be used according to the older methods (determination of the refractive index by the method of minimum deviation, measurement of the wave-length by means of gratings in transmitted light), another telescope, shown in the figure at the foot of the spectrometer, is supplied with it. It is connected with the divided circle in an easy manner, which need not be described here; the same applies to the counter-poises supplied with the apparatus.

The whole apparatus, in cabinet fitted with lock and key M. **800.–**

Auxiliary and Accessory Apparatus for the Spectrometer.

No. 2. Illuminating Apparatus mounted on a stand, adjustable in height.

This apparatus collects the rays proceeding from the transverse section of a GEISSLER tube and projects a convergent cone of its light upon the illuminating prism where it forms a real magnified image of the source of light.

Inclusive of a GEISSLER H-tube and stand for same **M. 55.—**

No. 3. Geissler Tubes for longitudinal vision, with Dr. RIEDEL's spiral aluminium electrodes.

Filled with hydrogen or hydrogen and mercury; these give a very pure and intense H-spectrum.

Each **M. 10.—**

No. 4. Glass Prisms for spetrometric examinations, with optically perfect surfaces (refracting angle about 30°).

The price varies according to the size of the prisms and the quality of the glass employed. We are also prepared to supply prisms cut from material sent to us.

No. 5. Hollow Prisms for examining fluids.

A block of black glass (black so as to exclude false reflections) has two good plane surfaces inclined to each other at 30°. In a direction at right angles to one of these surfaces the prism is traversed by a hollow cylinder of about 16 mm diameter. The open ends of the cylinder are closed by plano-parallel polished plates, one of which is silvered at the back; both plates have to be cemented to the prism every time a new experiment is made. The hollow cylinder is filled by means of a canule which may again be closed by means of a ground in stopper or a thermometer. Height of the prisms 40 mm.

M. 35.—

The so-called KUNDT prisms, which are chiefly intended for the examination of fluids lacking in transparency, are also made if specially required. The price of these depend upon the size of the plano-parallel plates.

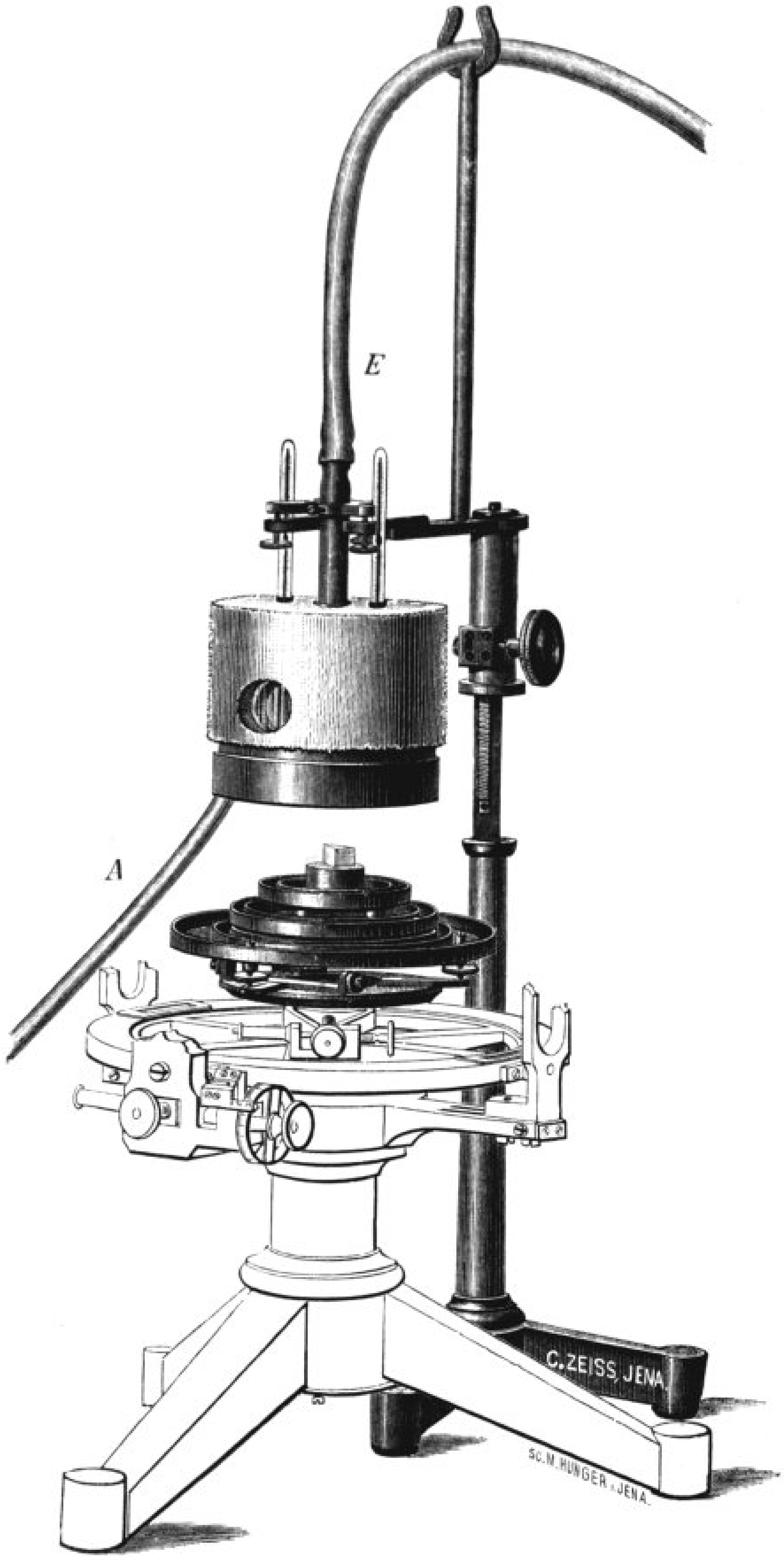

Fig. 3.
Heating Arrangement for the Spectrometer (No. 6).
$^1/_4$ Full Size.

No. 6. Heating Apparatus (Figs. 3 and 4).

By means of this apparatus it is possible to maintain the prism which is to be examined with the ABBE spectrometer at a constant temperature; it thus furnishes also the means of investigating the effect produced by change of temperature upon the refractive power of solid and fluid bodies.

Respecting this latter mode of application of the apparatus (viz. the influence of temperature upon the refractive power of glass) we refer to C. PULFRICH's paper in WIEDEM. Ann. 45, p. 609, 1892.

The apparatus consists mainly of a double walled cylinder the bottom of which is formed by three dishes; this bottom is adjustable and can be placed upon and moved with the spectrometer stage, the latter having previously been cleared of all its fittings, whereas the upper casing is supported externally and remains stationary. Air-tight connection between the upper double jacket and the bottom dishes is made by filling the three annular grooves of the latter with

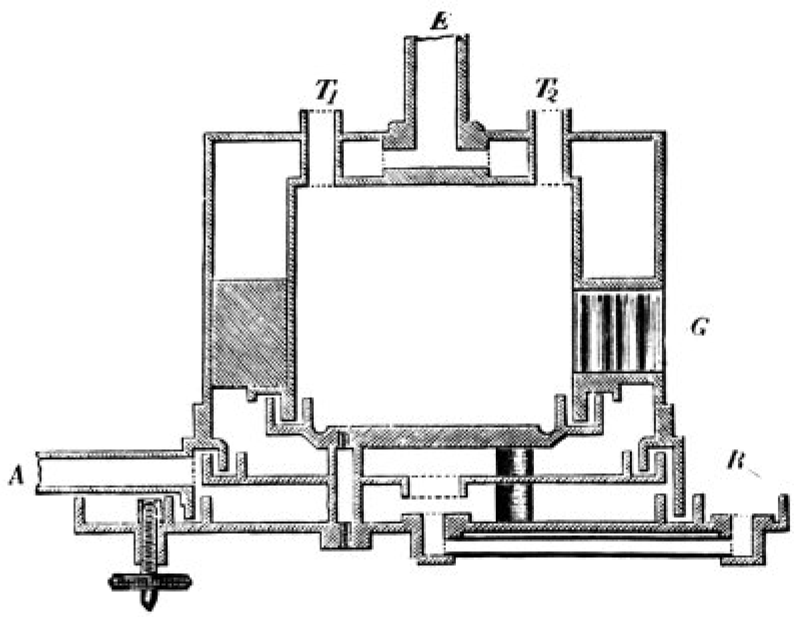

Fig. 4.
Cross Section of the Heating Chamber (No. 6).
½ Full Size.

mercury or oil or other suitable fluid; by this means the free movement of the bottom dishes and the spectrometer stage is in no way impeded. Fig. 3 shows the general arrangement of the apparatus coupled with the spectrometer, fig. 4 is a vertical section of the heating chamber.

Heating is effected by the vapours of liquids with constant boiling points. The vapour enters at E; A is the outlet. The middle bottom dish is perforated; the vapour is thus compelled to surround the inner casing which contains the prism. The condensed fluid collects partly in the lowest dish, which is made to form a reservoir, and partly it is allowed to flow off at *A*. The wide groove *R* is provided to catch any mercury that may accidentally flow over. The passage leading to the vapour jacket is closed by a stopper.

For the purpose of observation the casing is pierced by a tubulure, closed by a plano-parallel plate of glass (*G* in Fig. 4). The whole casing is surrounded by a coating of felt to minimise loss of heat by radiation; the same applies to the lower side of the bottom dish. The tubulures T_1 and T_2 serve for the insertion of two thermometers.

The upper stationary part of the heating chamber is supported by a stand placed near the spectrometer and may be raised or lowered by means of a rack and pinion movement. The prism may be placed either directly upon the upper dish of the bottom casing or upon a separate stage placed upon it. The prism is adjusted together with the dish by means of three adjusting screws.

Price of the heating chamber, incl. stand **M. 125.**—

Two thermometers divided into whole degrees, the one ranging from 0 to 50° C, the other from 50 to 100° C. **M. 4.50**

Abbe Refractometers,

principally for the examination of fluids.

All the instruments Nos. 7 to 11 described herein embody the same principle. The required number is deduced from the observation of the total reflection which a very thin stratum of the fluid under examination placed between prisms of a more highly refracting substance produces in transmitted light (ABBE, "Neue Apparate etc.", Jena 1874). A single drop of any fluid, let it be ever so intransparent in thick layers, is, therefore, sufficient for the examination. The whole process of examination, which may be made with diffuse day-light or lamp-light, consists in a single simple adjustment and subsequent notation, either from a graduated arc (Nos. 7 and 8) or from an ocular scale (Nos. 9, 10 and 11). This reading gives the actual result, no calculation being necessary.

The facility with which these refractometers lend themselves to exact measurements render them suitable for many scientific and practical purposes. Irrespective of the advantages which scientific chemists derive from the speedy and exact determination of refractive and dispersive powers, these instruments are of great utility to pharmaceutical and manufacturing chemists and others engaged in compounding substances; these, by the refractive index, are enabled to distinguish many substances and to ascertain their degree of purity (adulteration of victuals), or to determine the percentage or concentration of many solutions and mixtures.

No. 7. Large Refractometer (Figs. 5a and 5b).

The instrument consists of a double prism of a highly refracting flint-glass fixed to an alhidade, both revolving together about the center of a divided arc. This arc has fixed to it a small telescope, which turns with it on a horizontal pin; the whole is mounted on a heavy brass foot. The telescope supports before its objective a system of two revolving AMICI prisms (compensator for achromatizing the critical line of total reflection), the amount of rotation being indicated by a divided drum. The graduation of the arc directly reads the refractive indices to the third place of decimals. The 4th decimal is estimated with accuracy within 2 units, say, by means of a lens (not shown in the illustration) which is attached to the pointer. The dispersion (C—F) may be found from the reading taken from the divided drum of the compensator with the aid of

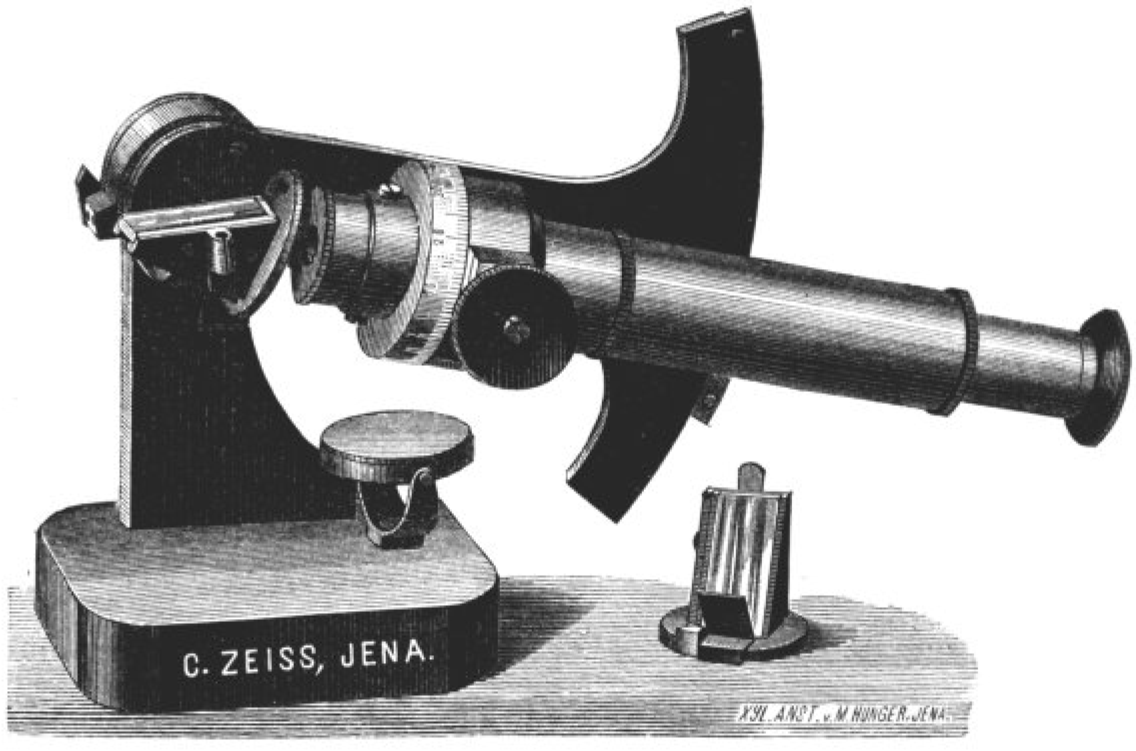

Fig. 5 a.
Large Refractometer (No. 7)
shown in the position in which the drop of liquid is applied.
½ Full Size.

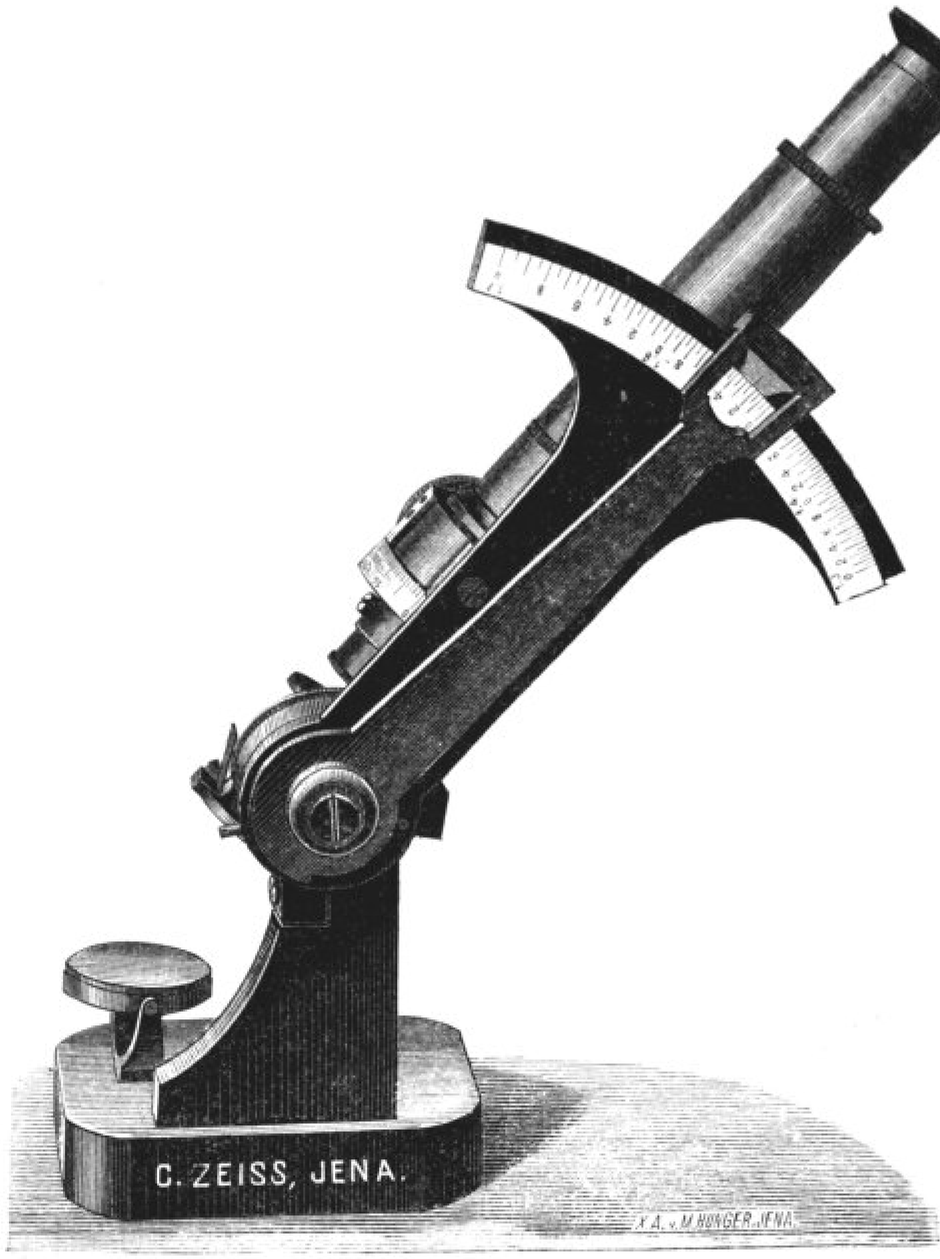

Fig. 5 b.
The same apparatus (No. 7)
shown in the position in which the reading is taken.
$^1/_2$ Full Size.

a table supplied with the refractometer. The refractometer may be used for refractive indices between 1.30 and 1.70.

For the examination of solid bodies having one polished surface by means of reflected (in lieu of transmitted) light, the metal cap should be removed from the small illuminating prism which is cemented to the fixed refractometer prism.

With directions for using, in case with lock **M. 260.—**

No. 8. The same Apparatus with heating arrangement.

The latter (designed by Dr. Wollny) consists, as in the case of No. 11, Fig. 7, of a double walled metal casing, which encompasses the two glass prisms cemented therein and leaving only those surfaces free which are traversed by the line of vision. Water of a constant temperature is made to flow through the casing. The two halves of the casing, which is made to open out, are joined by hinges. This arrangement may be used in conjunction with a reservoir for flowing water, or in conjunction with a thermostat for circulating water. In other respects the general arrangement and manipulation are the same as in the case of No. 7.

With directions for using, in case fitted with lock M. **300.**—

Thermometers, divided in whole degrees, 0—75° C. **M. 2,50**

By dispensing with the compensator and, therefore, with the means of measuring the dispersion, thus rendering the apparatus available for use as a refractometer only, limited to sodium-light, the prices of Nos. 7 and 8 become reduced to **M.** 185.— and 225.— respectively.

No. 9. Percentage-Refractometer, with ocular-scale, for finding the concentration of solutions and liquid mixtures (Fig. 6).

Small hand-telescope with revolving Amici prism for chromatic compensation; with ocular-scale reading refractive indices directly to units of the

Fig. 6.
Percentage-Refractometer (No. 9).
$^1/_3$ Full Size.

vide following page

third decimal, smaller differences being estimated. The scale ranges from 1.30 to 1.40. The two parts of the double prism are held together by a spring clamp.

With directions for using, in case, with lock **M. 105.**—

A second scale in the ocular field (beside the one reading refractive indices) for directly reading the percentage of a certain liquid (sugar solution etc.), extra **M. 5.**—

)* **Nr. 10. Refractometer after Prof. Krümmel** for determining the percentage of salt in sea-water (refracto-salinometer).

The refractometric, as compared with the hydrostatic, salinometer has the advantage of yielding accurate results without being interfered with by the motions of the ship.

An instance of the application of the refractometer for this purpose is given in Dr. G. Schott's account of his voyage, Verhandl. der Ges. f. Erdk., Berlin 1892, Heft 2, 3, 4.

The instrument includes a hand telescope about 30 cm in length fitted with compensation prism. The double prism is held together as in No. 9.

In this instrument distilled water is used as a comparison fluid together with the salt water which is to be examined. The reading is thus nearly unaffected by changes of temperature. For this purpose either of the prism surfaces enclosing the stratum of liquid are longitudinally divided in two halves by a deep incision of some millimeters. A drop of distilled water is placed upon one of these halves, a drop of sea water upon the other half. Thus two liquid strata lying in one plane are formed and there is a narrow interspace separating them. By means of a cap fitted before the double prism either half may be uncovered alternately for observation with transmitted light. The position of the critical line is first read off for pure water and then for sea water; from the difference of the two readings (which is practically independent of the temperature) the percentage of salt is found, exactly within 0.05 %, from a simple table of reduced values which is supplied with each instrument. The position of the scale is adjusted by means of a watch key.

With directions for using, in case M. **200.**—

No. 11. Refractometer for special technical purposes, with heating arrangement and ocular scale (Fig. 7).

In principle these refractometers differ from those previously described only in that in this case the critical line of total reflexion for a certain substance or a certain class of substances is achromatized, not as in the case of the other refractometers by a special compensating arrangement, but by the refractometer prisms themselves (patented) the dispersion coexistent with the total reflection between glass and substance being exactly compensated by the dispersion due to the surface whence the light emerges from the double prism in the direction of the telescope. Accordingly, the critical line appears colourless (achromatized) for the standard substance or

)* *In lieu of the Refractometers No 9 & 10 we are now supplying the Dipping-Refractometer, M. 220.—, with all accessories about – 280.— Descriptive price list will be forwarded free on application.*

standard solution for which the prisms have been calculated; whereas all other substances which differ from the standard substance with respect to refractive and dispersive power cause the critical line to appear more or less blue or red, the latter line being, however, in all cases, sufficiently distinct to admit of its exact position in the scale being ascertained.

Substances are thus distinguished not only by the different positions of the critical line but also by the differences in its appearance. Refractometer prisms of this class are, therefore, preeminently adapted for discerning adulterations and impurities and render, by their power of indicating differences in dispersion, a distinction possible even in such cases where the substances

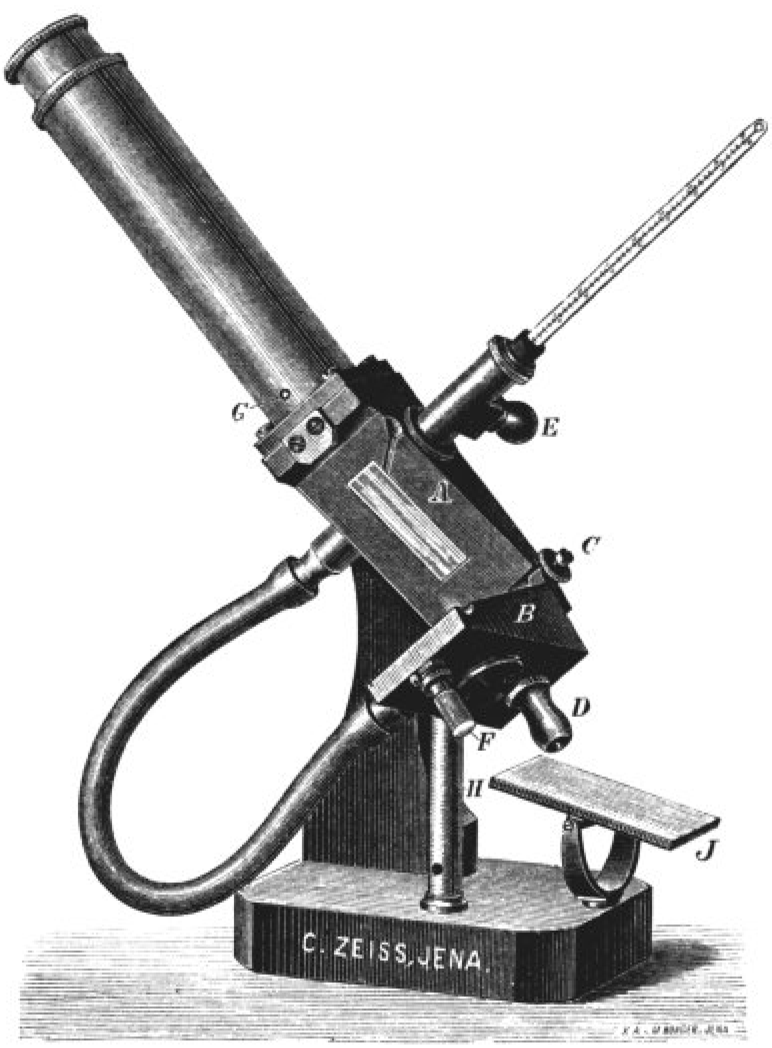

Fig. 7.
Butyro-Refractometer (No. 11).
$^1/_3$ Full Size.

have by refractometric examination proved to possess the same refractive index.

The refractometers constructed on this principle are mounted in a position suitably fixed for convenient observation. Fig. 7 represents a refractometer of this kind, specially adapted for refractometrical analysis of butter (distinction of margarine and natural butter). The prisms are, as in the case of No. 8, mounted in a double walled metal casing; this being passed through by water, the substance enclosed by the two prisms can be kept at a constant low or high temperature. The position of the critical line is ascertained by an ocular scale divided in 100 parts, which reads to $^1/_{10}$ divisions (mean equivalent 7 units of the 5th decimal of n). For adjusting (once for all) the ocular scale the objective may be set by means of a watch-key. The readings of the scale may be either directly compared with one another or they may be transformed in terms of refractive indices by means of a table of reduced values supplied with each instrument.

Self-evidently, any one of these instruments is, beside the immediate purpose which it serves, like any other refractometer, adapted for refractrometric examination of any liquid or liquified substance whose refractive index is within the limits of the scale of the particular instrument. For instance, the butyro-refractometer given above as an example (the scale of wich ranges from 1.42 to 1.49) may also be used for refractometric examination of fats and oils, for determining the percentage of water (within $^1/_3$ $^0/_0$ with accuracy) in concentrated glycerine solutions and for similar purposes.

With detailed directions for using, in case **M. 170.—**

Thermometer, divided in $^1/_2$ ^{0}, from 0^0 to 50^0, extra **M. 2.25**

Nr. 12. Differential Refractometer (Fig. 8).

This apparatus differs in principle from the preceding refractometers. The instrument consists essentially of two fluid prisms having equal refracting angles and placed one behind the other in such a manner that the deviations which they produce are in opposite directions; both prisms will, therefore, produce a deviation if the fluids differ from one another with respect to their refractive powers. The apparatus is fitted with two prisms of this kind so placed one above the other that the deviation produced by the upper double prism is directly opposite to that due to the lower double prism. A distant vertical line

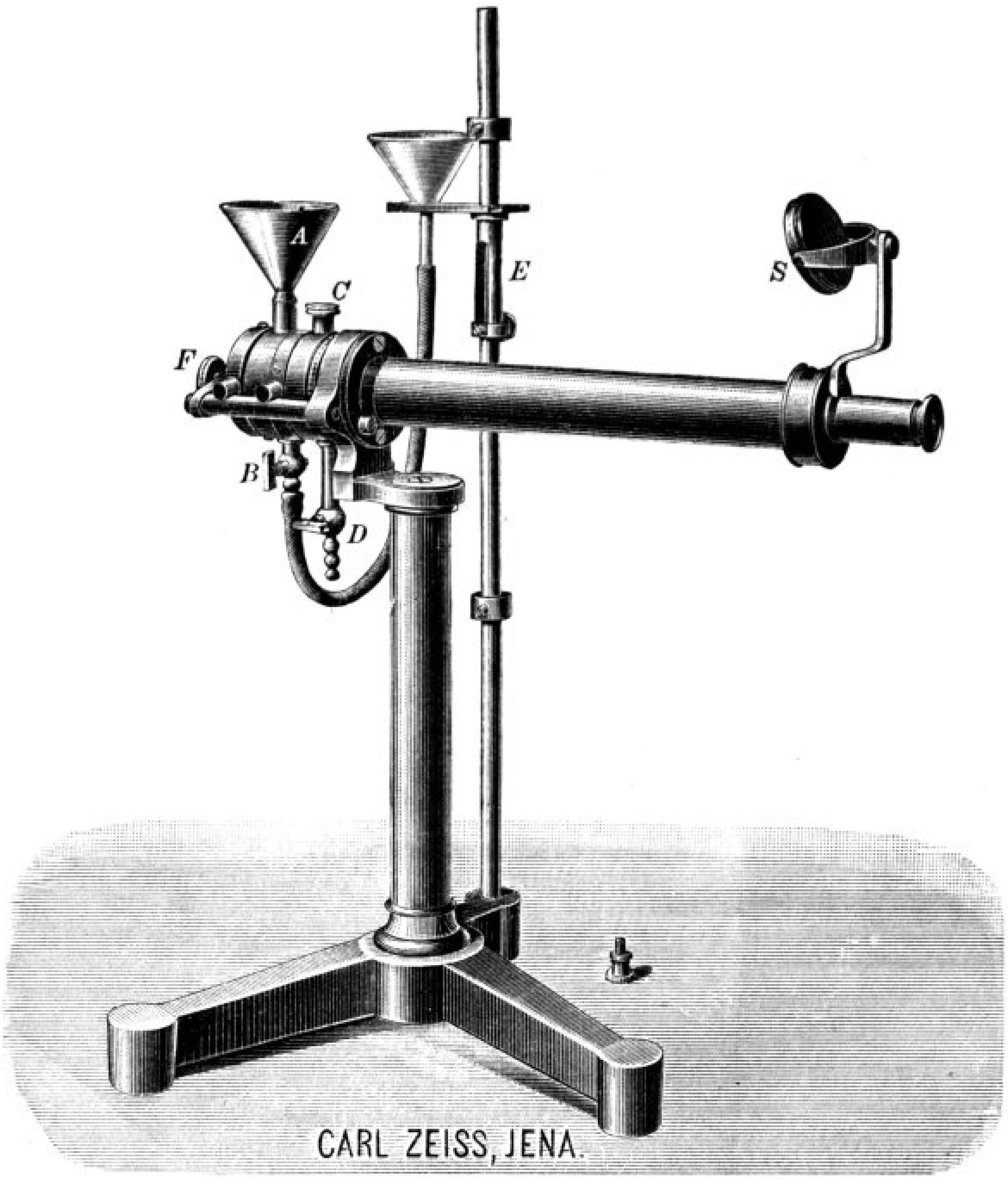

Fig. 8.
Differential Refractometer (No. 12)
$^{1}/_{4}$ Full Size.

(say, a staff) viewed through such a combination of prisms appears as two parallel halves of a staff laterally displaced, the distance between which is the greater the more the fluids differ in their respective refractive powers, both halves being in a straight line only when both liquids have the same refractive index.

The whole combination of prisms is fitted in a metal cylinder which is closed by glass plates and held together by means of the binding screw *F*, Fig. 8; the cylinder is provided with inlet and outlet tubulures. The standard fluid is placed in the two front chambers, which communicate with one another, and is protected against evaporation by a screw stopper (*C*). Similarly, the two back chambers, which form recipients for the fluid to be examined, communicate with one another. Both compartments are filled by means of glass funnels and india rubber tubing, the stopper *C* being replaced by the funnel *A*. The glass funnel is mounted upon the stand *E* and may be moved up or down when it is required to fill or rinse the compartments.

The reading is taken by means of a telescope (autocollimation) by noting the relative positions of the two images of an ocular scale placed in the focus of the telescope objective and illuminated by day-light (mirror *S*), the images being formed by reflection at a plane mirror placed behind the prisms. This apparatus furnishes extremely accurate results, so much so that differences in the refractive indices not exceeding a few units of the 5th decimal may be recognized and estimated with precision. As this method only involves differential measurement, variations in the temperature of the locality have no appreciable influence upon the accuracy of the reading. The apparatus is not subject to any limitation with respect to the height of the refractive index.

In such cases where liquids possessing definitely ascertained and prescribed properties are to be produced in large quantities, the Differential Refractometer will form a suitable gauge which might be permanently appended to the plant (inlet at *B*, outlet through piping screwed in lieu of the funnel *A*).

With directions for using M. **240.**—

Abbe Refractometer

for the examination of crystals.

No. 13. Crystal Refractometer, large instrument (Figs. 9 and 10).

The refractive indices of the substances which are being examined are deduced from the critical angle of total reflection in heavy flint glass with respect to that substance.

A detailed description of and directions for using this instrument will be found in the "Zeitschrift für Instrumenten-Kunde", 1890, p. 246; Neues Jahrbuch für Mineralogie etc. Beilage Band 7, p. 175, 1890.

A hemisphere (*K*, Fig. 10) of flint glass having a refractive index of 1.89 with respect to yellow rays may be rotated together with the azimuth circle *H* (divided in $^1/_1$ degrees) about its vertical axis and can be fixed in any position by means of the clamping screw *U*. The solid body which is under examination is loosely placed upon the plane surface of the hemisphere, optical connection only being established by a drop of a liquid having a higher refractive power than that body. The mirror *Sp* which is attached to an arm so as to be capable of rotation about the horizontal axis *Ff* reflects the light emitted from a (monochromatic) luminant placed in the direction of the axis *Ff* upon the surface in which the crystal touches the hemisphere in such a way that the incident light just grazes the hemisphere or passes through the latter in the direction indicated by its critical angle. The critical curve of total reflection is viewed through the telescope *Oc*-*Ob*, to which is connected the vertical circle *VV*. The position of the latter is read by 2 verniers *NN* fitted with lenses *LL*. The circle has a diameter of 135 mm and reads to 20″. It is fixed by clamping screw *M* and is finely adjusted by a screw fitted with counter spring (shown in Fig. 9). The telescope has three bends. By means of successive reflections at the oblique surfaces of the cemented glass prisms *PP* the rays emerging from *K* are at any position of the telescope made to pass into the horizontal limb *F*-*Oc*. This enables the observer to retain his head in a fixed position. By means of the ring *R* the telescope and the vertical circle may be rotated about their horizontal axis. Ocular *Oc* provided with single crossed lines serves for observation and adjustment.

The objective of the telescope is so constituted as to compensate the refraction of the reflected pencils produced by the spherical surface.

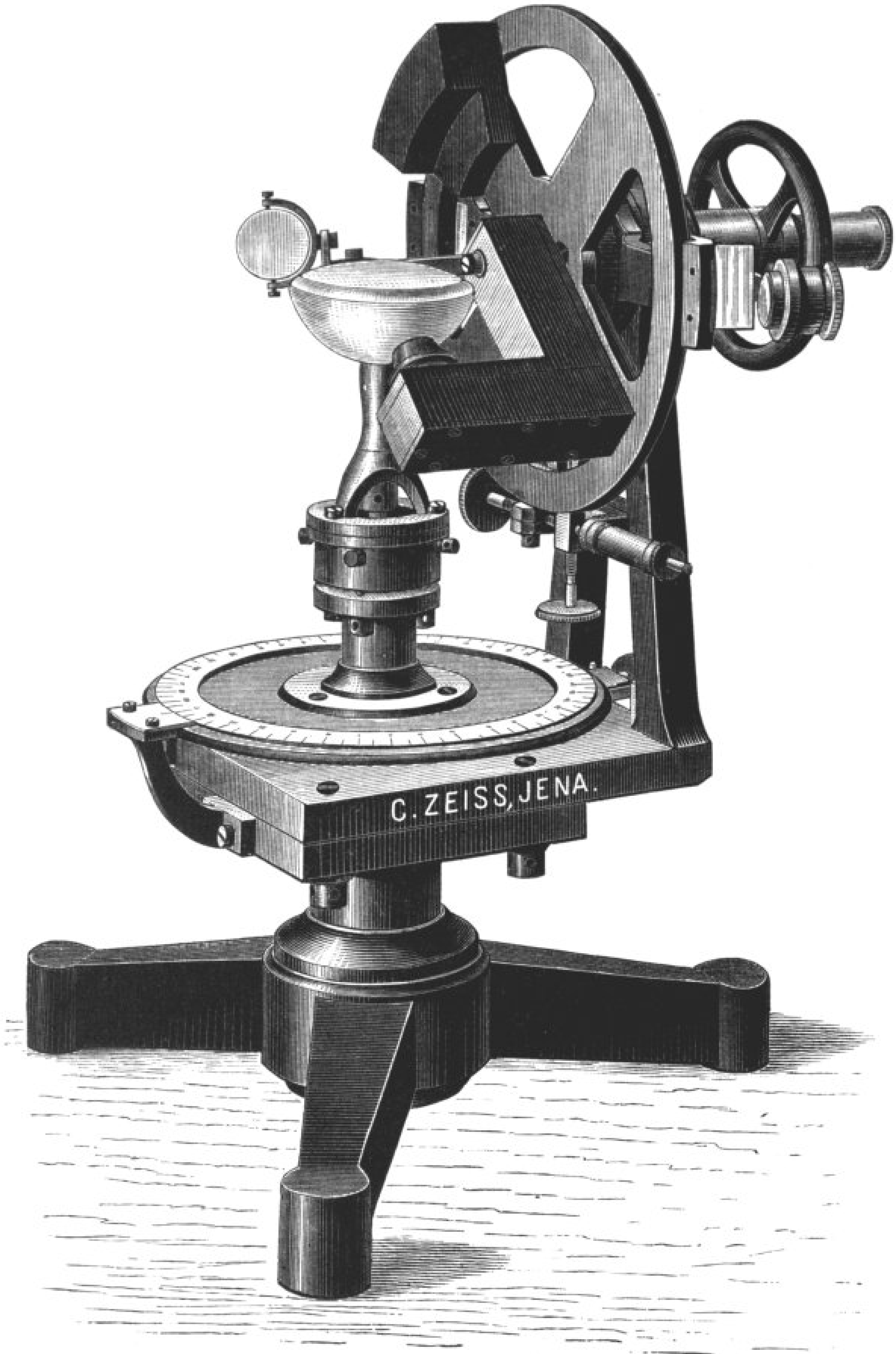

Fig. 9.
Large Crystal Refractometer (No. 13).
$^1/_2$ Full Size.

The critical curves are thus sharply defined. By means of an auxiliary lens it can, for the purpose of adjusting the apparatus, be commuted into an ordinary telescope (adjusted for parallel incident rays).

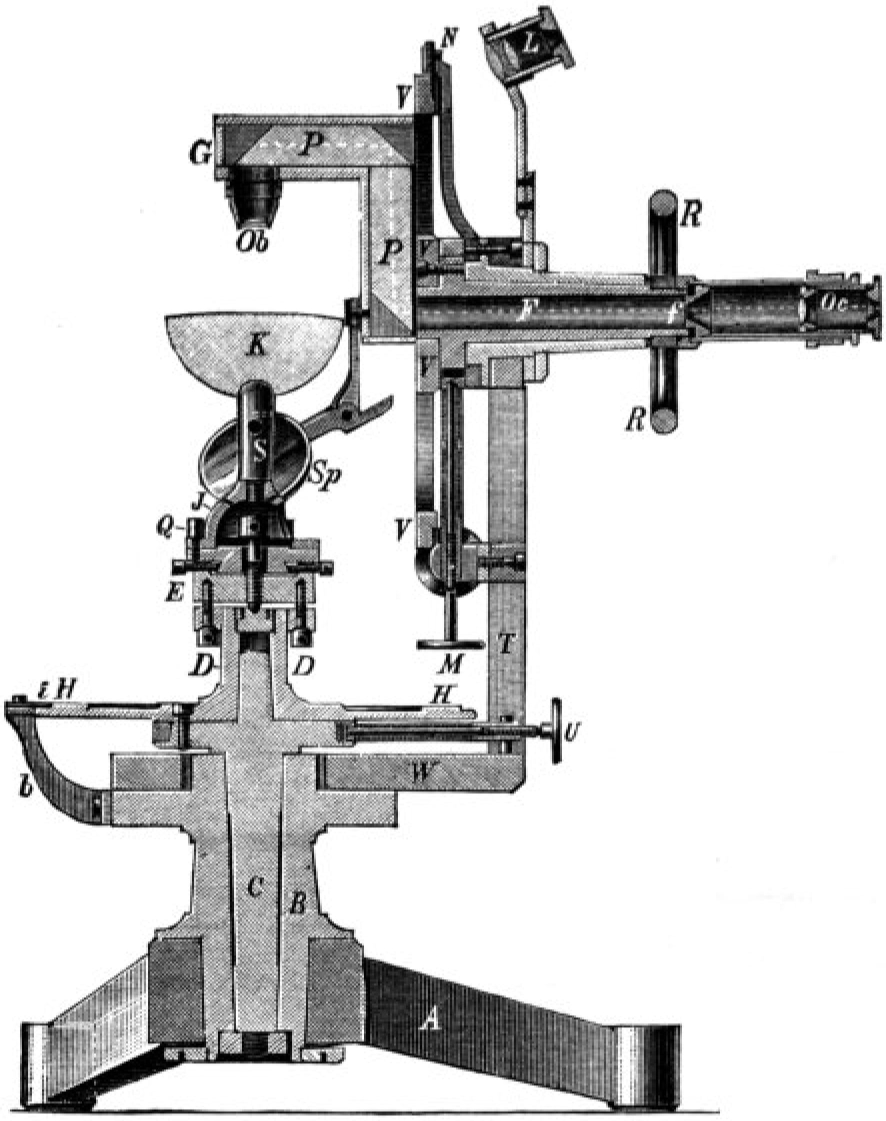

Fig. 10.
Cross Section of the Crystal Refractometer.
$^1/_3$ Full Size.

The hemisphere is, by means of a special fitting *DEQ* adjusted in such a manner as to satisfy the following conditions: 1) the axis of the hemisphere must be at right angles to that of the vertical circle, 2) both axes must intersect, and 3) the center of the hemisphere must be coincident with the axis of the vertical circle.

The vertical circle reads directly the value w of the critical angle of total reflection within the hemisphere with respect to the substance under examination. The refractive index of the latter is, therefore, $n = N . \sin w$, N being the refractive index of the hemisphere. This index is communicated by the maker and may, by total reflection of the hemisphere with respect to air, be verified at any time. A prism of the same glass as the hemisphere is supplied with the apparatus, if desired, for spectrometric verification of the optical constants of the hemisphere.

The apparatus arranged for observation with monochromatic light, in case with lock M. **650.**—

The same apparatus provided with a hemisphere of a lighter flint glass having a refractive index of 1.75 M. **640.**—

Accessory Apparatus for the Refractometer:

An analyser with or without divided circle may be placed upon the ocular (*Oc*) and the ocular itself may be replaced by a spectroscopic ocular or a goniometric ocular. The analyser furnishes the means of investigating the properties of the critical curves with respect to polarization; by means of the spectroscopic ocular readings may be taken with polychromatic illumination and the dispersion may be measured; the goniometric ocular serves for measuring the inclinations of the critical curves of double refracting substances.

Goniometric Ocular, containing a system of parallel lines placed in its focus, with divided circle M. **30.**—

Analyser (PRAZMOWSKI prism), fitting on ocular:

without divided circle M. **20.**—

with divided circle M. **35.**—

Goniometric Ocular and Analyser combined M. **50.**—

Spectroscopic Ocular for the refractometer M. **30.**—

In cases where these accessories are ordered at a later date separately from the refractometer itself it will be necessary to return the latter for the purpose of adapting the accessories.

No. 14. Crystal Refractometer, small instrument.

This instrument does not essentially differ from the larger instrument except in point of size, the dimensions being reduced throughout and its arrangement being simplified in consequence of such reductions while the principle of construction and the manner of using the instrument are the same in both.

The hemisphere made of flint glass having a refractive index of 1.89 with respect to yellow rays has a radius of 20 mm (as compared with 25 mm with the larger instrument).

The hemisphere is rotated about its vertical axis by means of a milled disc divided in $^1/_1$ degrees which is fitted below the centering arrangement and immediately above the standard supporting the telescope.

The vertical circle has a diameter of 80 mm (as compared with 135 mm with the larger instrument). It is divided in $^1/_1$ degrees reading by a vernier to 5′, equivalent to about 2 units of the 3rd decimal of the refractive index. This degree of exactness is sufficient for the great majority of cases in crystallographic determinations. The instrument is, therefore, applicable to all such cases which do not demand the highest degree of attainable exactness.

The telescope which rotates together with the vertical circle is essentially of the same type as that forming part of the larger instrument; it is, in particular, also fitted with an objective corrected with respect to the hemisphere by a plano-concave compensating lens. The triple bent form of the telescope, which somewhat complicates the larger instrument in the interest of more convenient handling (inasmuch as thereby the axis of the ocular coincides with that of the vertical circle and the eye retains a fixed position), is here replaced by a single bent telescope as, owing to the reduced distances, the necessary displacement of the eye does not constitute a serious objection.

This telescope is, as in the case of the larger instrument, made to rotate conaxially with the vertical circle. It may be clamped in any position and may also, in the usual way, be finely adjusted by means of a screw acting upon a pin fitted with counter-spring.

The illumination of the surface of the crystal placed upon the hemisphere is effected, in exactly the same manner as with the larger instrument, by a mirror which as with that instrument admits of rotation about the axis of the vertical circle and telescope independently of these.

The whole is mounted upon a single slightly conical pillar fixed in a disc-shaped foot. The height of the instrment is 25 cm. The instrument is used in precisely the same manner as the larger instrument.

In case with lock **M. 270.—**

All other parts as in No. 13.

Various
Optical Measuring Instruments
and
Apparatus for Demonstration.

Abbe Thickness Micrometer, Comparator and Spherometer.)ˣ

(Figs. 11, 12 and 13.)

The instruments described under Nos. 15, 16 and 17 are intended for measuring distances of a few centimeters with greatest exactness (within 0.001 mm). They are therefore specially adapted for use in physical laboratories. — Detailed description and directions for using will be found in Dr. Pulfrich's paper in the "Zeitschrift für Instrumentenkunde", 1892, p. 307.

All these instruments have been designed with a view to realizing the following two conditions:

1) The measurement to be exclusively based in all cases, both contact and by sight-adjustment, upon a divided standard of length with which the unknown length is directly compared.

2) To so construct the apparatus that the unknown length forms the continuation in a straight line of the divided standard.

The former condition arises from the consideration that divided measures can be made with greater certainty and accuracy than any other measuring appliances, their individual defects may be once for all determined, the laws governing their changes due to oscillations of temperature can be taken into consideration and, finally, such irregular and incontrollable sources of error, which are e. g. inseparable from screws, can practically be eliminated.

The second condition envolves the aim of rendering the comparison of the unknown lengths with the standard independent of the degree of perfection of the

)ˣ For the last few years we supply for each measure fitted to the apparatus described hereafter a Certificate from the "Physical-Techn. Reichsanstalt" for which we only charge the cost-price (from 15 to 30 Marks) mechanism effecting the movement for comparison. By this means it is possible to employ loosely fitting guides for the moving parts. With all other measuring appliances where this condition is not satisfied, the reading envolves an error equal to the product of the distance of the two straight lines and the angle of deviation of the guide block. If that distance be equal to 0, as is the case with the present instruments, the influence of deviation upon the reading is almost completely eliminated, viz. to the approximation of small quantities of the second order.

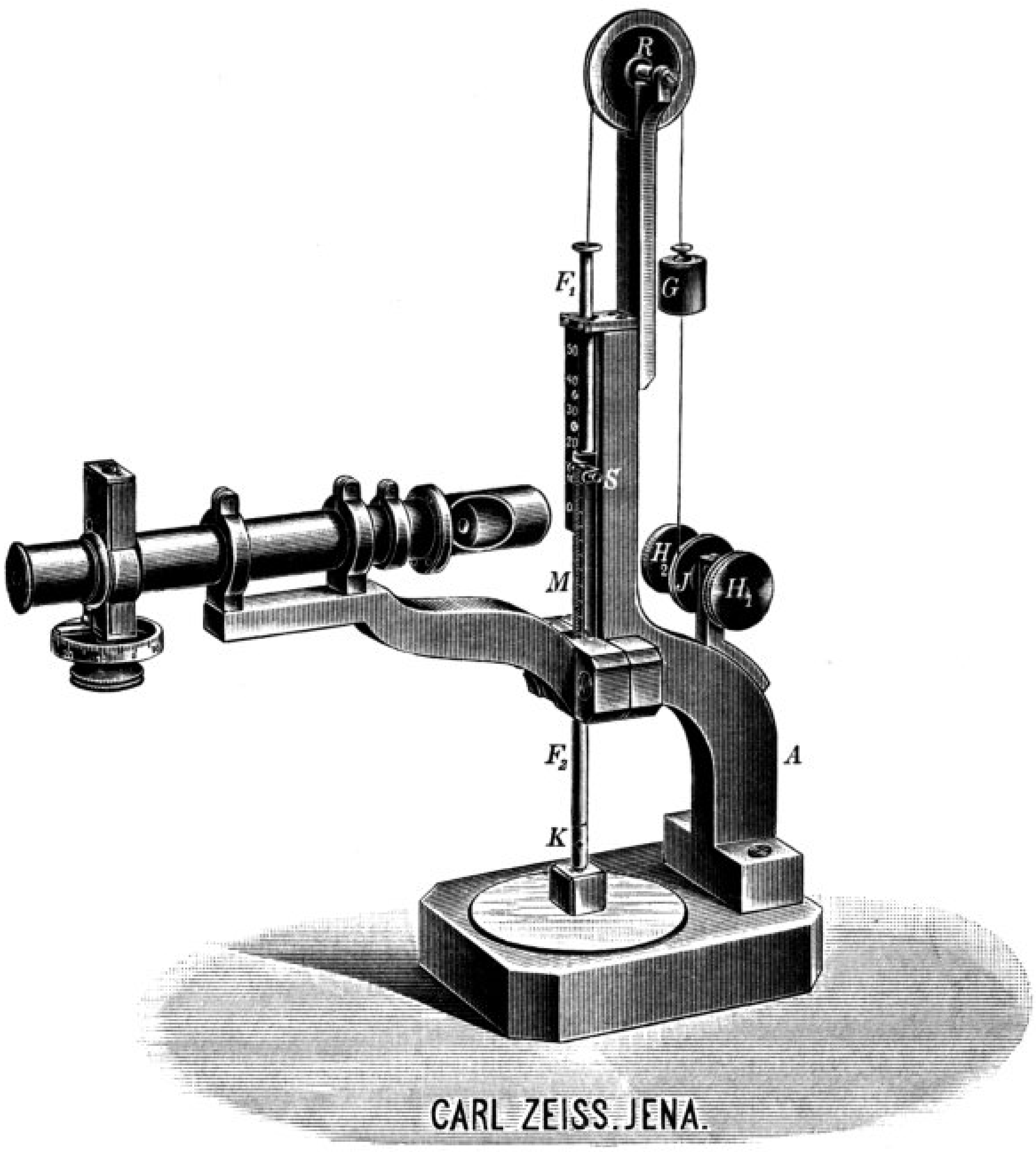

Fig. 11.
Thickness Micrometer (No. 15)
$^1/_8$ Full Size.

No. 15.[a] **Contact Micrometer,** a thickness micrometer, measuring up to 50 mm, for bodies possessing solid boundaries suitable for fixing the point of contact (Fig. 11).

Divided silver lamina (*M*), suspended between two pointed pins (*S*) forming the rectilinear continuation of the contact pin (*K*), the lower extremity of the guide-bar (F_2). The contact pin (*K*) is fitted with a spherically bevelled agate tip. The guide-bar is raised and lowered, as will easily be seen from the illustration, by means of a combination of a cord, pully (*R*), counter-weight (*G*), guide pully (*J*) and the two milled heads (H_1, H_2). The contact tip rests always with uniform pressure upon the object or the base disc. The latter is a plane polished glass disc 7 cm in diameter and 1 cm thick let into the sole plate and resting upon three metal heads.

The scale is divided in $^1/_5$ mm, each integer being figured. The subdivisions of the $^1/_5$ mm are read off by a stationary micrometric microscope which is so adjusted as to indicate each division of the scale by two complete turns of the drum; the latter being divided in 100 parts, each division indicates 1 μ.

In case, with lock — M. **280.**—

№ 15[b] Large Thickness Micrometer, measuring up to 100 mm — M. 450.—

№ 15[c] " " " with measure of 100 mm length, together with the reading microscope this apparatus may be shifted by 100 mm on a threeedged guide-prism provided with a mm scale; Measuring up to 200 mm; about M. 600.—

No. 16.[a] **Small Comparator,** for visual adjustment, measuring up to 100 mm for measuring divided scales, gratings, spectra, sidero-photograms etc., or, in general, for ascertaining the dimensions of such objects the boundaries of which can be focussed by means of a microscope (Fig. 12).

Short firm tripod surmounted by a bed fitted with slide plate (*AA*). Microscope I for observing the standard measure (*M*), microscope II for observing the object. The slide plate is displaced by hand and also by means of the adjusting screw (S_1). A second plate fitted so as to slide upon the main slide plate *AA*, the object slide (*B*), moves with the main slide but can also be moved independently by means of the adjusting screw S_2. Illumination: reflected light by means of the reflectors of the microscopes, transmitted light by means of the mirror underneath the slide plate (*B*). The comparator is fitted with adjusting appliances in such a manner as to enable the observer to adjust the parts of the apparatus himself with the greatest ease. Division of the standard scale as in No. 15.

In case, with lock — M. ~~400.~~— 450.—

№ 16[b] Large Comparator with inclinable object-plate, measure of 200 mm length, & reading microscope of 50 diameters. Without objective & eyepiece of the object microscope — about M. 1050.—

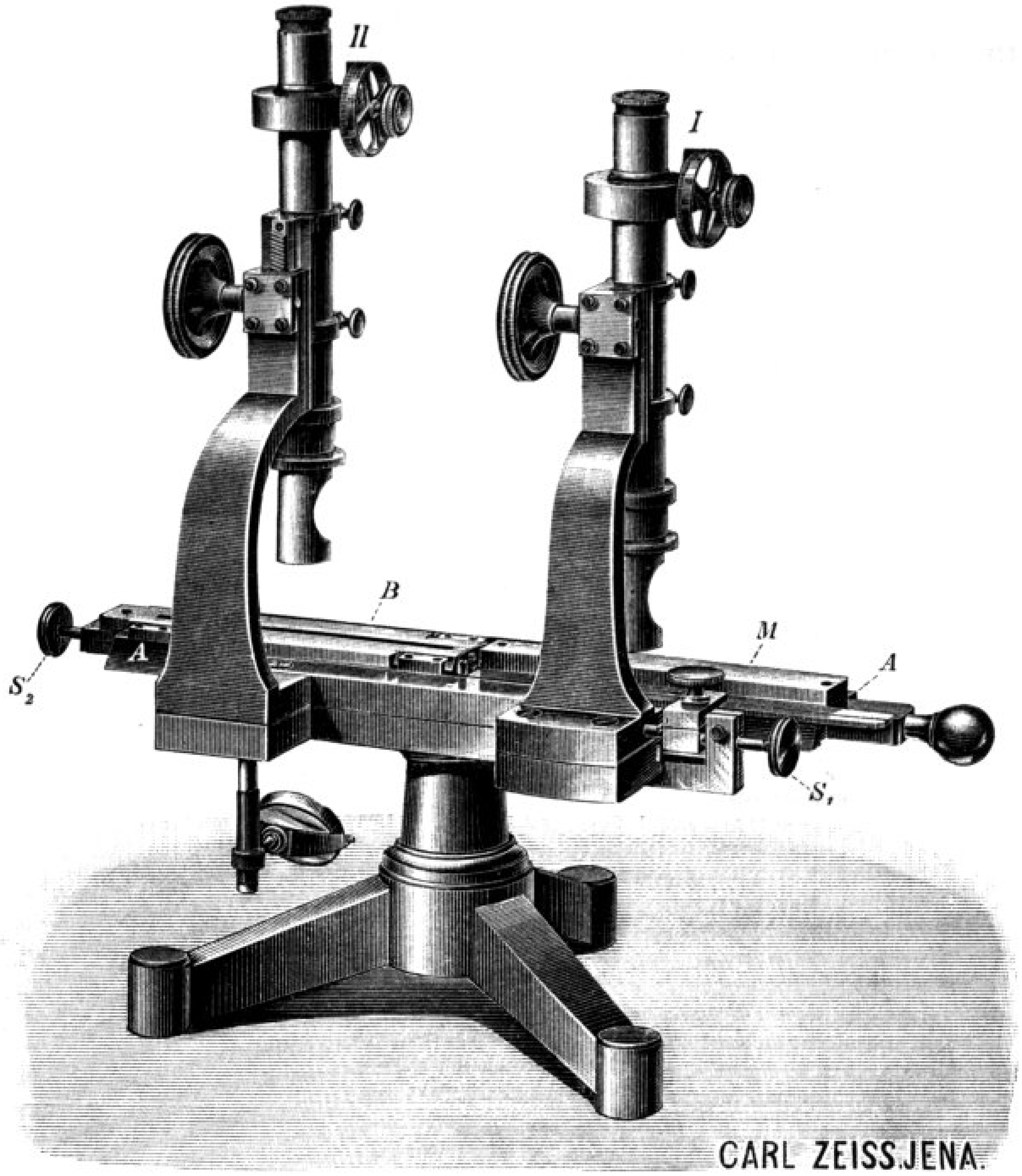

Fig. 12.
Comparator (No. 16).
$^1/_3$ Full Size.

No. 17. Spherometer, for determining the radii of curvature of spherical surfaces (Fig. 13).

The mathematical principle of this instrument is the same as that of all other spherometers: The instrument measures the height h of a spherical segment, the radius r of the circular base of which is known, and hence the required radius R of the sphere is found by the formula

$$R = \frac{r^2}{2h} + \frac{h}{2}$$

Detachable rings of hard gun metal (upon which the spherical surfaces are to be placed) with carefully ground edges. The innermost of the two circles, which are 0.5 mm apart and whose diameters are measured by the comparator, is intended for taking convex, the outer circle for taking concave lenses. This device reduces considerably the risk of injury as compared with a single sharp edge. Owing to the ring being loosely placed upon face plate *P* which is supported by stout standards the danger of twisting or bending the rings, which with rings or parts of rings held down by screws is scarcely avoidable, is entirely obviated.

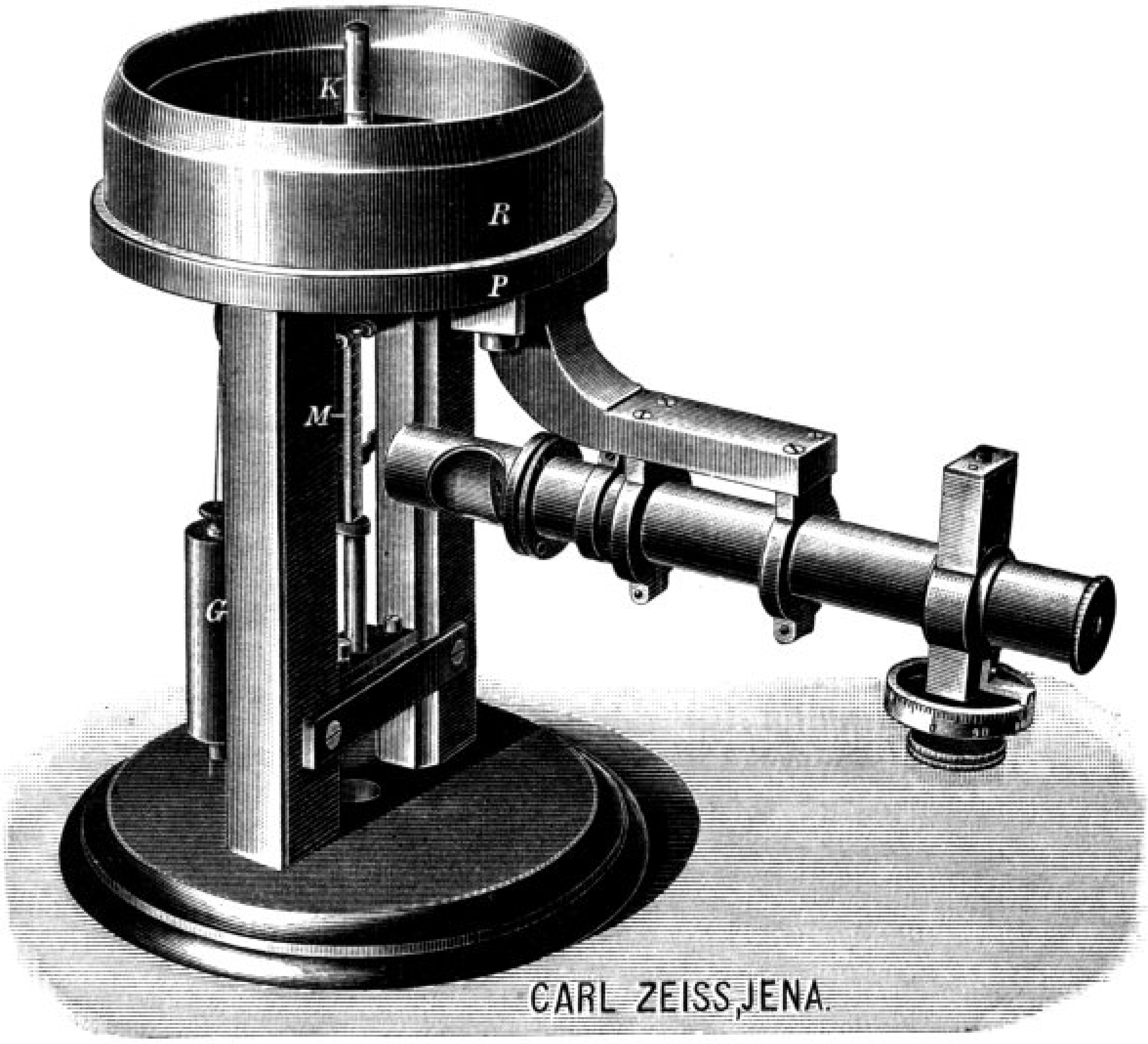

Fig. 13.
Spherometer (No. 17).
½ Full Size.

The other parts of the spherometer are copied from the thickness micrometer (No. 15). The contact pin (*K*) is caused to abut from below upon the spherical surface with uniform pressure just sufficiently great to ensure contact. Divisions and micrometric reading appliances as with the two other instruments.

The apparatus is supplied with two rings. In ordering, selections should be made from the following diameters: 100, 80, 65, 50, 40 and 30 mm.

In case fitted with lock	M. **290.**—
Each separate ring beyond the two supplied with the instrument	M. **10.**—

No. 18. Apparatus for measuring the focal lengths of systems of lenses (Focometer) (Figs. 14 and 15).

The construction of this instrument is based upon the method of determining the focal length of a system of lenses and the position of its cardinal points from the magnifications of the images of two objects of given distances, in this case divided glass rules. By this method the required magnifications are found entirely independently of the position of images; only the distance of bodily objects, which admit of certain measurement, supply the necessary data. The linear magnitude of the image of such an object (glass scale) is, however, determined by a method which 1) admits of deducing from the ratio of magnitude of image and object obtained with finite (greatest possible) dimensions of either the fundamental value of the magnification, i. e. the ultimate value of this ratio for infinitely small dimensions, and which 2) renders it possible to determine the ratio of the magnifications independently of the uncertainty inseparable from the determination of the position of an image.

In its present form as described in the following lines the apparatus is adapted for the determination of the constants of positive and negative systems of about 50 mm focus and upwards, provided the dimensions do not exceed 100 mm in diameter and 50 mm in thickness (or height).

With achromatic lenses with focal lengths exceeding 100 mm the focus can easily be measured correctly within 0.1 % and the distances of the principal points are correctly measurable within 0.1 mm.

A detailed description of the method and the instrument and directions for its use have been published by Dr. Czapski in the Zeitschrift für Instrumentenkunde, 1892, p. 185.

The apparatus consists essentially of a microscope stand of large size with draw-tube having upon its stage a movable slide *W*. This slide is roughly adjusted by hand, the fine adjustment is effected by a micrometer screw. The amount of the displacement may be found by means of a micrometer scale *s* reading by vernier *N* to about 0.02 mm.

Beneath the stage a glass scale *T* divided in $^1/_2$ millimeters is fixed at a distance of about 100 mm. Another smaller glass scale divided in $^1/_{10}$ millimeters may by means of the small lever *H* be passed into the axis of the microscope and temporarily fixed by a projecting tooth in a level with the upper surface of the slide *W*.

The system of lenses which is to be measured is placed upon the slide *W* approximately in the axis of the microscope. An objective of suitable focus is attached to the centering nose-piece *Z* of the microscope tube and the microscope is first made to focus the image formed by the system of lenses of scale *T* and then (after changing the objective) it is adjusted so as to have the image of the upper scale *t* in focus. After each adjustment a reading is taken of the displacement of the slide *W* which is necessary to cause certain lines (symmetrically disposed with respect to the axis) of either scale to be successively superposed by the cross line of the ocular.

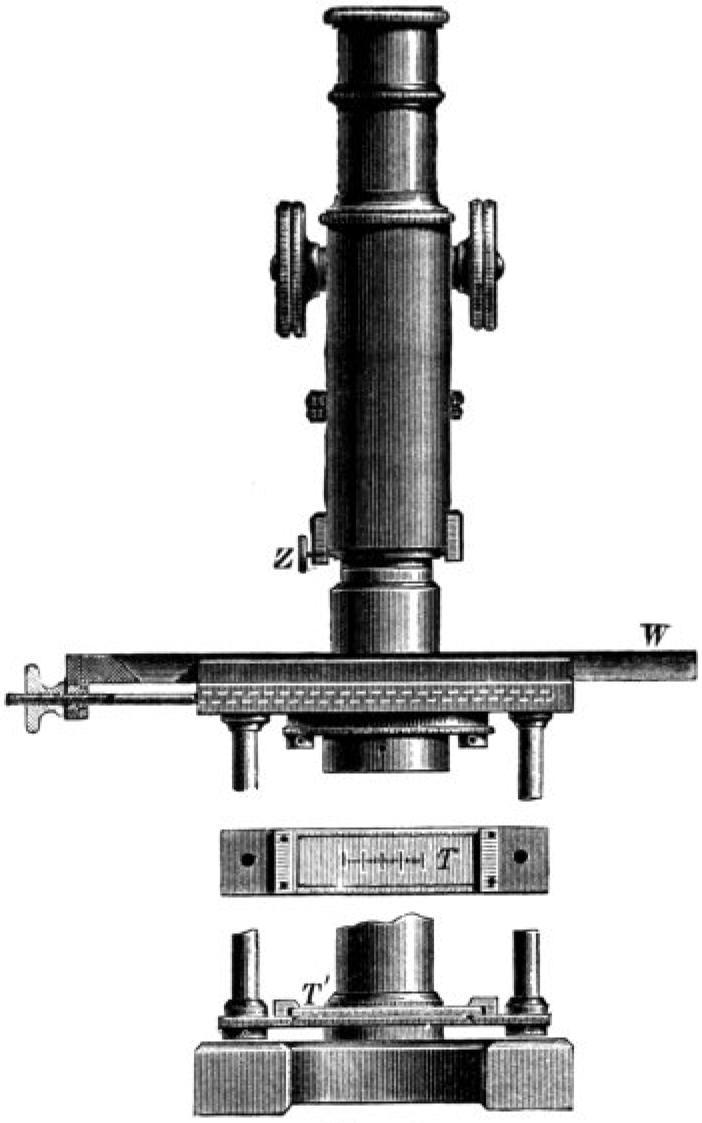

Fig. 14.

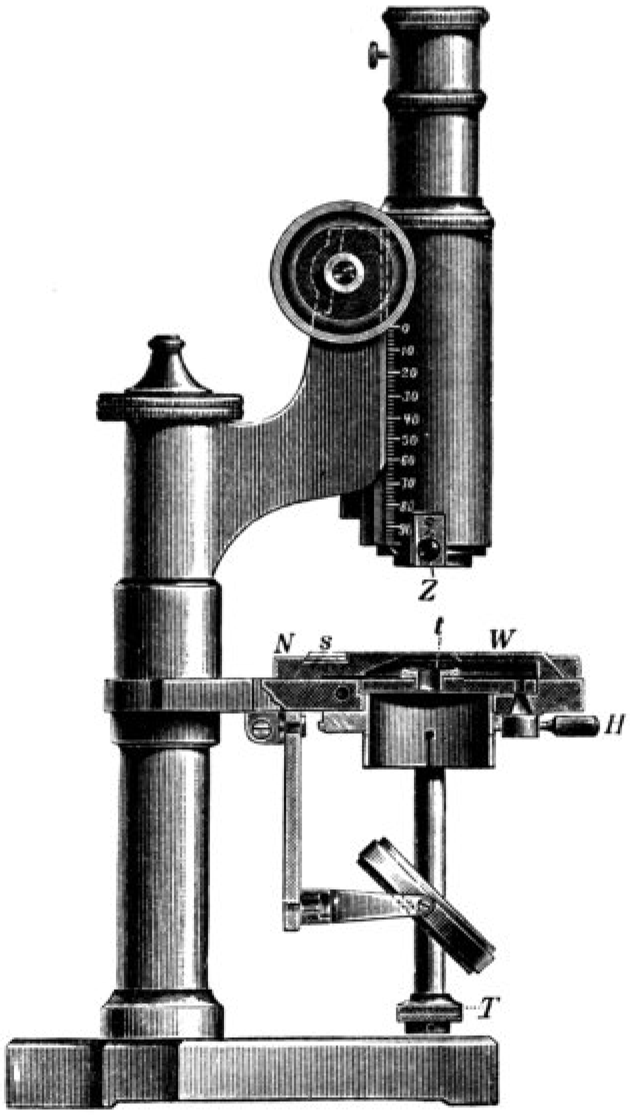

Fig. 15.

Focometer (No. 18).
$^{1}/_{3}$ Full Size.

The amount of the necessary displacement for two or more divisions read off scales *T* or *t* furnishes the data for finding the ultimate value of the linear magnification of the image, formed by the system of lenses, of infinitely small objects taking the place of the corresponding scale. The data thus obtained are free from errors due to inexact focussing of the image viewed by the microscope. The measurement of the distance between scales *T* and *t* from the upper surface of the slide completes the data required for the calculation of the focal length of the system as well as the distances of the principal points from the slide *W*.

The apparatus includes: 5 objectives of suitable focal lengths, a micrometer ocular fitted with interchangeable double cross lines and micrometer scale (10 mm divided in 0.1) and a gauge for measuring the distances of the two scales and of the two apices of the lenses from the slide *W*, divided up to 100 mm, reading by vernier to 0.1 mm.

The whole apparatus, in case fitted with lock M. **380.**—

As this instrument possesses all the essential features of a large-sized microscope stand, it may with the addition of higher powers be used as a microscope proper, especially for physical research, in particular for determination of foci of microscope objectives, oculars etc. according to usual methods.

If the instrument be intended for use in this manner beyond its original limited purpose, it is advisable to add to it a condenser and iris-diaphragm (price M. 40.—) which fits into a sleeve fixed to the under side of the stage.

No. 19. Abbe Dilatometer, for determining after the manner of Fizeau the coefficients of expansion of solid bodies.

(The general arrangement of the dilatometer is shown in Fig. 16 on the following page. Fig. 18, p. 33 illustrates the path of the rays. Fig. 17, pag. 32 represents Fizeau's adjustable tripod stage).

This dilatometer was constructed by Prof. Abbe in 1884 and was first described by G. Weidmann in a paper contributed to Wiedemann's Annalen 38, p. 453, 1889, which also contains a few notes concerning measurements of the expansion of glasses made with the apparatus. During the last two years the apparatus has been utilized by Dr. Pulfrich in numerous determinations of the coefficients of expansion of glasses made in the Jena Glass Works. The results of these measurements have partly been published (Dr. Schott, "Ueber die Ausdehnung von Gläsern und über Verbundglas", Berlin 1892, and Pulfrich, "Lichtbrechung des Glases", Wiedemann's Annalen 45, p. 659, 1892). The experiences gathered from these researches have given us abundant opportunity of carefully testing the arrangement of the apparatus and to remove any deficiencies which became noticeable during usage. The new apparatus now fitted up in our laboratory is calculated in its present form, as compared with the temporary instrument which preceded it to satisfy the most advanced exigencies as regards ease and precision in taking the readings.

A detailed description of the dilatometer and its mode of manipulation will shortly be published in the Zeitschrift für Instrumentenkunde.

Abbe's dilatometer differs considerably from the original arrangement of Fizeau [1]) in several important respects. The modifications to which Abbe has

1) which has been introduced in a slightly modified form in the bureau international des poids et mesures by the investigations of Benoit "Etudes sur l'appareil de Fizeau pour la mesure des dilatutions", Travaux et mémoires etc. I. 1881, and "Nouvelles études etc." ibid, VI. 1888.

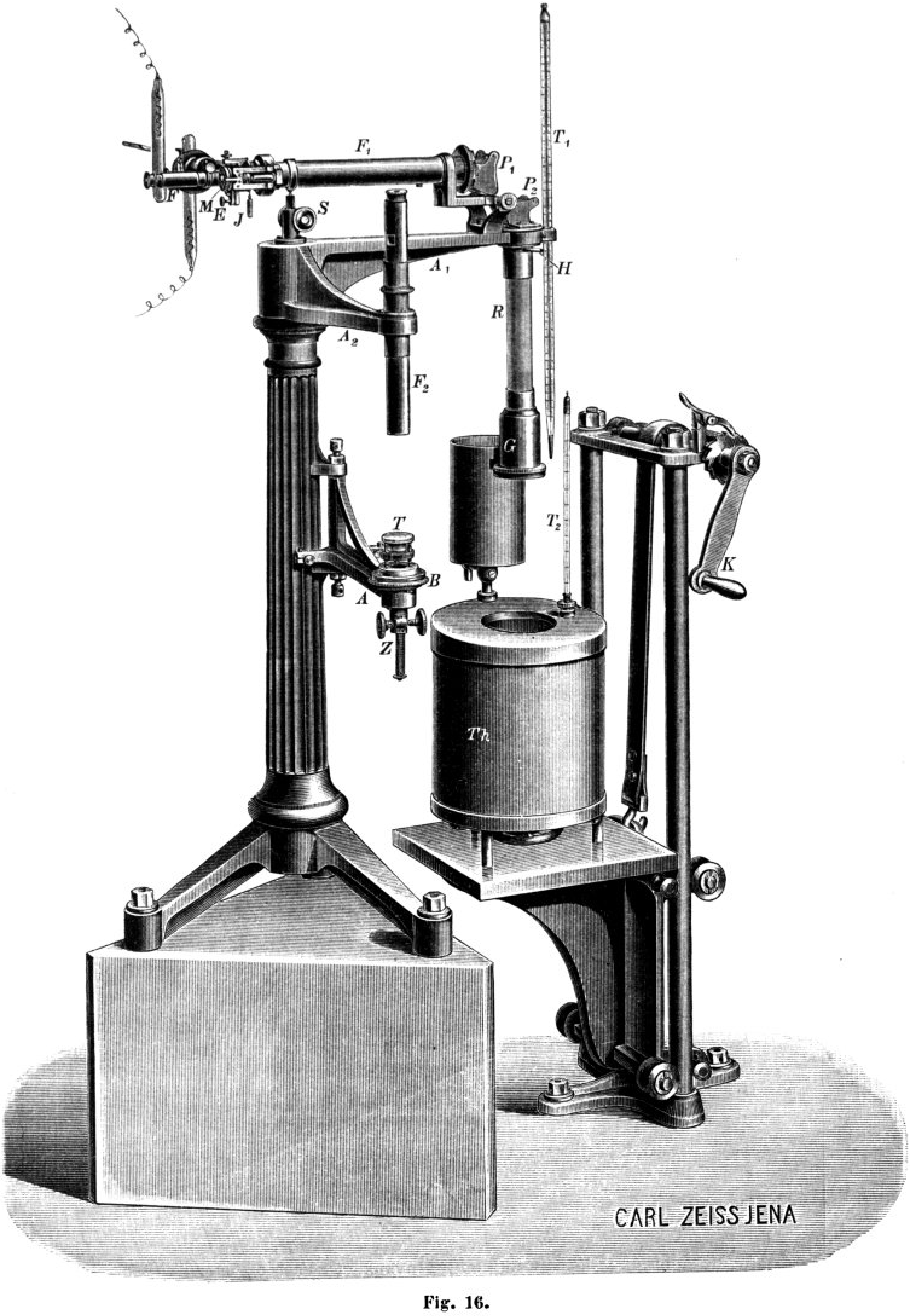

Fig. 16.
Dilatometer (No. 19).
$^1/_7$ Full Size.

subjected FIZEAU's apparatus tend to essentially simplify and quicken the process of observation but also to enhance the delicacy of the measurements.

These improvements envolve:

1) the simultaneous employment of monochromatic light of two or more wave lengths in observing the positions of the systems of striae corresponding to each of these wave lengths, and

2) the determination by micrometric measurement of the displacement of the striae produced by a certain difference of temperature.

In the first place the illumination is not, as in the case of FIZEAU and BENOIT, effected by monochromatic flames (sodium light) but by the projection of spectroscopically decomposed light upon the interference apparatus. This arrangement has the advantage of admitting of the employment of luminants, such as GEISSLER tubes, which in themselves are not monochromatic but possess a greater intensity. The most important feature, however, is that light waves of differing lengths are simultaneously brought into operation. This renders it possible to deduce by calculation the entire multiples of the displaced striae from successive observations made with two different colours and from the ratio of the wave lengths of the rays employed. Changes which occur in widely separated intervals may thus be completely determined by solely observing the initial and final position of the striae, continuous observation of the changes for ascertaining the number of displaced striae being entirely dispensed with.

Furthermore, ABBE fixes the position of the striae, unlike FIZEAU and BENOIT, who estimated the relative position of the striae with respect to a number of fixed points, by means of micrometric measurement, which has the advantage of being both more methodical and practical. In order to obtain sufficiently exact results, FIZEAU determined the relative position of the striae not only with respect to one but 10, BENOIT as many as 25 to 30 regularly arranged fixed points. This method is both very inconvenient and coupled with many disadvantages. ABBE's dilatometer has only one such marking point, viz. a small circular disc of silver with sharp edge and about $^3/_4$ mm in diameter. For micrometric measurement it is essential that the striae be as rectilinear and equidistant as possible, which is easily obtained by providing the object plate with an approximately plane surface.

The interference apparatus proper, FIZEAU's tripod stage, is shown full size in fig. 17. It consists of the following parts: T is a steel disc which is well annealed, i. e. free from internal strains, fitted with three setting screws of equal length treated in the same manner and made from three successive pieces cut from the same steel rod so as to ensure greatest possible uniformity of expansion; *O* represents the object which is to be examined and *P* the glass plate cover provided with plane slightly inclined surfaces; to the lower of these surfaces is attached the above mentioned silver disc (*m*). The glass plate cover is placed upon the points of the three screws while the object plate *O*, which has approximately plano-parallel surfaces, is made to rest upon three points projecting from the steel tripod stage (*T*). The stratum of air separating the object and glass cover is regulated by means of the three screws [1]). To prevent the three screws from working loose, they can be fixed by three small set screws sunk into the stage *T*; by means of these the position of the screws may be fixed without straining. — In order that this same tripod stage may also be used for absolute measurements (longitudinal expansion of the screws), the underside of the steel plate is ground and polished perfectly plane.

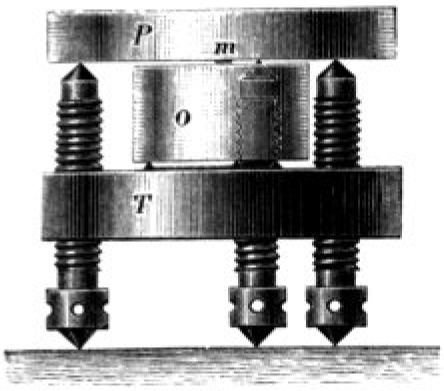

Fig. 17.
Interference Apparatus.
Full Size.

The arrangement of the optical apparatus is as follows: In the anterior focus of the objective *O* (Figs. 16 and 18) of a telescope F_1 fixed in a horizontal position is placed a totally reflecting prism (*p*) which is illuminated from the side by a source of light (GEISSLER tube filled with H and Hg, vid. No. 3 of this catalogue) by means of an illuminating lens *L*, all these parts being rigidly connected with the telescope. The rays meeting the prism *p* form a 4 times magnified image of the luminous section of the GEISSLER tube and have an angular aperture which corresponds to the size of the objective *O*, the latter being thus completely filled with rays. The parallel pencil of rays emerging from the objective passes through two flint glass prisms P_1 and P_2 with horizontal refracting edges, the angles of which have been computed so as to make the total deviation of the rays of medium refrangibility equal to 90°. By raising and lowering the telescope by means of the screw *S*, the homogeneous pencils of rays of different colours are successively made to emerge from prism P_2 in a vertical direction. The axis of rotation of the telescope coincides with the line of intersection of the two prism

1) Fig. 17 represents, through an error of the engraver, the threads of the three setting screws far too coarse. The pitch of the thread is in reality only 0.2 mm.

surfaces facing each other. Thus the system of prisms adjusted so as to produce minimum deviation with respect to a particular colour, will also in any other position of the telescope produce minimum deviation with respect to that pencil of coloured rays.

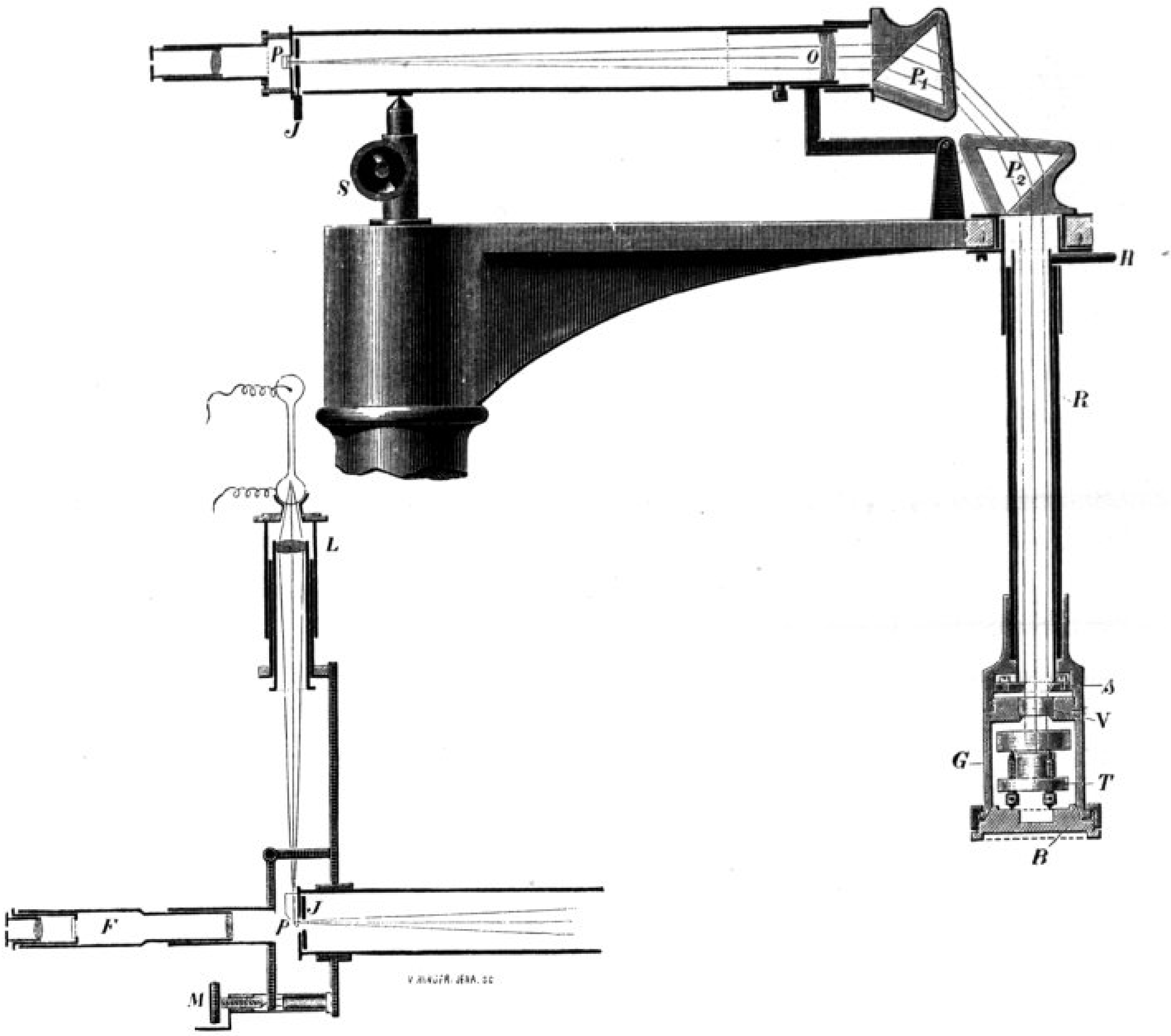

Fig. 18.
Path of Rays in the Dilatometer.

That pencil with respect to which the apparatus has been adjusted, enters vertically into the porcelain tube (*R*). This porcelain tube terminates in a brass casing (*G*) into which is placed the FIZEAU tripod stage. The rays pass through the opening of a metal slide (*s*) which is intended to prevent loss of heat due to continous radiation upwards and is only opened while the readings are being taken. Thence the pencil proceeds through a slightly cuniform plate of glass (*V*) placed in the upper part of the casing and provided with plane surfaces inclined to each other at 20′. The position of the refracting edge is marked by a line drawn parallel to it upon the glass. The plate is mounted in such a way that this line is placed at the right hand side of the observer and also so as to exclude displacement of the plate during transport. The deviation of the pencils of rays produced by plate *V* is compensated by the glass cover plate ***P*** of the Fizeau stage, which also has its plane surfaces inclined at 20′ to each other, provided that in adjusting the interference apparatus care be taken that the refracting edge of the glass cover plate (***P***) whose direction is also indicated by a line drawn parallel to it, is placed at the left hand side of the observer, the expressions "right" and "left" referring to the position of the observer.

The rays being reflected normally by the lower surface of the cover plate and the upper surface of the object return by the same path into the telescope and form in the focal plane of the telescope objective two partly superposed images of the aperture illuminated by the prism ***p***. In order that the aperture may be accurately focussed, the objective *O* is made to move in the direction of the axis. By slightly turning the prism P_1 (or P_2) these two images, which are viewed by an ocular at the back of ***P***, may be projected into the free aperture immediately beside the prism ***p***. As soon as the mages have been placed in their correct relative position, the striae of interference become already visible to the naked eye.

An iris diaphragm ***J*** is placed immediately behind the prism ***p***. The center of this iris diaphragm is made to exactly coincide with the edge of the prism and the optical axis of the telescope. In finding and adjusting the images due to reflection, the iris diaphragm should be fully opened. In this case also the image due to reflection by the upper surface of the cover plate becomes visible. The reduction of the aperture of the iris diaphragm — which may be adjusted by means of an external scale — not only causes that reflected image and all other extraneous light to be cut off by the diaphragm but also allows of all rays which are incident upon the prism only those to be transmitted which emanate from points lying in the proximity of the axis; the distinction of the interferential striae produced by thick plates renders this limitation necessary.

The curvatures of the objective lens *O* have been chosen in such a manner as to avoid indistinctness arising from reflections at the anterior and posterior surfaces of *O*. The first, concave, surface having a radius of curvature equal to the focus, produces an image which by placing the objective slightly oblique, is projected behind the prism *p* or the iris diaphragm. The image due to the second surface lies immediately before the objective and, owing to the great divergence of the rays, produces only the effect of slightly enhancing the general brightness of the field.

The interference apparatus is adjusted by means of a special adjusting telescope fitted with slit and reflecting prism (F_2, Fig. 16), which is supported by bracket A_2 fixed to the main standard. The FIZEAU stage placed upon the foot plate B rests in this case upon three setting screws with rounded points screwed into a plate supported by bracket A and is by means of these brought into its vertical position with respect to the axis of the telescope. In order to adjust the tripod stage it is sufficient to notice the position of the images, due to reflection, of the slit illuminated with white light. The adjustment being completed, bracket A, which is made to swing on a vertical axis and is fitted with stops, is swung out so as to bring the tripod stage under tube R. The tripod stage may then by rack and pinion movement Z be raised into tube R and plate B connected with the casing G by a screw union, the conical shoulder of B being firmly screwed into its conical seat in G.

The following directions may serve for the adjustment of the interference apparatus with the aid of the adjusting telescope: Let the thickness of the stratum of air be less than 0.1 mm and let also the three images, produced by reflection, of the ocular slit be visible in the ocular field of the adjusting telescope, the slit being parallel to bracket A and receiving its light from the left (or right). Let also the glass cover plate be so placed that the line drawn upon it appears on the right hand side of the observer standing before the adjusting telescope and let this line be nearly parallel to bracket A. Then the first requirement is that also the refracting edge of the air wedge shall be parallel to bracket A, in order that the striae may be vertical in the field of the reading telescope proper. To avoid errors respecting the direction of the displacement of the striae, it is a good plan to let the refracting edge of the air wedge always point towards the same side, either to the right or to the left. Let, therefore, the air wedge have its refracting edge in the opposite position to that of glass cover plate P, then the same rule always holds good for the relative position of the three images: 1) the image of the slit due to the surface of the object, which may be easily distinguished from the other two images of the slit by removing and replacing the glass cover plate (the latter images being at fixed distances) must in all cases be brought together with the image of the slit on the left; 2) the two images of the slit must with their entire lengths be so placed one beside or above the other that the first named image always appears on the right hand side of the second image. — By illuminating the slit with sodium instead of white light, the appearance of the striae may be examined, the simple lens having previously been removed. The amount of superposition necessary to obtain striae of a suitable width (say 1 turn of the micrometer) for measuring is fixed for all future cases by a single preliminary experiment.

Assuming the interference apparatus to be adjusted in the manner described, the displacement of the interferential striae viewed by telescope F acts as follows. If the striae be displaced in a direction from right to left, the inference is that the stratum of air has increased, i. e. the expansion of the screws is greater than that of the object. Conversely, wandering of the striae from left to right indicates diminution of the stratum of air; the expansion of the screws is in this case less than that of the object.

While the apparatus is being adjusted, bracket *A* can easily be fixed by means of a pin (not shown in the figure). A dish lined with velvet, which is supplied with the apparatus, may in a most expedient manner be temporarily attached to bracket *A* during the adjustment of the tripod stage. It is intended to act as a guard preventing parts of the interference apparatus from dropping upon the ground. It will also be found a useful receptacle for accessories, such as the focussing lens, fixing pin etc.

The width of the striae and the position of the silver disc within the system of striae is measured by a small special telescope (*F*), which is substituted for the single lens. This telescope has fitted to it a micrometer screw (*M*) with drum divided in 100 parts and pointer and also a short double line drawn upon glass which may be brought to coincide with the single lines of interference and the silver disc. By means of the adjusting screw *E* shown in Fig. 16 the telescope may be turned about a horizontal pivot so as to obtain the correct position of the mark. A single micrometer reading taken of the relative position of the striae and the silver disc envolves an error which does not exceed the $^1/_{100}$ part of the width of the striae. The changes in the thickness of the stratum of air are thus indicated to the approximation of about $^3/_{1000000}$ mm. — The thickness of the object plate and that of the stratum of air can easily be ascertained by means of the thickness micrometer (No. 15 in this catalogue).

The last appendage to be described is the heating apparatus (*Th*), which is a D'Arsonval thermostat specially adapted for the dilatometer. The casing is filled with water or linseed oil. If the latter be used, the temperature may be raised beyond 250 C. The temperature is taken by a thermometer (T_1) suspended alongside of the porcelain tube *R*. The inner chamber is closed by semi-circular discs so shaped as to clear tube *R* and the thermometer. The heating apparatus is envelopped in a coating of asbestos mill board to minimise radiation of heat. The apparatus may be conveniently raised or lowered by means of a winch. Detailed instructions for working the thermostat are supplied with the apparatus.

Fig. 16 shows the apparatus mounted so as to be suitable for observation in a sitting posture. The foundation stone is 30 cm high. By increasing the hight of this stone the apparatus may, of course, also be used in an erect posture.

The whole apparatus, incl. a Geissler tube filled with H and Hg (No. 3 in this catalogue), without thermometer . **M. 1060.**—

Note: For connection with a hot air chamber, the optical part is also mounted by us in a different manner so as to have the prisms in a horizontal position. The hot air chamber used by Benoit consists of a series of concentric metal cylinders the sides of which are fitted with glass plates arranged along a horizontal straight line. The rays pass normally through these plates and are by means of a rectangular prism reflected downwards upon the tripod stage placed in the interior. A dilatometer adapted by us to an existing heating chamber of Benoit's type has already been fitted up in the First Division of the Imperial Physical and Technical Institute in Charlottenburgh.

No. 20. Apparatus for observing curves of interference produced by glass plates (Figs. 19 and 20).

By means of this apparatus Fizeau's curves and Mascart's rings exhibited by nearly or perfectly plano-parallel plates may be observed under conditions which may be accurately determined and which may be modified so as to suit the nature of the case. A detailed description of this apparatus has been published by Dr. Czapski, Zeitschrift für Instrumentenkunde, 1885, p. 149.

Newton's (or Fizeau's) curves of interference, which are produced by variations, due to oscillations in the thickness of the plate, of the difference of the undulatory phases of rays reflected from the front and back surface and which appear in the vicinity of the former, are only in that case also the curves of uniform thickness of the plate, when the rays meeting the plate have all the same angle of incidence. For various reasons normal rays are the most suitable for producing these curves. Accordingly, a monochromatic luminant placed behind screen *M* at the side of the apparatus is, by means of a reflecting prism *P*, reflected into the anterior focal plane of a system of lenses *O*, whence the pencils emerge with their axes parallel to the axis of the system (Fig. 20). The plate which is to be examined, is by means of spring clips attached to the adjustable stage which is approximately mounted in the second focus of the system *O*. By adjusting the inclinations of the stage the plate may be set at right angles to the

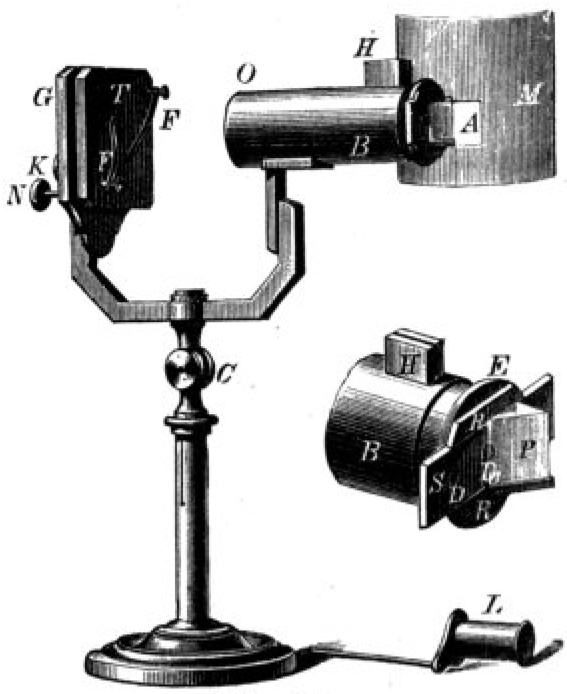

Fig. 19.
1/6 Full Size.

axis of the system. This is accomplished when the semi-circular image of that half of the aperture at *F* which is covered by the prism, has its diameter exactly superposed by that of the other half.

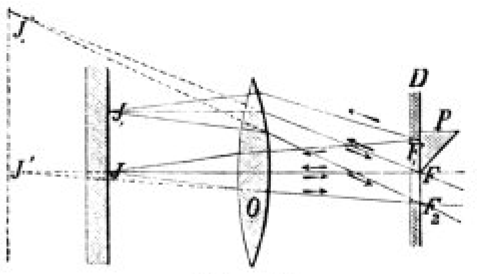

Fig. 20.

If the aperture be correctly placed in the focus of *O* and if the test plate have plane surfaces, the aperture and its image must simultaneously appear sharply defined. If this be not the case, the necessary correction may be effected by lengthening or shortening the diaphragm draw tube *E*.

The greater the thickness of the plate which is to be examined, the narrower must also be the incident pencil in order that by too great a diversity of effects produced within each pencil, the phenomena be not destroyed. Accordingly, the apparatus is fitted with a plate *S* provided with various sized holes D, D_1, which slides in a frame *R* fixed below the refracting prism and by means of which the aperture of the pencils may be limited according to requirement.

The curves become visible by looking towards the plate through the uncovered semicircular aperture *D* of the diaphragm.

With plano-parallel plates of very high perfection, in which FIZEAU's striae are 1 cm apart or entirely absent, the interferential rings first described by MASCART may be viewed. These are due to variation in the difference of the phases produced in pencils of parallel rays of varying inclinations in one certain place of the plate. These rings become, therefore, visible in the focal plane of the system *O* itself. In order that they may be viewed, the plate and illumination should be adjusted as before and the lens *L* be placed so as to focus the plane of the diaphragm; then on removing the slide *S*, a system of concentric semi-circles will be perceived in the plane of the diaphragm, the center of which may be either bright or dark. If it remain unchanged while the plate is being displaced upon the stage, this shows that the variation of the thickness of the plate along the path of the displacement is less than $^1/_4\ \lambda$ in glass. Whenever the difference of thickness is exactly $^1/_4\ \lambda$, the center of the circles passes from brightness to darkness or vice versa.

The area of the surface brought into operation should be diminished in a measure as the inclination of the two surfaces of the plate increases, in order that the differences of the phases due to different thicknesses of the plate may not neutralize the interferential curves. This limitation of the effective surface is obtained by a very narrow aperture in the ocular cap of the lens *L*.

No. 21. Apparatus for demonstrating the connection between diffraction and the image of an object (Figs. 21 and 22).

The apparatus is essentially a horizontal microscope fitted with an objective of very long focus, by means of which objects (viz. gratings) are viewed by transmitted light.

The objective which is composed of two similar achromatic lenses mounted at the ends of tube *M*, has a focal length of about 28 cm and an aperture of about 25 mm. Its foci are situated at *O* and *D* respectively. The object is

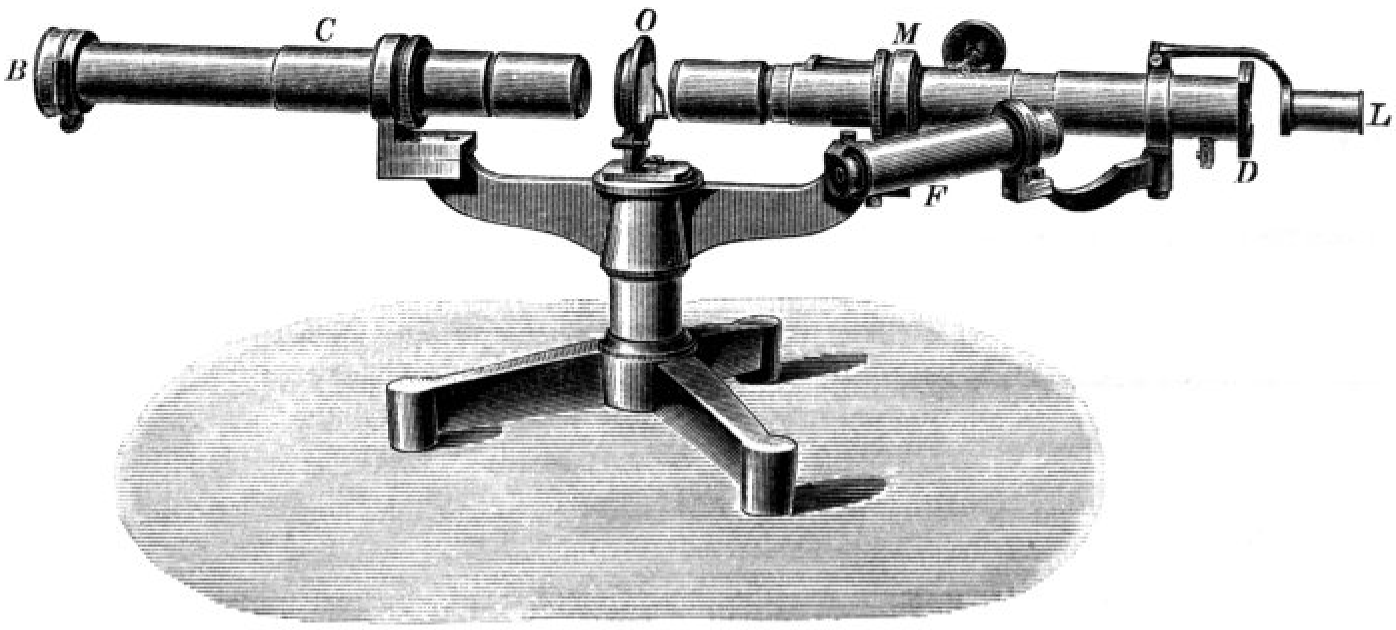

Fig. 21.
Apparatus for demonstrating the connection between diffraction and the image of an object (No 21).
ab. 1/6 Full Size.

placed at *O*. The real image formed at *D* by the objective of the Fraunhofer diffraction phenomena produced by this object, may be viewed by means of a hinged lens *L* and stopped down to any desired degree by means of various devices. The virtual image of the object itself formed by *M* is viewed by means of telescope *F* which is made to take the place of the ocular; for quickly throwing it into and out of action it is mounted upon a pivot.

The object is illuminated by means of a condenser system *C* which for reasons of convenience has a focal length equal to that of *M*. Any bright lamp may be used as an illuminant. In the anterior focal plane *B* an adjustable slit or iris diaphragm may be fixed and by lateral movements of these all the effects of central and oblique illumination may be produced.

The object stage O is made to swivel on a vertical pivot for demonstrating the difference between oblique position of a centrally illuminated object and normal position of an obliquely illuminated object.

A detailed description of the instrument will shortly be published in the "Zeitschrift für Instrumentenkunde", vid. also DIPPEL, "Das Mikroskop", 2nd ed., Brunswick 1882, p. 144—161.

The apparatus may also be used for objective demonstrations. In this case a lower power ocular should be placed on the telescope and sun light or electric light should be substituted for the lamp.

The apparatus is supplied together with 5 specimens, viz. gratings of various forms reproduced photographically, with the aid of which several particularly characteristic experiments illustrative of the theory of secondary delineation may be made. These experiments are shortly described in the following paragraphs.

The whole apparatus in case fitted with lock M. **400.**—

The most important experiments which may be made with the specimens are:

1st **Specimen**, being a narrow single parallel grating. Place the slit parallel to the direction of the lines and let only the central and one lateral maximum of the first order enter the objective. Let by means of the sliding diaphragms only the central non-diffracted light enter so as to exclude the lateral spectra; then only uniform illumination of the ocular field will be the result; this is the case with this as well as any other specimen. The addition of a lateral spectrum is sufficient to render the structure visible.

If the effective aperture of the objective be reduced to the distance of two adjoining spectra and if the illumination be central and sufficiently narrow, only one spectrum goes to form the image: in this case the ocular field is of uniform brightness. If the slit be displaced until its image reaches the margin of the effective aperture, then the spectrum nearest to the first spectrum also enters the free aperture and the structure again becomes visible (this case illustrates the effect of oblique illumination). The same result is obtained by opening the slit in its central position, until the lateral maxima reach into the aperture from both sides (effect of illumination by wide pencils).

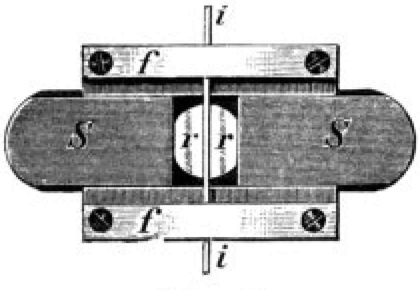

Fig. 22.
½ Full Size.

If the aperture at D of the objective be left undiminished and if only the central (non-diffracted) light be cut off by a cross bar, the distance of the remaining efficient spectra becomes doubled and consequently the image is a grating which is twice as fine as the actual grating.

2nd Specimen. Single reciprocal parallel grating. Ratio of the width of the cross bar to that of the slit in the lower half of the field 1 : 2, in the upper half 2 : 1. The spectrum of the grating which is visible at *D* consists in the principal maximum and several lateral maxima, provided a sufficiently narrow slit be placed at *B* parallel to the lines of the gratings. The 3rd, 6th etc. spectrum on either side of the bar have zero intensity, i. e. do not exist. With respect to the intensity of the remaining lateral spectra it is immaterial which of the two halves of the grating is made to form the image (this alternative may be effected by closing the upper or lower half or the grating by means of a card); only the intensity of the principal maximum (non-diffracted light) varies according to the two halves of the object, being greater in the case of the brighter half. The stoppage of this principal maximum by means of a thin bar or thin needle fixed with wax has the effect of making the images of the upper and lower halves of the object equal, i. e. the effect is that of a single parallel grating (ratio of width of bar to that of slit 2 : 1 with diminished contrast) viewed with the telescope *F*.

3rd Specimen. Reciprocal parallel grating. Ratio of width of slit to that of bar in both halves of the grating = 1 : 1, the upper half being displaced one width of bar with respect to the lower half. Diffraction may be seen at *D*, the same slit being used as before: again we have an achromatic principal maximum and lateral spectroscopically decomposed maxima. The 2nd, 4th spectrum at either side have zero intensity, they are, therefore, invisible. By stopping the non-diffracted principal maximum, a series of spectra remains which are throughout of double the distance as compared with that of the principal maximum and its two adjacent maxima. The image viewed with the telescope represents a grating which is twice as fine as the real object (i. e. as the object seen without the stop). By adjusting with extreme exactness the ratio of the width of the bar to that of the slit in the grating and by carrying out the experiment with extreme care, the width of the lines which are very fine in any case, becomes 0, i. e. the field appears to be uniformly bright within the limits of the grating.

4th Specimen. Gratings crossed at 90°. At *B* replace the slit by a circular diaphragm or an iris diaphragm, and do the same at *D*. Stop all spectra with the exception of the principal maximum. Then all difference of structure will be found to have disappeared from the image viewed by *F*. The iris diaphragm being opened at *D*, the image successively approaches, as in the case of specimens 1, 2, 3, in appearance that of the merely geometrically magnified object. If all the spectra be stopped with the exception of a series of spectra which may be vertical or horizontal or inclined at 45°, the effect produced is that of a single parallel grating of striae which are horizontal, vertical or inclined at 45°. By stopping the principal maximum, only the ratio of the intensities of the field become reversed (dark becomes bright, bright becomes dark).

5th Specimen. Grating crossed at 60°. Adjust iris diaphragms at *B* and *D* as previously. Place diaphragm *B* central and admit only the first series of diffraction spectra surrounding the principal maximum. Then the image at *D* will be similar to that formed by microscopes of high aperture in the case of Pleurosigma angulatum. Admit partially or wholly the 6 diffraction spectra; the image will then have a changed appearance; this proves the analogy of Pleuros. ang. viewed with dry and immersion systems. Limit diffraction to single series or spectra grouped at different angles; the image will exhibit striation in a direction at right angles to the series of the diffraction spectra as under 4.

Beside these 5 specimens, the following two **accessories** will be found useful for demonstrating the manner in which variation of phases and rotation of the direction of undulation in the diffraction spectrum affects the image.

Glass wedge compensator. 2 similar glass wedges of small angularity are cemented together so as to have their horizontal refracting edge on opposite sides, thus forming a plano-parallel plate. One half (right) of one of these wedges is detached and may be moved from top to bottom by means of a micrometer screw. This half of the compound plate is capable of undergoing variation of thickness and retarding power. Use specimens 1, 2, 3, set the slit narrow at *B*, admit at *B* only two spectra, blocking out the principal maximum. Adjust the compensator at *D* so as to cause one spectrum to pass through one half, the other spectrum through the other half of the compensator before reaching *F*.

In the middle or zero position of the right wedge there will be uniform retardation of both spectra; the image will, therefore, appear unchanged as when viewed without compensator. If now the wedge be moved, the striae in the image wander towards one or the other side. By increasing the amount of the displacement of the wedge and by using white light, the structure may be ultimately made to disappear in either direction of the displacement. If monochromatic light be used, the effective difference of retardation is unlimited.

Price of the compensator M. **40.**—

Double quartz plates: a) 2.1 mm, b) 4.2 mm thickness, for placing before *D* in lieu of the compensator. In other respects the experimental arrangement is the same as before. Monochromatic illumination (sodium light). If a) be used, the plane of polarization of one of the spectra undergoes a rotation of 45° in one direction, that of the other in the opposite direction to the same amount, the result being that both lose their power of giving rise to interference, no structure being therefore visible at *F*. If b) be used one of the quartzes rotates the plane of polarization of one of the spectra through 90° in one direction, the other quartz that of the other spectra through the same angle in the other direction, the result being that the directions of polarization become again coincident, there being only a difference of phase of half a wave length. Image at *F* the same as without quartz plate but laterally displaced as far as half the width of one of the striæ.

Price of each mounted double quartz plate M. **22.**—

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