THE GEODETIC INSTRUMENTS
produced by Messrs. Carl Zeiss, Jena.

A BRIEF REVIEW OF THEIR OUTSTANDING CHARACTERISTICS.

Technical progress in the domain of Surveying has, in the past, been distinctly slow. Whilst other branches — we need only refer to Mechanical, and perhaps Electrical engineering of all kinds — have developed with remarkable rapidity, we still find that the surveyor is very frequently using the methods and instruments which served his grandfather or great-grandfather with more or less adequacy. There are various reasons for this. A large factor is undoubtedly the special mathematical nature of "practical geometry", the early established general principles of which precluded any such basic changes as have recently occurred in the sphere, say, of technical physics.

It would be misleading, however, to deduce that the technical side of survey work cannot or need not, see substantial advances. On the one hand, a number of important discoveries and developments made during the last two or three decades show clearly that the efforts made towards improving surveying instruments and methods have been more persistent and more successful than at any previous time. This is sufficiently substantiated by citing the invention of the closed telescope with internal focussing lens, the development of precise optical telemetry, the advances made in the production of accurate circles and reading devices, the introduction of the parallel faced rocking prism for fine measurement, and finally the rapid evolution of photogrammetric methods and instruments.

On the other hand, however, much greater demands are now made upon the surveyor in all highly civilised countries. The nature of the tasks has become far more complex, while much greater economy of time is expected. The firm of Carl Zeiss of Jena has taken a prominent position in the design and production of modern surveying instruments which meet such requirements, and it is proposed to offer here certain details of a few of their instruments, to give some idea of their extreme accuracy, their convenient manipulation and their suitability for particular kinds of work.

Fig. 1 ; shows Theodolite II. This instrument is intended for triangulation work up to the second order, main polygonal traverses, precise tacheometry and also for underground and astronomical night observations. Special additional equipment (see below) adapts it for astronomical location work of high accuracy. The following description is made somewhat detailed since certain essential features of design are common to the other Theodolites.

Externally, the instrument is of very compact and handsome appearance. The supports carrying the transverse axis bearings, together with the enclosed lower portion, house and protect the optical and mechanical parts employed for illumination, for reading the circles and for the various movements. These parts are therefore very efficiently protected against dust, moisture and mechanical damage. Nevertheless, important adjustments can be made by merely loosening a few screws. As in all Zeiss Geodetic instruments, the telescope has an internal focussing lens and is therefore similarly completely enclosed and protected. With the objective aperture of 1 9/16 inches (40mm) the magnification is 27x combined with very careful construction. These figures confer great clarity and brilliance of field together with maximum definition in reading and focussing on the distant object. The diaphragm, of optical glass, has horizontal subtense lines for a multiplication constant $K = 100$ (the additive constant for all Zeiss geodetic telescopes may be disregarded, so that $c = 0$). *Horizontal and Vertical circles* are of glass, with diameters of 3 3/4 ins. (95 mm) and 1 7/8 ins. (48 mm) respectively. The suitability of this material was questioned in many quarters when Messrs. Zeiss first introduced it, but it has proved extraordinarily advantageous. It is exceptionally resistant to shock or breakage. Properly mounted glass circles will survive bad falls of the instrument. They have two decisive advantages over metal circles :

1. Glass permits of drawing considerably finer and sharper graduations, which in turn enable a higher degree of magnification to be used.
2. The method of illumination by light *passing through* the glass gives a much more brilliant image than can be obtained by reflected light from metal circles.

The *reading of either circle* is effected (at will by turning a switch-over stud) through an eye-piece immediately alongside the telescope eye-piece. This makes it unnecessary to waste time running round the instrument, a movement that may well be dangerous in certain places, and also makes for much greater efficiency.

The *Reading image of the Horizontal circle* is shown in Fig. 2. With the screw of the *optical micrometer,* the observer establishes accurate coincidence between the pairs of double graduations in the upper and lower circle images, and then reads off this result of the *automatic optical* mean of diametrically opposite readings directly and in the same field of view with an accuracy of 1 second (and by estimation to 1/10 second). Tests of the accuracy of the circle graduation in a series of instruments produced under similar conditions have shown a total maximum diametral error of 0.6''.

The illumination in Theodolite II is designed to give most satisfactory lighting to all four circle reading points by means of a single rotating and folding reflector. This reflector is fixed on the trunnion support of the transverse axis. It is thus at all times in the same position relatively to the observer and is never obscured during the observing. For surveying at night time and in dark places such as mines, tunnels, etc..., two types of electric lighting have been devised. In the simpler arrangement an ordinary pocket lamp is used, which is clamped on to one of the telescopic supports. Electric lighting I is built into the instrument and is weatherproof. A battery clipped on to one of the tripod legs is connceted with the tribrach by a cable and plug. One small bulb illuminates all the circle points, the vertical index bubble, the centrally supported alidade bubble and also the diaphragm (by means of a regulating stud).

Threefold provision is made for *centring* : plumb line, centring staff and optical plumb. There are three models of the last, either incorporated in the tribrach, interchangeable with socket fitting for plumbing over a ground station point, and for plumbing over a ground point or vertically under a point above the instrument. It is well known that the rigid and optical plumbs are superior to the plumb line as regards convenience and accuracy.

A number of *additional fittings* ensure maximum suitability of the instrument for particular operations. We may mention :

1. The *Distance measuring prism* which fits over the objective. Used with a horizontal tacheometric staff, it gives an accuracy of 2 to 3 cms. at 100 metres oblique distance.
2. The *Precise Polygonal Traversing equipment* with three sockets on tripods for interchanging instrument and illuminated targets.
3. *Mine Surveying equipment* with tilting signal lamps and bracket arm supports.
4. Attachable *Tubular and Whole circle compasses.*
5. *Eye-piece and Objective prisms,* also *Zenith eye-pieces* for steep of zenith sighting.
6. *Attachable level to Telescope,* sensibility 10'' per 2 mm.
7. *Horrebow-level* and *Eye-piece micrometer* rotating through 90° for astronomical measurements.

Some of these additional fittings may also be used in conjunction with the other Zeiss theodolites, to which the foregoing description of principal features such as telescope, circles etc. also applies. Only the outstanding characteristics of Theodolites III and IV will be briefly explained in the following paragraphs.

Theodolite III has the same telescope as Theodolite II. Its reading efficiency, amounting to 2' direct and 12'' by estimation, can be further improved for the horizontal circle by introducing a micrometer, the accuracy then being 20'' direct and 2'' by estimation. The hinged reading eye-piece mounted to the side of the transverse axis shows both reading points of the horizontal circle and one reading point of the vertical circle simultaneausly, all reading being viewed through the scale microscope. For measuring distances by observations on a horizontal base staff of 1 m, 2 m or 3 m length, Theodolite III can be provided with a horizontally operating tangential screw which also serves as lateral fine setting screw.

For topographical and cadastral tacheometry and also for polygonal traversing and setting-out, *Theodolite IV* shown in Fig. 3, has been designed. The telescope characteristics are : Magnification 28x, objective aperture, 1 3/8 ins. (35 mm), and diameters of horizontal and vertical circles, 3 9/16 ins. (90 mm) and 2 3/4 ins. (80 mm) respectively. As in Theodolite II, the reading eye-piece is mounted alongside the telescope eye-piece.

In the reading micro field (Fig. 4) it is seen that *one* point of the horizontal and vertical circles is read with (360° graduation), a 60-division scale microscope. This gives maximum clarity of image and speed of reading. Small residual errors in the centring of circle and axes can be eliminated, in accurate work, by measuring in two telescope positions and taking the mean.

Optical tacheometry, especially the polar co-ordinate method is rapidly gaining a firmer foothold in modern survey practice. This is very largely due to the constant improvements in the instruments. The *Bosshardt-Zeiss Reducing Tacheometer* (Fig. 5) represents a highly developed type of automatically reducing double image tacheometer. It has long proved its worth in many countries and has been the subject of a large number of papers by different authorities.

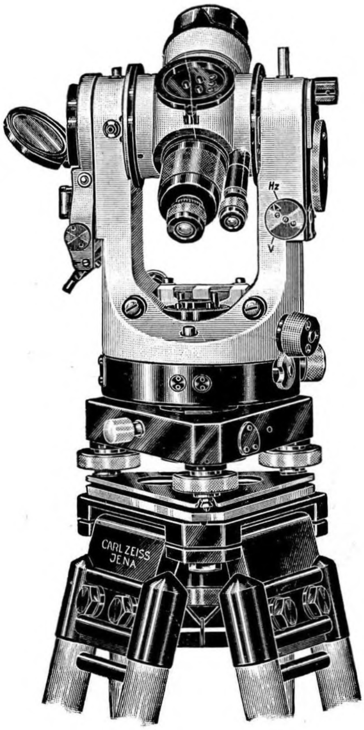

FIG. 1.
Zeiss Theodolite II. About 1/4 actual size.
Théodolite Zeiss II.
Environ 1/4 de la dimension réelle.

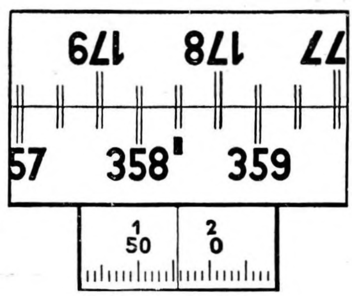

FIG. 2.

Reading		358° 20'
Lecture	+	1' 55.7"
		358° 21' 55.7"

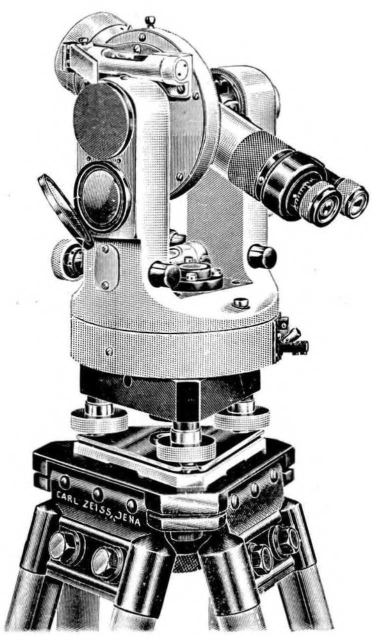

FIG. 3.
Zeiss Theodolite IV. About 1/4 actual size.
Théodolite Zeiss IV.
Environ 1/4 de la dimension réelle.

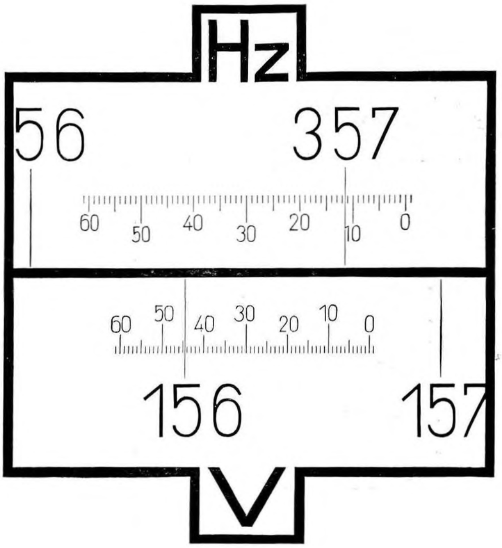

FIG. 4.
Field of view in reading micro
of Zeiss Theodolite IV (3/4 apparent size).
Horizontal circle, 357° 11.4';
Vertical circle, 156° 44 5'.

Champ du micromètre de lecture
du Théodolite Zeiss IV (3/4 de la dimension
réelle). Cercle horizontal, 357° 11.4';
Cercle vertical, 156° 44.5'.

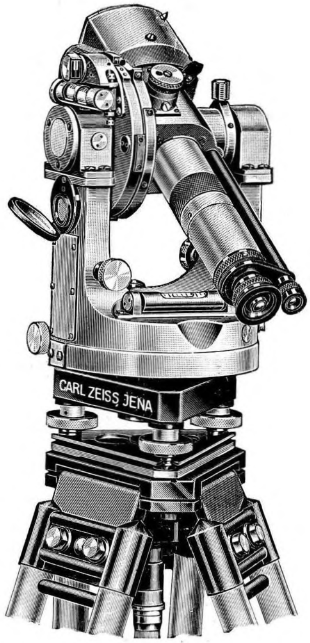

FIG. 5.
Bosshardt - Zeiss
Reducing Tacheometer.
About 1/5 actual size.

Tachéomètre Réducteur
Bosshardt - Zeiss.
Environ 1/5 de la dimension réelle.

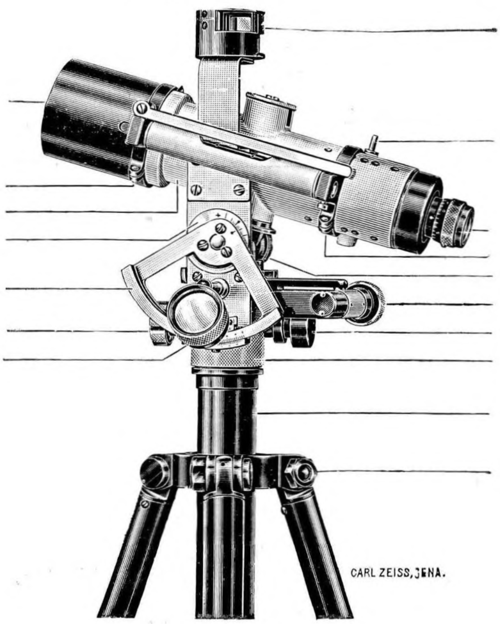

FIG. 6.
Zeiss Kipplodis. About 1/3 actual size.

Zeiss Kipplodis.
Environ 1/3 de la dimension réelle.

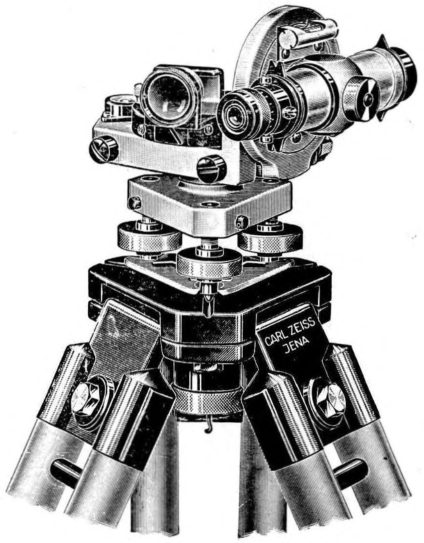

Fig. 7.

Zeiss Tachytop on Tripod I (a or b). About 1/3 actual size.

Tachytop Zeiss sur Tripode (a ou b). Environ 1/3 de la dimension réelle.

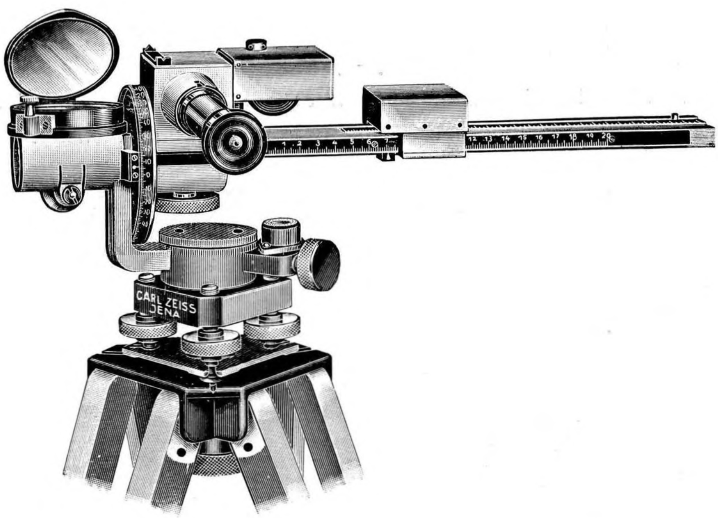

Fig. 8.

Zeiss Teletop with support on tripod. About 1/4 actual size.

Teletop Zeiss avec support sur trépied. Environ 1/4 de la dimension réelle.

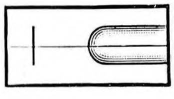

Fig. 9.

Reading image of tubular level.

Image de lecture du niveau tubulaire.

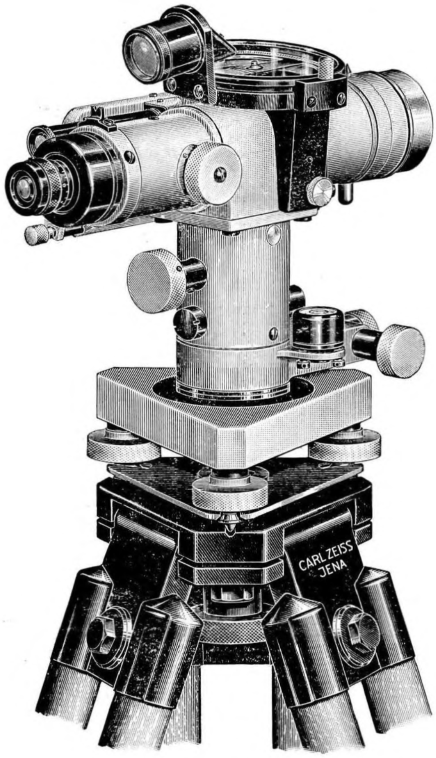

Fig. 10.
Zeiss Level B with circular compass attached. About 1/3 actual size.
Niveau Zeiss B avec compas circulaire. Environ 1/3 de la dimension réelle.

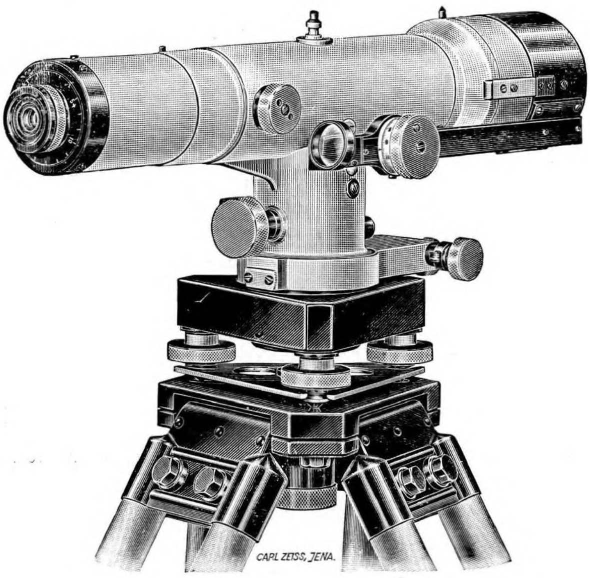

Fig. 11.
Zeiss Level A with parallel rocking prism. Bubble reading in telescope field. About 1/5 actual size.
Niveau Zeiss A avec prisme parallèle à bascule. Lecture de la bulle dans le champ de la lunette. Environ 1/5 de la dimension réelle.

By means of two prisms disposed in tandem and covering one-half of the objective field, a double image of the distant staff is seen, one image being viewed directly and the other by refraction, the refracted image being displaced in a direction parallel to the staff. The appearance in the telescope field is that of a staff split longitudinally with one half slid longitudinally relative to the fixed or directly viewed half. The distance measurement is obtained by setting a scale division of the staff vernier coincident with a division of the main staff scale, by using the micrometer screw, and then reading the apparent horizontal displacement direct to 1 cm.

The coincident setting is made rapidly and very accurately even if the air is considerably disturbed in hot weather. If the instrument is used with a 2.20 metre staff fixed horizontally, a mean accuracy of reduced horizontal distance of 2 to 3 cm. is obtained at the maximum distance which can be measured in one sight, i.e. 200 metres.

The displaced refracted image can be cut out of the field by rotating a ring. The reading eye-piece then exhibits a full field showing two reading points on the horizontal circle, one point on the vertical circle and also a tangent scale whereby an immediate calculation of the height may be made.

With the refracting prisms thus switched out of action the instrument is ready for any of the operations of a universal theodolite. A recently designed light hand staff increases the mobility of the party, especially in town street work.

Whilst the Bosshardt-Zeiss Reducing Tacheometer is intended more particularly for optical surveying by the method of polar co-ordinates, Messrs. Zeiss have produced also the *Plumb Staff Tacheometer* (*Lodis*) for expediting and simplifying surveys to be plotted by rectangular co-ordinates. In this instrument the double image principle is used in conjunction with two vertical staves — one moving along the base line and giving the abscissae corresponding to chain distances by the old fashioned method, and the other giving readings for the ordinates of "offsets" previously roughly measured by a tape. Here again, as in the Reducing Tacheometer, there are no *dim or confused images*. Only clear and distinct *separated* images are produced. The range of measurement is 50 metres. The chief advantages of the Lodis instrument are most marked when working in busy town streets where chains and tapes are most inconvenient. This instrument has lately been adapted for working in hilly country in the form of the Kipplodis which is provided with a tilting telescope (Fig. 6). The interpolation of the instrument in the base line (axis of abscissae) between two known points, and the determination or setting out of the right angles, are made possible even among slopes where the ordinary double prismatic optical square is quite helpless, by using the new *Steep sighting attachment.*

The steep sighting attachment may also be used — independently of the Kipplodis — as an accessory to the double prism for setting-out and plotting in hilly country.

For tacheometric plotting of a lower degree of accuracy, such as is required for preparing or filling in topographic maps to scales of 1/2500 and smaller, particularly 1/5000, the well-proved compass still gives good results for a modest expenditure of labour. As such work is increasing nowadays both in actual quantity and urgency, the special outfit known as the *Tachytop Tacheometric Compass* has been produced.

Its principal components are a distance measuring telescope with a vertical circle and a whole circle compass with swinging dial (Schmalkalden compass). Vertical circle and compass scale are read simultaneously in the field of a microscope without moving away from the telescope and without eye-strain, the magnification being 5x.

The Topographic Tacheometer "Teletop" is used for similar purposes as mentioned above for the "Tachytop", chiefly for topographic, tacheometric measurement of a low degree of accuracy for geographic and geological detail, and for land and forest valuation. When the Teletop is used, it is not necessary to place a staff at the point to be sighted, provided it is sufficiently prominent. The Teletop is primarily suitable for the rapid fixing of conspicuous site points, as for instance for surveying the stock of trees in the re-distribution of lots, especially for surveying such points which are difficult or impossible to reach (rocks, islands, caves, electric overhead cables, etc...). Since the work proceeds simply and quickly the Teletop can often be used with advantage even in open country where the accuracy obtainable is sufficient (for example in the plotting of polygon nets for the checking of known lengths and to procure data for photogrammetry).

The Teletop consists essentially of a distance meter with a variable base (up to 200 mm.) and a support for the distance meter. In the support are combined : tribrach with vertical and transverse axes, vertical circle and compass. (See Fig. 8).

Some information will now be given regarding Zeiss *Levelling Instruments*. The spheres of activity that call for geometric levelling can be divided into three essential categories :

1 Simple building site levelling operations involving short distances and relatively no very great accuracy.

2. Engineering works of medium and greater magnitude, such as construction of roads, waterworks, bridges, railways, etc.

3. Precise geodetic levelling for establishing exact altitudes, primary and secondary bench marks, measurement of exact deflections and subsidences, etc.

Three groups of levelling instruments correspond to these different categories. In the design of the first group, relatively low sensitivity and very easy manipulation were the main considerations. The third group called for very accurate centring of the bubble and reading of bubble and staff, whilst for the second group a suitable combination of both desiderata was essential.

Enclosed telescopes with internal focussing lens are used in all types. All the diaphragms, which are made of optical glass, have horizontal subtense lines with a multiplication constant of 100, the additive constant being virtually zero in all instruments. The tubular levels of instruments of categories 2 and 3 possess a prism system through which (Fig. 9) the two bubble ends (halves) are seen side by side. The bubble is central when the two halves exactly complete each other. This gives a considerably more accurate bubble setting, particularly if a microscope is also placed in front of the prism (as in Fig. 10). These bubbles remain of constant length in any temperatures likely to be encountered. It may also be mentioned that Zeiss levels and theodolites have steel *cylindrical* vertical axes, not conical ones. The greater difficulty of manufacturing such axes, involving very accurate fitting to 0.001 mm. and less, is well rewarded by the more uniform and smoother movement secured.

Level B, shown in Fig. 10, possesses the degree of accuracy requisite for good technical levelling. A second model has a horizontal circle instead of the detachable whole circle compass. The instrument possesses a fine tilting screw in addition to lateral clamping and slow motion screws.

Since the telescope is rotatable about its axis, and the level of the reversible type, adjustment can be made from one position. This instrument gives a vertical accuracy of $\pm$ 2,0 mm. per 1 kilometre of double levelling under average, — not specially favourable — conditions. This accuracy may be increased threefold if instead of the ordinary wooden staves, recourse is had to Zeiss Invar staves and the millimetres of the staff reading are not estimated, but measured by a micrometer screw in conjunction with the attachable parallel faced rocking prism. Level B is transformed by these additions into a really precise instrument.

The ideal instrument for work demanding the highest possible degree of accuracy, is Level A (Fig. 11). This instrument is normally only used with the rocking prism attachment and in conjunction with Invar staves. By tilting the rocking prism, the sighting line is slightly displaced vertically, by refraction, so that it may be set to the nearest definite staff graduation, when the fractional part of the staff reading is accurately read off from the micrometer drum. To enhance the accuracy of this setting, the horizontal line in the telescope field is of wedge-shaped form. With the precision staff the graduations are engraved on a narrow strip of Invar in the form of a half centimetre scale. This makes the length of the staff metre virtually unaffected by temperature changes. Direct readings of 1/100 of a graduation, namely 0.05 mm., can be made on the micrometer drum which is connected with the rocking prism. The accuracy which may be expected by observers of average skill, under average conditions, is 0.4 mm. per 1 kilometre of double levelling.

The reflection of the bubble of the tubular level is seen in the field of the telescope eye-piece. The observer is thus able to read the staff and observe the bubble practically simultaneously. The level is not only fitted with the well-known Zeiss prism system to give accurate centring of the bubble, but it also has a bubble scale on which deviations from the horizontal, up to 50" can be read quickly to an accuracy of about 0.2". As the design incorporates this scalar bubble together with the parallel rocking prism, Level A is suitable for each and all of the different levelling methods, so that each may be used according to circumstances to secure the best results with a minimum expenditure of time and labour.

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