SOLAR EPHEMERIS for 1969

AND

SURVEYING INSTRUMENT MANUAL

KEUFFEL & ESSER CO.

MORRISTOWN, N. J.

Branch and Distributor Offices in all Principal Cities

COVER DESIGN . . .

This year's cover design depicts the Zeiss Th43 Theodolite. Offered exclusively by K&E in the United States the Th43 contains many outstanding features.

A modern instrument with reading microscope, the Th43 serves a score of applications requiring optical setting out, alignment, and measurement of vertical and horizontal angles and distance stadia measurement.

The Th43 is especially suited for building-site surveys, lot surveys in cadastral and urban surveying, traverse surveys for cadaster, reallotment or mining, topographical tacheometry, low-order triangulation, ground-control work, fixing astronomic geodetic positions, and trigonometric leveling.

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K+E

SURVEYING INSTRUMENTS

K&E has been manufacturing Surveying Instruments since 1885. From the start, the company's policy has been to build only instruments of the highest quality. K&E has developed new materials, better methods of manufacture and radical improvements in design. To-day K&E's leadership is unquestioned.

The superb performance of K&E Surveying Instruments is recognized throughout the world. They are renowned for their fine workmanship, for the accurate results they produce and for the long years of service that they give. They need little attention, even under the most adverse field conditions.

Space does not permit an account of the many features that give these instruments their accuracy and long life, as for example the chrome plated center or the non-magnetic stainless steel trunnions, but several of their most outstanding features are described in the next paragraphs.

AUTOMATIC INDEXING

Automatic indexing is the most important recent development made in optical surveying instruments. It has increased considerably the speed and accuracy of operation. This feature is now incorporated in the following K&E instruments:

1. The Zeiss Self-Leveling Levels
2. K&E Theodolites, in which the index for zenith angles is set automatically
3. The Self-Indexing Plane Table Alidades

PRINCIPLES

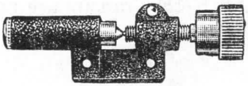
In all automatic-indexing devices, optical parts, actuated by a pendulum, compensate for slight tilts in the main instrument. Since knife edges cannot be used to support the pendulum, as they would soon become dull, wires or membranes are substituted. These supports become stiffer in cold weather and more flexible in warm weather, and thus the compensation is too little or too great. However, when properly designed, the supports are relaxed when the instrument is level, so that temperature has a negligible effect on the slight movement of the pendulum.

The plane of the pendulum swing must be parallel to the line of sight. If not, a slight error in leveling left and right will create an error in compensation. In an automatic level, if the circular bubble adjustment is slightly in error transversely and the telescope is always pointed in the same direction when set-up, the backsights will always contain a certain error, and the foresights the same error but of opposite sign. To avoid this accumulation of systematic error, the telescope should be pointed in alternate directions when leveled at successive setups. In K&E theodolites, taking the average zenith angle of a direct and reversed observation will eliminate this error. The error is too small to affect alidades.

If an instrument is stored for a period of time or allowed to stand slightly out of level for thirty minutes or so, the pendulum support takes a slight temporary set which soon disappears as the instrument is used. This has very little effect when running levels if the foresights are taken immediately after the backsights. However, for the best results, the instrument should be leveled when stored or left standing on the tripod. This set has no effect on zenith angles measured with a theodolite if direct and reversed observations are taken alternately and averaged. However, this makes it very difficult to adjust the zenith-angle index precisely, because the set changes during the time required for the adjustment. Therefore, zenith angles observed only once may be in error by as much as ±8 seconds, i.e. about ±0.02 feet in 500 feet. This set or hysteretic effect is too small to affect alidades.

2-SPEED TANGENT SCREW

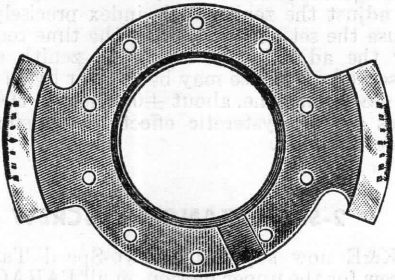
K&E now supplies a Two-Speed Tangent Screw for the upper motion on all PARAGON® Transits except the 74 0070 and 74 0075. It can be installed on all K&E transits built since 1954, by merely unscrewing the present tangent screw and screwing in the two-speed device.



When this screw is turned continuously in one direction, it operates at normal speed. When its direction is reversed, the alidade is turned at ⅛th normal speed for a short distance. Then normal speed is picked up again. In this way high accuracy is attained in aiming at a point or in setting the vernier. Merely turn past the desired position then use low speed in both directions to make the precise setting.

SPANNED VERNIERS

K&E now makes the two plate verniers as a single unit. This is a revolutionary development in transit design. It results in perfect verniers, perfectly positioned. Spanned verniers ensure precise alignment when assembled on the



transit and eliminate the possibility that the verniers might be too "long or short." It follows that transits with spanned verniers are more accurate than similar instruments not so equipped. All K&E Transits are now furnished with spanned verniers.

OPTICAL SYSTEM

Keuffel & Esser Co. is a leader in the recent general advance in optical design. In every K&E telescopic instrument the field of view is exceptionally brilliant and free from color rings, the focus is sharp over the entire area of the field, and the cross lines are exceptionally sharp and black.

These results have been attained by extremely careful optical design. Coated lenses are used throughout.

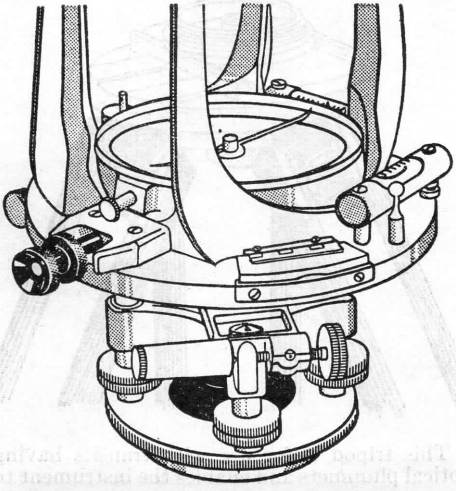
Most transits today have a color-corrected objective lens. Very few have a color-corrected eyepiece. On all PARAGON® Transits, except the 74 0070 and 74 0075, an achromatic eyepiece makes the cross lines appear jet black.

With a K&E instrument it is possible to identify objects more readily, to sight points more precisely, to work more accurately in poor illumination, to read the stadia rod and the level rod at greater distances, and to observe Polaris earlier in the afternoon.

OPTICAL PLUMMET

All K&E Transits are available with built-in optical plummets. The optical plummet enables the instrument to be centered over a given point quickly and precisely by means of an optical system built into the vertical center of the instrument.

The line of sight to centering point is turned

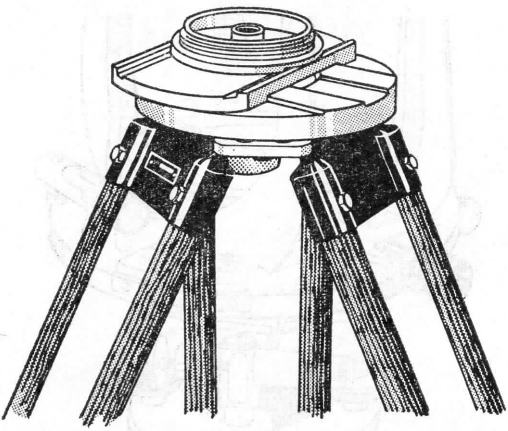


90° by a prism so that viewing is actually horizontal, facilitating ease of observation.

Instruments equipped with this device can cut as much as one-third off the set-up time where the conventional plumb bob is used. The device provides even greater time-saving and centering precision on windy days.

Centering accuracy is ensured by rotating the optical plummet about its axis. Eye-piece focusing of centering point is possible through a range of 10 in. to infinity, thus allowing for a variety of set-up heights. The optical plummet is equipped with 2½X magnification and a circular reticule (bull's eye with small cross line) in the eyepiece.

PARALLEL-SHIFT TRIPOD



This tripod is for use with transits having optical plummets and enables the instrument to be moved in any direction during the centering operation. Since proper functioning of the optical plummet requires that the instrument be level, the tripod is constructed so that the instrument remains level throughout the centering operation. In this way any sight obtained with the optical plummet is perpendicular to the level of the instrument. Movement on the parallel shift tripod is 2 in. in all directions. The all-Teflon coating on the tripod plate ensures smooth sliding action.

ZEISS THEODOLITES

The exclusive U.S. distributor of world-famous Zeiss Theodolites, K&E carries a wide range of these precision instruments and their accessories.

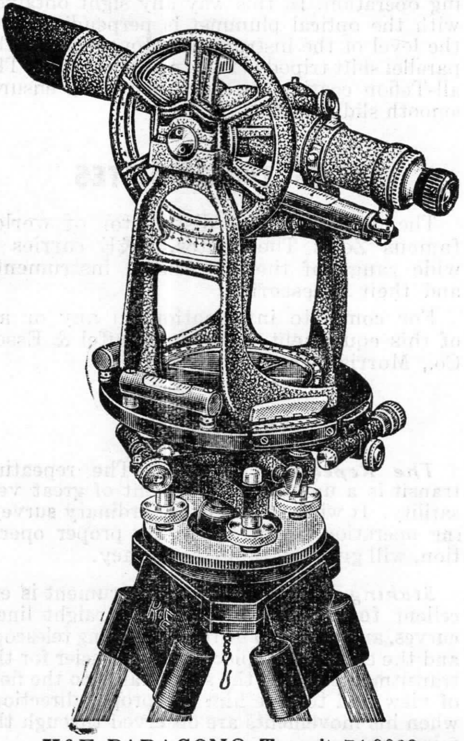
For complete information on any or all of this equipment, write to Keuffel & Esser Co., Morristown, New Jersey.

TRANSITS

The Repeating Transit. The repeating transit is a universal instrument of great versatility. It will perform every ordinary surveying operation required and, by proper operation, will give any desired accuracy.

Staking out Work. The instrument is excellent for setting out angles, straight lines, curves, and grades. The relatively long telescope and the erecting eyepiece make it easier for the transitman to bring the stakeman into the field of view and to give him the proper directions when his movements are observed through the telescope.

The double center makes it possible to set the vernier at zero (or at any required setting) before taking a backsight. This is an important element in any layout work. Short lines of levels can be run and grades can be established well within the accuracies usually required, and high accuracy in leveling can be attained when desired by keeping the sights short.



K&E PARAGON® Transit 74 0000

Difficult Sighting Conditions. The fine optics of the K&E instrument make it especially useful for stadia work, Polaris observations and wherever the target is poorly illuminated.

Traverse Angles. By "repeating" angles in such a way that the sum of the measurements is accumulated on the circle, traverse angles can be measured as accurately as desired and with approximately the same speed as with a direction theodolite.

Triangulation. The angles of a triangulation system can also be measured as accurately as desired with a repeating transit, but the many repetitions required take longer than measurements of the same accuracy made with a direction theodolite.

Essential Design. A repeating transit consists of three major assemblies: the alidade, the circle assembly and the leveling head. Because of its double center, the alidade turns within the circle and the circle within the leveling head.

Principle of the Clamps

On the circle assembly, immediately below the circle itself, are two collars, which serve as brake drums for the upper and lower clamps. When the upper clamp is tightened, the circle is clamped to the alidade. When the lower clamp is tightened, the circle is clamped to the leveling head, hence to the ground. After either clamp has been tightened, a precise setting between the two parts clamped together can be made with the appropriate tangent screw.

To measure an angle, both clamps should be loosened, then the zero of the vernier on the alidade is brought to the zero of the circle, the upper clamp is tightened and a precise setting is made with the upper tangent screw. The telescope is then directed toward the first point, the lower clamp is tightened and the cross lines are brought exactly on the point with the lower tangent screw. The line of sight will now be exactly on the first point and the vernier will be at exactly zero.

The upper clamp is loosened and the telescope is directed toward the second point, thus moving the vernier around the circle. The upper clamp is then tightened and the cross lines are brought exactly on the second point with the upper tangent screw. The vernier will then give the exact value of the horizontal angle.

With this as a beginning, the reader is referred to the many excellent textbooks available.

THE USE OF TRANSITS

While every transitman is familiar with the operation of a transit, certain important points in using the instrument, which make for better results, are outlined here.

To Tighten the Tripod Shoes. It is essential that the tripod shoes be kept tight. On a conventional tripod, if the shoes are loose, tighten the wood screws that hold them to the tripod legs. If this fails, remove the shoes and refit the ends of the tripod legs. On a K&E Wide Frame Tripod, the shoes practically never become loose. They may be tightened with the hexagonal headed bolt found on the opposite side of the shoe from the spur.

To Adjust the Tripod Hinges. If the tripod hinges are too loose, there will be play that may destroy the accuracy of the work. If they are too tight, residual friction may suddenly give way and the instrument will move slightly off line, without the knowledge of the transitman.

On a conventional tripod, each of the wing nuts should be just tight enough to allow the leg to fall *slowly* by its own weight. On a K&E Wide Frame Tripod, the hinges hardly ever require adjustment. Occasionally they should be oiled and wiped dry. The hinge friction adjusting nuts are located under the corners of the tripod head. They should be adjusted so that the leg will fall *freely*, but still develop a slight friction that can be felt when the legs are moved by hand.

To Mount the Transit. Set up the tripod with the legs well spread, the feet set firmly into the ground and with the head nearly level. Unscrew the tripod cap.

Place the transit case on a flat surface, open the door, grasp the leveling head and carefully slide out the instrument on its base plate. Take off the objective cap and replace it with the sunshade. (The sunshade should always be used, as it reduces glare, never cuts off any useful light, and gives the telescope a more nearly even balance.)

Grasp the instrument with both hands at the leveling head, unscrew it from the base plate and screw it firmly home on the tripod head. Open the eyepiece shutter by moving the small pin into its slot.

To Focus the Telescope. Unless the eyepiece is focused accurately for the observer's eyesight, and the objective is also accurately focused, parallax may impair the accuracy of the work.

Point the telescope at a bright, unmarked surface or at the sky, and rotate the eyepiece focusing ring until the cross lines appear at their maximum sharpness. Next sight the telescope at some well defined point and bring the object into sharp focus by means of the objective focusing pinion. Move the eye left and right or up and down and observe whether the cross lines remain on the point sighted. If they appear to move, adjust the focus by rotating the eyepiece focusing ring back and forth while making small adjustments with the objective focusing pinion until all apparent motion is eliminated.

To Level the Instrument. Always begin the process of leveling the instrument by loosening *two adjacent* leveling screws. Level the instrument by adjusting two pairs of opposite leveling screws alternately, keeping the pressure on the tripod plate very light until the instrument is practically level. Finish by slightly increasing the pressure until the screws are firm but not tight. If one pair of screws should bind, loosen *one* screw of the *opposite pair*.

To Level the Instrument with the Telescope Level. When sights are taken to objects at a considerable vertical angle above or below the instrument, the accuracy of the results depends to a large degree on how accurately the instrument has been leveled. No system of observations will eliminate errors of leveling. It is a good rule to level the instrument with the telescope level when sights with a vertical angle of over 20 degrees are to be observed.

Level the instrument in the usual manner. Turn the vertical circle vernier to zero, set the upper clamp and turn the instrument until the telescope is aligned with a pair of opposite leveling screws. Set the lower clamp. Center the telescope bubble with the vertical tangent screw. Free the upper clamp and turn the instrument 180°. If the telescope bubble does not center, bring it half way toward the center with the vertical tangent screw. Level again with the leveling screws and repeat until the telescope bubble will center in both positions. Turn the instrument 90° and level with the leveling screws. The telescope bubble should now remain centered when the telescope is pointed in any direction.

Avoid any Contact with the Instrument. While operating the instrument never allow the clothing to come in contact with the tripod or the instrument. Never touch the instrument itself, except at the points necessary for operation, and when completing a sight be sure to touch only the tangent screw involved.

Reading the Vernier. To read the vernier hold the reading glass at least 1½ inches above the window. Steady the hand by touching the upper plate with the little finger. Keep both the center of the glass and the eye exactly in line with the lines on the part of the vernier that is being observed.

Raise the Compass Needle. Never pick up the instrument without raising the compass needle from its pivot. The least jar will cause the hard jewel to break off the fine pivot point, and thus make the needle sluggish. The needle will never be accurate again until the pivot has been resharpened.

To Use the Stadia Circle. Some transits are equipped with the K&E Stadia Circle No. 74 0505. The use of these circles facilitates stadia surveying by eliminating measurement of the vertical angle and the use of tables. For more detailed description of stadia surveying see page 102.

To Use the Base Plate for a Trivet. Three sharp pointed threaded studs are packed in each instrument box. When they are screwed into the bottom of the base plate it becomes a trivet. It can be used instead of a tripod for set-ups on wood or masonry or for very low set-ups.

To Return the Instrument to its Case. Be sure that the leveling head is near the center of the tripod plate. Level the instrument so that the leveling head is parallel to the tripod plate. Clamp the telescope securely so that it is approximately horizontal. Tighten the upper clamp securely and free the lower clamp. Unscrew the instrument from the tripod and screw it securely on the base plate. Turn the telescope so that it faces left and is parallel to the long edge of the base plate. Tighten the lower clamp securely. Loosen the leveling screws slightly, so that the instrument will shift.

Slide the base plate under the guides in the bottom of the case. If there is a chocking block at the back of the case, shift the instrument as it moves in, so that it is centered in the block. If there is no block in the case, center the instrument carefully. Push the base home and tighten two adjacent leveling screws securely.

Make sure that the telescope is free from all contact with the case and that the leveling screws and the clamps are all tight. See that the door closes without interference. Do not force the door. If it will not close without strain, something is wrong. Finally close the door and fasten the hooks. Replace the tripod cap and strap the tripod legs.

To Transport the Instrument. Keep it from vibration and away from contact with any hard surface. On the floor of a car, stand the case on its rubber feet. Place some soft material around it to prevent it from falling. Before shipping instruments see page 93.

TRANSIT CARE

Rain, Snow or Dust. Rain or snow will not damage the instrument. If it becomes wet, let the instrument dry off, if possible in some dust-free place. It is not necessary to wipe it off. Excess dust penetrating an instrument will damage it. It is for this reason that K&E instruments are made virtually dustproof and moistureproof. If it is necessary to work in dust or in rain, keep the waterproof hood over the instrument as much as possible.

To Clean the Lenses. Considerable dirt can accumulate on the objective lens (front lens) without affecting the operation of the instrument. If the light through the telescope appears to be dim, it is probably caused by dirt on the exterior surface of the rear eyepiece lens rather than on the objective. To reach this surface remove the eyepiece end cap. To clean the lenses work off the dust with the camel hair brush provided. It is almost never necessary to remove the objective lens from a K&E telescope. This operation should be performed only by a competent instrument repairman. Even loosening and reseating the lens will disturb adjustments 4, 6, and 7 (pages 31-34) and, unless the lens is removed in dry, dust-free air, the telescope may be damaged.

To Avoid Damage. The instrument should never receive a blow of any kind. If it should fall over, a factory repair will usually be required. It is advisable to follow these two well known rules:

1. Never leave the instrument unattended when it is out of its case.

2. Never set up the instrument without finding good footing for the tripod and spreading the legs wide.

PARAGON® TRANSIT WITH OPTICAL PLUMMET

The K&E Optical Plummet and Parallel-Shift Tripod provide the quickest, easiest, and most accurate means of setting an instrument over a point. The operation is simple, but certain important points concerning procedure are outlined below. See illustrations on pages 7-8.

General

When the transit is mounted on the tripod, or when it is picked up after work at a station, loosen the tripod clamp screw under the tripod head, and center the instrument on the tripod. Retighten the clamp screw. CAUTION: To prevent possible damage to the instrument, ***never*** pick up the transit and tripod without tightening the tripod clamp screw.

Procedure

The instrument may be set up over a point either with or without a plumb bob as a preliminary aid.

1. Position the tripod over the point. When using a plumb bob, suspend it from the hook located inside the tripod clamp screw. (This hook is locked out of the way when not being used.) Adjust the tripod legs to bring the plumb bob to about an inch of the point, at the same time keeping the tripod head nearly level. Remove plumb bob and lock hook to side of tripod clamp screw.

2. Level the instrument with the leveling screws.

3. Focus the Optical Plummet by sliding the outer ring of the eyepiece in and out until the cross lines of the reticule are sharp. Grasp inner ring and slide in and out until the ground or the mark is in focus. (The outer ring moves with the inner ring and the reticule remains in focus.)

4. Loosen the tripod clamp screw. While looking through the Optical Plummet, shift the instrument until the cross lines are precisely centered on the mark. Tighten the tripod clamp screw, and check to see that mark is still centered. If necessary, relevel the instrument. (Minor releveling will not affect the Optical Plummet.)

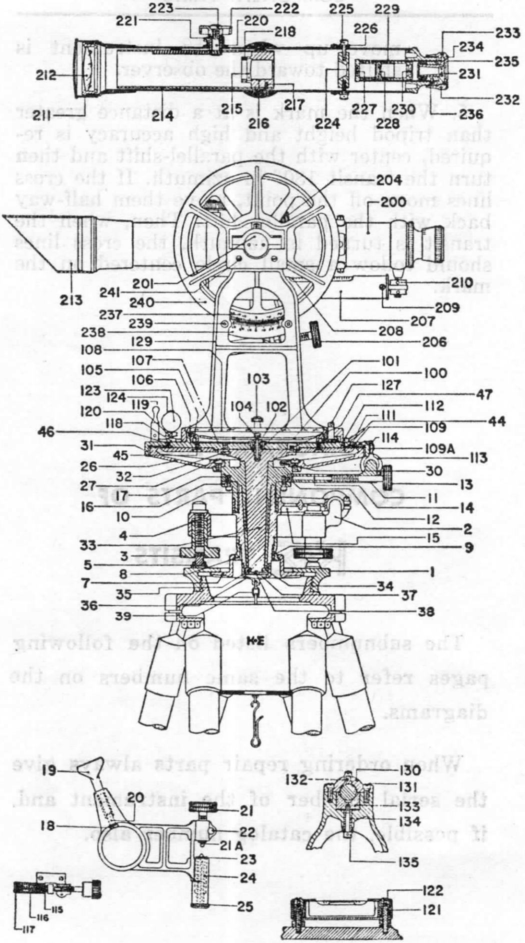
Note: When looking through the Optical Plummet, the cross lines appear to move to the right when the instrument is shifted to the right. They appear to move up when the instrument is shifted toward the observer.

5. When the mark is at a distance greater than tripod height and high accuracy is required, center with the parallel-shift and then turn the transit 180° in azimuth. If the cross lines move off the point, move them half-way back with the parallel-shift. Then, when the transit is turned in azimuth, the cross lines should follow a small circle centered on the mark.

DIAGRAMS AND COMPONENT PARTS OF K+E TRANSITS

The subnumbers listed on the following pages refer to the same numbers on the diagrams.

When ordering repair parts always give the serial number of the instrument and, if possible, the catalog number also.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5206-1 Tripod Plate
2 Leveling Head
3 " Screw Head
4 " " Stem
5 " " Shoe
7 Shifting Plate
8 Half Ball
9 " " Lock Screw
10 Outer Center
11 Vernier Plate Clamp
12 " " " Gib
13 Vern. Pl. Cl. Screw
14 Vernier Plate Clamp Screw Pin
15 Lower Clamp
16 " " Collar
17 " " " Mounting Screw
18 Lower Clamp Gib
19 " " Screw
20 " " Screw Pin
21 Lower Clamp Tangent Screw
21A Clamp Tangent Screw Pivot Pin
22 Clamp Tangent Screw Tension Screw
23 Lower Clamp Tangent Screw Plunger
24 Lower Clamp Tangent Screw Spring
25 Lower Clamp Tangent Screw Cap
26 Horizontal Circle
27 " " Mounting Screw
30 Horizontal Circle Centering Screw
31 Vernier Plate
32 " " Mounting Screw
33 Inner Center
34 Center Nut
35 " " Lock Screw
36 Center Cap
37 " Spring
38 " Ball
39 Plumb Bob Chain and Hook
44 Spanned Verniers
45 " " Mounting Screw
46 Spanned Verniers Height Adjusting Sc
47 Spanned Verniers Centering Screw
100 Compass Needle
101 " " Lifter
102 Compass Needle Lifting Bushing
103 Compass Needle Lifting Screw Assembly
104 Compass Needle Pivot
105 " Ring
106 " " Spring
107 " Dial
108 " Cover Glass & Mount
109 Vernier Cover Glass
109A Vernier Cover Glass Strap
109B Vernier Cover Glass Strap Screw (not shown)
111 Vernier Reflector
112 " " Frame & Hinge
113 Vernier Plate Clamp Tangent Screw
114 Vernier Plate Clamp Tangent Screw Spring Box
115 Tang. Sc. Plunger
116 " " Spring
117 " " Cap
118 Plate Level Bracket & Posts complete
119 Plate Level Vial Guard
120 Plate Level Adj. Nut
121 Plate Level Spring
122 Plate Level Post Cap
123 Plate Level Vial, Tube & Ends complete
124 Plate Level Vial
127 Declination Adjustment Pinion & Washer
129 Standard
130 Trunnion Cap
131 " " Screw
132 " Friction Screw

When ordering parts, state Serial No. of instrument.

5206-133 Trunnion Bearing Block
134 Trunnion Bearing Block Adjusting Screw
135 Trunnion Bearing Block Lock Screw
200 Telescope Barrel & Axle
201 Tele. Axle End Cap
202 Telescope Clamp (Not shown)
203 Telescope Clamp Gib (Not shown)
204 Tele. Clamp Screw
205 Telescope Clamp Screw Pin (Not shown)
206 Telescope Clamp Tangent Screw
207 Tele. Level Vial, Tube & Ends complete
208 Tele. Level Vial only
209 Telescope Level Tube End Lock Screw
210 Telescope Level Adjusting Nut
211 Objective Cap
212 " Lens & Mount
213 Sunshade
214 Telescope Draw Tube
215 " Focusing Lens
216 Telescope Focusing Lens Mount
217 Telescope Focusing Lens Mount Lock Screw
218 Telescope Focusing Lens Lock Ring
219 Telescope Focusing Pinion, Pinion Head (222) & Screw (223) complete
220 Telescope Focusing Pinion
221 Telescope Focusing Pinion Lock Screw
222 Telescope Focusing Pinion Head
223 Telescope Focusing Pinion Head Screw
224 Reticule
225 Reticule Adjusting Screw
226 Reticule Adjusting Screw Shutter
227 Eyepiece Lens I & Mount
228 Eyepiece Lens II & Mount
229 Eyepiece Tube
230 Eyepiece Lens III & Mount
231 Eyepiece Focusing Lens & Mount
232 Eyepiece Focusing Ring
233 Eyepiece Focusing Ring Set Screw
234 Eyepiece Cap
235 " Focusing Sleeve
236 Eyepiece Focusing Sleeve Screw
237 Vertical (Stadia) Circle
238 Vertical Circle Vernier
239 " " " Post & Nuts
240 Vertical Circle Guard
241 " " " Screw

When ordering parts, state Serial No. of instrument.

MAINTENANCE, LUBRICATION AND DISASSEMBLY OF TRANSITS

Precautions for Taking the Instrument Apart. *In general, the instrument should never be taken apart.* If it becomes absolutely necessary to take it apart for lubrication, this should be done indoors and where there is no dust. The greatest care should be exercised throughout the entire operation as *there is more chance for damage and for the infiltration of dust when the instrument is taken apart than in many years of field service.*

Transits must be lubricated only very occasionally. Only special instrument lubricant should be used. Very little should be applied, as excess lubricant collects dust. Each surface to be lubricated should be wiped dry with a clean lint-free cloth. If the surface is gummy, a little naphtha may be used to clean it. Interior surfaces can be reached by covering a wooden stick with the cloth. Lubricant equivalent to not more than one drop of fine watch oil should be applied at each of the points listed. The lubricant should be applied to each part just before re-assembly. It should be well spread and worked in and then all excess carefully wiped dry. To work the lubricant into the center bearings, put the two mating parts together, then raise and turn and lower to four or five positions.

PARTS TO BE LUBRICATED

1. Bearing surface and shoulder of inner center.

2. Outer bearing surface and shoulder of outer center.

3. Telescope axle bearings.

4. Spring and plunger for each tangent screw.

5. Threads of clamp screws, tangent screws and leveling screws.

6. Collars and surfaces of the three clamps.

7. Surface of half ball and both surfaces and thread of tripod plate.

To reach some of these points the transit must be partly disassembled. The steps for taking it apart and reassembling it are given here.

TO DISASSEMBLE THE TRANSIT

1. Turn the telescope horizontal, tighten all three clamps, and unscrew and remove the three tangent screws. Note where each belongs.

2. Unscrew and remove the three tangent screw spring box caps together with their springs and plungers. Note where each belongs.

3. Remove the vertical circle guard fastening screws and remove the guard, taking great care not to touch the vertical circle.

4. Remove the telescope trunnion cap screws and lift the trunnion caps off.

5. Lift out the telescope. Unscrew the telescope clamp lock nut. Unscrew the telescope clamp screw and take off the clamp, being very careful not to touch the vertical circle. Lay the telescope assembly down without allowing the vertical circle to touch anything.

6. Lay the instrument carefully on its side and unscrew the plumb bob chain and eye or center cap 36, if provided. Be careful not to drop out the ball 38 and spring 37.

7. Loosen the center nut lock screw, if one is provided. Remove the center nut 34 with the special wrench provided.

8. While pushing the leveling head and the standards together, carefully set the instrument

upright. Lift out the alidade carefully, rotating it back and forth slightly to start it. Avoid touching the center bearing surfaces with the end of the center. Lay the alidade carefully on its side with the center horizontal but not touching anything. Lift out the circle assembly with the same care, being sure to avoid touching the circle graduations with the fingers. Lay it face down on a clean, soft cloth.

9. Loosen the leveling screws. Turn the leveling head on its side and remove the half ball lock screw 9 and unscrew the half ball 8. The shifting plate and the tripod plate will come off with it.

10. If the instrument has fully enclosed leveling screws, unscrew the leveling screw caps. (These are left hand threads.) Unscrew the four leveling screws. Note where each belongs. Unscrew the leveling screw stems. Thread and unscrew the leveling screw shoes.

If the instrument has exposed leveling screws, remove the leveling screw dust caps if any. Unscrew the leveling screws. Note where each belongs. Thread and unscrew the leveling screw shoes if the instrument has this type.

11. Loosen the lower clamp screw and remove the assembly. Note which side is uppermost.

12. Unscrew the upper clamp collar screws. These are the slotted screws, and they are nearest the center. (On some instruments these are on the lower side of the collar.) Mark the position of the collar with a pencil. Be very careful not to touch the circle centering screws or vernier disc centering screws. If these are disturbed, the centering of the circle and vernier disc will be lost. Re-centering is impossible except by a trained instrument repairman. Remove the collar. Loosen the upper clamp

and remove it. The gib and the connecting shaft can be dropped out.

13. Remove both upper and lower clamp screws.

All surfaces that need to be cleaned and oiled are now exposed.

TO RE-ASSEMBLE THE TRANSIT

1. Replace the upper clamp screw, the connecting shaft and the gib. Replace the assembly on the drum with the lug up. Replace the upper clamp collar and screws and screw them home, with equal pressure on each. Tighten the clamp.

2. Replace the lower clamp screw, replace the assembly, and tighten the clamp.

3. Replace the leveling screw assembly. Make sure the stems are tight and the leveling screws are screwed well in (on instruments with fully enclosed leveling screws).

4. Place the tripod plate and the shifting plate in position and screw on the half ball. Turn the half ball home so that the lock screw can be replaced, and screw in the lock screw.

5. Stand the leveling head upright, tighten the leveling screws so that the head is about parallel with the tripod plate and not free to tilt. Lower the circle assembly carefully into place. Avoid touching the bearing surface or the shoulder with the end of the center. While the circle assembly is being lowered, turn it so that the lower clamp fits over the lug on the leveling head.

6. Carefully lower the alidade into place. Avoid touching the bearing surface or the shoulder with the end of the center, or the circle with the vernier plate. While the alidade is being lowered, turn it so that the lug on the clamp fits between the two parts of the spring

box. When it has been lowered almost home, see that the circle assembly still rotates freely and be careful to avoid striking the verniers against the edge of the graduated circle.

7. While pushing the leveling head and the standards together, turn the instrument on its side and replace the center nut. Screw it home. Tighten the lock screw, if provided. Replace the center nut cap, if provided. Then stand the instrument erect.

8. Replace the telescope clamp and the telescope clamp lock nut. Place the telescope axle in its bearings.

9. Replace the telescope trunnion caps according to the matching numbers. Be sure that the bearing surface of the friction screw is aligned with the axle. Replace the screws and screw them home.

10. Replace the tangent screw plungers, springs, caps and tangent screws.

11. Replace the vertical circle guard.

12. Adjust the friction screw at the top of the left hand telescope axle trunnion cap so that the telescope is free, but will not move from its own weight with the sunshade in position and the instrument focused at a distant point.

To Remove the Reticule. If it is necessary to remove the reticule, proceed as follows:

1. Loosen the set screw at the eye end of the main telescope tube and unscrew the eyepiece.*

2. Remove the two horizontal reticule adjusting screws. Loosen the top adjusting screw and, by turning both top and bottom screws, turn

*On some instruments it is first necessary to remove the four eyepiece centering ring screws.

the reticule so that its plane is parallel with the telescope.

3. Thread a pointed stick of soft wood into the side screw hole of the reticule now facing the eyepiece end of the telescope.

4. Remove the two remaining reticule adjusting screws and carefully withdraw the stick with the reticule on it.

If the reticule has spider web cross lines, the spider web can be removed with alcohol.† New spider web should be replaced under tension and placed exactly on the scribed marks on the reticule. This should be done under plenty of light and using the eyepiece as a microscope. The new spider web can be held in place with a drop of shellac.

To replace the reticule in the telescope reverse the order of the steps for removing it.

After replacement, the stadia ratio should be re-determined.

CAUTION

After the instrument is completely re-assembled, all adjustments should be tested.

Preparation for Arctic Temperatures. A K&E repeating transit will operate perfectly at Arctic temperatures if lubricated with special cold temperature lubricant. This can be purchased through any K&E dealer or branch. The instrument should be disassembled and all the old lubricant removed with naphtha before applying the special lubricant.

ADJUSTMENTS

Surveying instruments should be tested frequently but adjusted rarely. Modern instruments seldom get out of adjustment. Adjustments are sometimes necessary after repairs, but the chief need for adjustment is caused by improper adjustments that were not required in the first place.

†This operation should be attempted only if it is impossible to obtain the services of a skilled instrument repairman.

Before it is assumed that adjustments are necessary, it is essential to be positive that any apparent lack of adjustment is actually due to the condition of the instrument and is not caused by deficiencies in the test. To test an instrument properly, observe the following precautions:

1. If possible, choose a cloudy day.

2. See that the tripod shoes are tight and the instrument firmly screwed to the tripod.

3. Set up on firm ground, out of the sun but in good light, where clear sights of about 200 ft. can be made in opposite directions.

4. Spread the tripod feet well apart and place them so that the tripod plate is nearly level. Press the shoes firmly into the ground or place them in chipped depressions in masonry.

5. If a conventional tripod is being used, after setting up, free and then tighten all three tripod hinge screws to relieve residual friction. With a K&E Wide Frame Tripod, this operation is unnecessary.

6. Attach the sunshade and carefully focus the eyepiece. After leveling the instrument, loosen all four leveling screws slightly and relevel to relieve any residual strain. Have all screws equally firm but not too tight. Too much force will deform the centers and introduce both friction and play.

7. Go through all of the tests in the order given for the type of instrument being tested. Do not adjust the instrument unless a particular test indicates the *same* amount of error at least three times.

Be on the lookout for *creep*, particularly when adjusting the levels. Creep is caused by tripod settlement, or by the temperature of the instrument changing. This is particularly apt to happen if the instrument has just been brought out-of-doors or is exposed to body or other radiant heat. After setting a bubble or the line of sight, let it stand a few seconds to see that no movement occurs.

8. Before making the adjustment, consider whether or not the error discovered will have a material effect on field results. In making this decision remember that most tests make the error appear double in amount.

Adjustments should be made in the order given, so that no previous adjustments will be disturbed. At the completion of the adjustment the parts should be set firmly home without strain. After any adjustment has been made, the proper test should be applied at once. After all the contemplated adjustments have been completed, all of the tests should be applied again in the proper order, in case some other adjustments might have been disturbed.

TRANSIT ADJUSTMENTS

First read the general directions under "Adjustments" on pages 28-30.

Plate Levels

1. ***Object.*** To adjust the plate levels so that the bubbles will center when the azimuth axis of the instrument is placed in the direction of gravity, i.e. made truly vertical.

Test. Set the horizontal circle vernier at zero. Clamp the upper clamp. With the lower clamp free, turn the instrument in azimuth until each plate level is aligned with a pair of opposite leveling screws. Set the lower clamp. Center the bubbles precisely. Free the upper clamp and turn the instrument 180° in azimuth. The bubbles should center.

Adjustment. If either bubble fails to center, bring it half way back with the leveling screws. Then, by turning the capstan head nut at the adjustable end, raise or lower that end of the level tube until the bubble centers.

The Cross Line Reticule

2. ***Object.*** To center the cross lines on the optical axis. This adjustment should not be made if it can be avoided, as it needs to be only approximately correct and it disturbs three other adjustments.

Test. If the cross lines appear to be in the center of the field of view they are near enough to the optical axis to give good results.

Adjustment. The cross line reticule is held in position by the four capstan head reticule adjusting screws in tension. Loosen two adjacent screws. By adjusting the four screws with the fingers, center the cross lines. Tighten the screws by alternately turning a vertical screw and a horizontal screw by small increments.

3. ***Object.*** To rotate the reticule until the vertical cross line is in a plane perpendicular to the elevation axis.

Test. Aim at a sharply defined point. Move the line of sight up and down with the telescope tangent screw. The vertical cross line should remain on the point.

Adjustment. Loosen two adjacent reticule adjusting screws. Gently tap the sides of the screws so that they move around the telescope until the vertical cross line is rotated to its correct position. Tighten the same screws. As the cross lines are placed on the reticule at right angles at the factory, when the vertical line is correct, the horizontal line is also in its correct position.

4. ***Object.*** To make the line of sight perpendicular to the elevation axis.

Test. Sight some well defined point 200 feet or more distant. Reverse the telescope on its elevation axis and note or mark a point appearing on the vertical cross line at about the same elevation and distance from the instrument as the first point, but in the opposite direction. By turning the instrument approximately 180° in azimuth, again sight the original point. Again reverse the telescope on its elevation axis. The vertical cross line should fall on the second point.

Adjustment. Loosen the top reticule adjusting screw. Then by loosening one side screw and tightening the other alternately by small increments, move the cross line one quarter the distance toward the second point. Tighten the top screw. Recheck adjustments 2 and 3.

The Elevation Axis

5. ***Object.*** To make the elevation axis perpendicular to the azimuth axis.

Test. Sight some elevated point, such as a church steeple. Depress the telescope and note or mark a point near the ground on the vertical cross line. Reverse the telescope and turn it approximately 180° in azimuth. Sight the lower point. Raise the telescope. The vertical line should fall on the upper point.

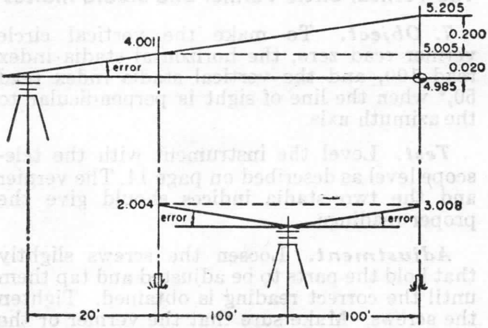
Adjustment. Move the cross line between one quarter and half the distance toward the upper point by raising or lowering the movable bearing block in one of the standards.

The Telescope Level

6. ***Object.*** To make the telescope level center when the line of sight is horizontal.

Test. The test is made by the *peg* method.

On fairly level ground set up the instrument where it is protected from the direct rays of the sun, and drive two stakes in opposite directions at exactly equal distances from the instrument. Preferably the stakes should be about 100 feet from the instrument. Take a rod reading on each stake. Level the telescope carefully for each reading, using the telescope level. The difference between the two readings will be the true difference in elevation between the stakes. Then set up in line with the two stakes, but at a known distance beyond one of them equal to some convenient decimal fraction of the distance between the stakes. Level the telescope carefully, and take a reading on the near stake.



The figure illustrates the operation described. If the reading of the near stake is 4.001, the reading on the far stake should be 4.001 plus the difference between the values obtained at the center set up, i.e. $3.008 - 2.004 = 1.004$. $4.001 + 1.004 = 5.005$. Assume that the horizontal cross line strikes at 5.205. The line of sight must slope upward at a rate of 0.200 ft. in 200 ft. In the 20 ft. between the instrument and the near stake, the error introduced by this slope is, by similar triangles, 1/10 of 0.200 ft. or 0.020 ft. Applying the two errors to the reading of the far stake, $5.205 - 0.200 - 0.020 = 4.985$. A target set at 4.985 will be level with the instrument.

If the line of sight, instead of striking above the computed reading, strikes below it, the two errors must be added to the rod reading instead of being subtracted from it.

Set the target accordingly. Using the vertical tangent screw, bring the horizontal cross line to the target.

Adjustment. Center the telescope level by raising or lowering the adjustable end by means of the adjusting nuts.

The Vertical Circle Vernier and Stadia Indices

7. ***Object.*** To make the vertical circle vernier read zero, the horizontal stadia index read 100, and the vertical stadia index read 50,* when the line of sight is perpendicular to the azimuth axis.

Test. Level the instrument with the telescope level as described on page 14. The vernier and the two stadia indices should give the proper readings.

Adjustment. Loosen the screws slightly that hold the parts to be adjusted and tap them until the correct reading is obtained. Tighten the screws. Make sure that the vernier or the indices have not been set so close to the circle that they bind.

ADJUSTMENT OF THE OPTICAL PLUMMET

The K&E Optical Plummet is factory adjusted and, with ordinary handling, field adjustment is rarely required. Before assuming adjustment is necessary, the test described below should be made at least three times. If all three results show the same error, adjustment is required.

Object. To adjust the line of sight of the Optical Plummet so that it coincides with the azimuth axis of the instrument.

*Omit references to stadia indices if the instrument is not so equipped.

Test. Draw a cross on a small card, fasten the card to a stake or other object so that it will not move. Level the instrument over the cross.

1. Aim the optical plummet exactly at the cross.

2. Rotate the transit 180° in azimuth. If the reticule moves off the cross, adjustment is required.

3. With the reticule cross lines remaining in the same position as found in 2 above, follow the adjustment procedure noted below.

Note: This test should be made at instrument height.

Adjustment. Proceed as follows:

1. Remove the plate level assembly located opposite the optical plummet eyepiece. To accomplish this, remove the screws at either end of the level assembly. Note which end of the level is forward so that it can be replaced in the original position. Remove the level, keeping it right-side up so that the springs do not fall out.

2. Remove the screw that is now exposed, and lift off the thin metal cover. This exposes three adjusting screws which appear as shown in the figure below.

3. With the leveling screws, bring the Optical Plummet cross lines half-way toward the mark. Then bring them precisely on the mark with the adjusting screws. (See instructions below.)

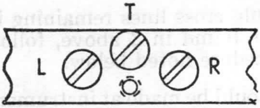
4. Repeat test and make further adjustments if necessary.

5. Replace the plate level assembly in its original position so that adjustment will not be required.

Operation of the Adjusting Screws

The screws should be adjusted with the narrow-tip screwdriver provided. All three screws oppose each other so that when one is loose, all are loose.

The movement of the cross lines, given below, refers to the appearance of the field of view when looking through the optical plummet. The indications of the screws to be used refer to their appearance (see figure) as you face them.

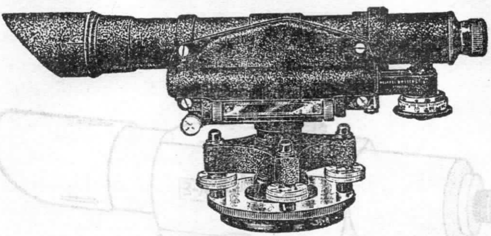


To move cross lines to right	Loosen L	Tighten R
To move cross lines to left	Loosen R	Tighten L
To move cross lines up	Loosen T	Tighten R & L equally
To move cross lines down	Loosen R & L equally	Tighten T

LEVELS

K&E offers three types of leveling instruments. The distinctive qualities of these instruments are described in the following pages.

The Tilting Level (K&E 75 0000). This instrument is designed for precision and speed. It has an erecting telescope of about 30 power. The bubble is observed through a coincidence device from a position about one inch to the left of the eyepiece. The bubble is centered by turning a micrometer screw, placed directly below the eyepiece end of the telescope, until the two ends of the bubble appear to coincide. This gives an extremely accurate setting and makes it possible to read the rod and to check the bubble almost simultaneously.

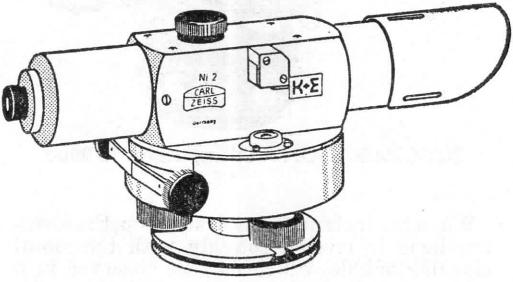


K&E PARAGON® Tilting Level 75 0000

When the instrument is first set up, the leveling head is leveled roughly with the small circular bubble, which may be observed in a mirror from a point about one inch to the right of the eyepiece. No time is wasted in walking around the instrument, or in turning it in azimuth, or by unnecessary precision in leveling it.

Adjustment is checked by means of the peg test. Any adjustment necessary is accomplished by moving the coincidence assembly backward or forward with a single screw. The instrument is recommended for all leveling work where speed with accuracy is essential.

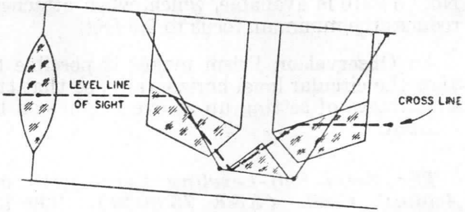
The Zeiss Self-Leveling Level (K&E 75 0020). This level is an unparalleled instrument. When it has been leveled by centering the circular level, it holds the line of sight precisely level *automatically*. It has been known to give first-order accuracy and is very fast and simple to use. These qualities make it an all-purpose level, which can be used with great advantage for any type of work from cross-sectioning to benchmark leveling. It is faster and more accurate than any of the instruments usually employed.



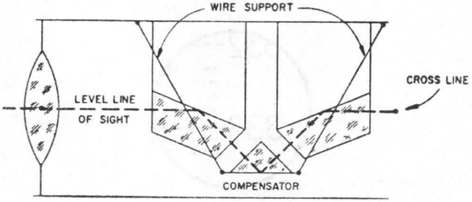
Zeiss Self-Leveling Level (K&E 75 0020)

The schematic line drawing (page 39) shows how it works. When the telescope is tilted, a prism called the *compensator* swings to a position that levels the line of sight. The movement of the prism is air-damped by a disk-like cylinder which moves over a stationary piston (not shown).

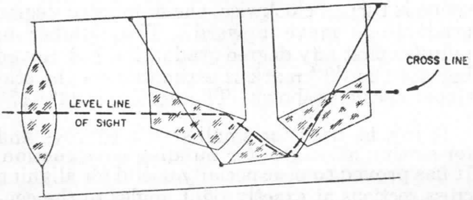
The three leveling screws have a fast pitch for rapid, approximate leveling. There is no azimuth clamp. The azimuth movement of the upper part of the instrument is controlled by an adjustable brake. The exact azimuth desired is set with an endless tangent screw, with two thumb screws, for either hand. The stiffness of the screw can be regulated by turning one thumb screw against the other. The focusing device has a high and low gear. A continuous motion in one direction utilizes the high gear. When the motion is reversed, the low gear operates for a short distance for precise focusing.



WHEN TELESCOPE TILTS UP
COMPENSATOR SWINGS BACKWARD



TELESCOPE HORIZONTAL



WHEN TELESCOPE TILTS DOWN
COMPENSATOR SWINGS FORWARD

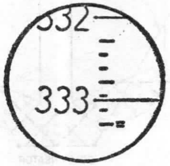
The reticule has stub stadia lines placed to give a stadia ratio of 0.3 : 100 for three-wire leveling. Other ratios* are available to order. The minimum focus is 11 feet. A focus reducing lens

* Other ratios, 0.6:100 and 1:100.

No. 75 0210 is available, which, when attached, reduces the minimum focus to 5.9 feet.

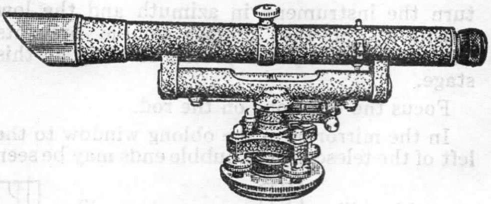
An Observation Prism makes it possible to view the circular level horizontally, so that the advantages of setting up at eye height can be utilized.

The Zeiss Self-Leveling Level with an Azimuth Circle (K&E 75 0030). The instrument described in the preceding section is also made with an azimuth circle. The circle is read through an auxiliary telescope to the left of



the main telescope. The line drawing shows what appears in the field of view. As the telescope is turned clockwise, the numbered degree graduations move upward. The number of minutes that any degree graduation has moved beyond the "0" mark is estimated on the stationary scale as shown. The reading is 333° 17′.

It can be used for small stadia surveys and for setting off angles for building construction. It has proved to be especially useful for aligning cross sections at exactly right angles to the centerline. In level country the rod can be aligned, the reading taken, and the offset distance determined by stadia in one operation. Spot elevations and topographical details can be located from the centerline by angle and stadia when a transit is not available and, in general, many operations can be carried out for which a transit is usually required.



K&E PARAGON® Dumpy Level 75 0300.

The Dumpy Level (K&E 75 0300). This is designed for accuracy, reliability and permanence of adjustment, and low cost. It contains a minimum number of parts. It is recommended for high grade leveling when fast operation is not a controlling factor.

The Transit. This can also be used as a level with excellent results. However, it is difficult to see the bubble through the standards and the speed of operation is accordingly reduced. But for general all-around surveying utility, of course, the transit is unsurpassed.

THE USE OF LEVELING INSTRUMENTS

THE TILTING LEVEL

If the optimum performance of the Tilting Level is desired, the proper procedure for first order leveling and the "least squares" method of adjusting the results should be followed. For these the reader is referred to Special Publications Nos. 239 and 240 of the U.S. Department of Commerce, Coast and Geodetic Survey, *Manual of Geodetic Leveling* and *Manual of Leveling Computation and Adjustment* by Howard S. Rappleye.

To Take a Rod Reading center the circular bubble with the leveling screws. This is a very quick operation, as it is unnecessary to turn the instrument in azimuth and the low sensitivity of the circular bubble prevents waste of time by too precise leveling at this stage.

Focus the telescope on the rod.

In the mirror or in the oblong window to the left of the telescope the bubble ends may be seen

something like  or perhaps like 

Turn the screw until the bubble ends are in

coincidence like this: 

The line of sight is now horizontal.

Take the rod reading.

Check the bubble coincidence immediately.

If the bubble ends coincided both ***before*** and ***after*** the observation, they must have coincided ***during*** the observation.

If the bubble ends are not bright, turn the reflector under the bubble so that more light is reflected up through the bubble tube. If the bubble ends do not appear, turn the micrometer screw until they come into view.

In extremes of temperature, the point of coincidence will appear near the top or the bottom of the window, according to the actual length of the bubble. This, of course, does not affect the accuracy of the instrument.

For Faster Rough Leveling. Profile leveling, cross sectioning and other rough leveling can be speeded up by use of the reversing point. The reversing point is the position of the tilting screw operating wheel that causes the bubble to center when the vertical axis is vertical. When the wheel is in this position, the instrument can be precisely leveled with the leveling screws exactly like a dumpy level. Once it is leveled in this manner, cross-section shots can be safely taken to hundredths of a foot without releveling.

Set up the instrument, center the circular bubble, turn the telescope until it is in line with a pair of opposite leveling screws, and center the main bubble with the tilting wheel by observing the coincidence of its ends. Turn the telescope 180° in azimuth and center the bubble by moving it half the distance with the leveling screws and half the distance with the wheel. Turn the telescope 90° in azimuth and center the bubble with the leveling screws. Repeat this procedure until the bubble ends remain in an 1/8 inch of coincidence in all positions. The tilting wheel will now be at its reversing point. Mark this position with a pencil or note the reading of the graduated circle if the instrument is so equipped.

The reversing point should be checked from time to time as it will change as wear occurs in the instrument.

When the circular level is in good adjustment, cross-section shots up to 200 feet long can be safely taken to tenths of a foot when the instrument is leveled with the circular level alone. Set the tilting wheel at its reversing point and center the circular bubble. Less than 10% of the shots will be in error by more than 0.05 foot.

ZEISS SELF-LEVELING LEVEL

Open the case, remove the instrument and place it on the tripod. The hold-down screw, attached to the tripod, is threaded into the hole at the base of the instrument. Tighten the screw firmly.

There is a very important rule that must be followed. *Always keep the circular level in perfect adjustment* as described under adjustment of levels on page 55. Neglect of this rule may cause the compensator to stick or to give inaccurate readings. The instrument should always be leveled so that the bubble is near the center of the vial. In precise leveling operations it must be centered *accurately*. When it is centered, the movement of the compensator is at a minimum. As the compensator is especially accurate near the center of its movement, this improves the accuracy of the work.

When very accurate results are required, the telescope should be pointed backward while the instrument is being leveled at the first instrument position, forward while being leveled at the second instrument position, and so on alternately throughout the level run. This eliminates the accumulation of certain, very small systematic errors. See section on Automatic Indexing, page 3.

Never relevel after the first sight has been taken. Unlike a 4-screw leveling head, the movement of any screw in a 3-screw leveling head changes the height of the instrument.

Be very careful when using the instrument on bituminous surfaces or on frozen ground. Unlike conventional spirit levels, it gives no indication of settlement by going out of level. Thus, changes in the height of instrument may go unnoticed.

For very precise leveling follow these two rules:

(1.) Keep the circular bubble centered when the instrument is not in use, especially when it is stored over night.

(2.) When two rods are used, take the foresight first at alternate set-ups.

THE DUMPY LEVEL

The Dumpy Level operation is well known. Certain important points in using any type of leveling instrument that make for better results are outlined here.

(1) ***Operations like those of a Transit.*** The following operations are accomplished in

the same manner as described for transits on pages 12-14, 16:

1. To tighten the tripod shoes.
2. To adjust the tripod hinges.
3. To focus the eyepiece.
4. To level the instrument.
5. To avoid contact with the instrument.
6. To transport the instrument.

(2) ***Make sure the Bubble is Centered.*** The telescope should be aimed at, and focused on the rod before the bubble is precisely centered. The moment it is centered, the rod should be read and the bubble checked immediately afterward. When this procedure is followed the bubble is sure to be exactly centered at the moment the rod is read.

(3) ***Balance the Sights.*** At any instrument position the backsight, to obtain the height of instrument, and the foresight, to carry the elevation forward, should have nearly equal horizontal lengths in order to neutralize any residual error in instrument adjustment.

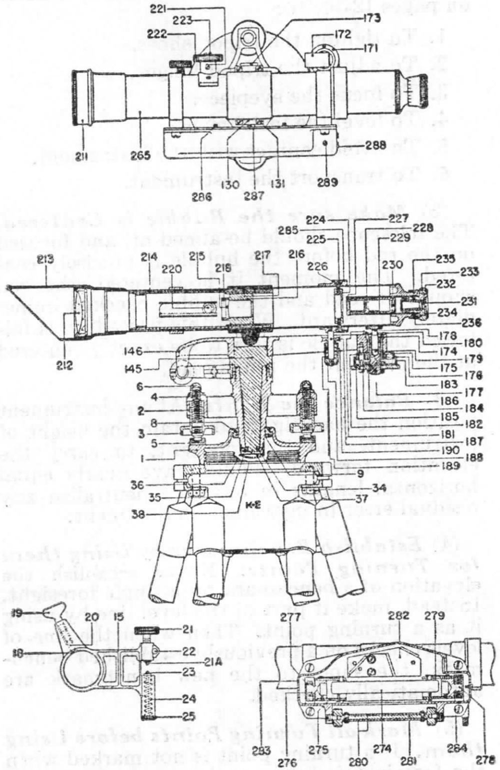
(4) ***Establish Benchmarks by Using them for Turning Points.*** Never establish the elevation of a benchmark by a single foresight. Instead, make it part of the level line by using it as a turning point. Then when the line of levels checks on a previously established benchmark, the shots to the new benchmark are automatically checked.

(5) ***Mark all Turning Points before Using them.*** If a turning point is not marked when the foresight is taken on it, some other point might be used in error for the next backsight.

CARE OF LEVELING INSTRUMENTS

Same as for Transits (pages 16-17).

K&E PARAGON®
TILTING LEVEL



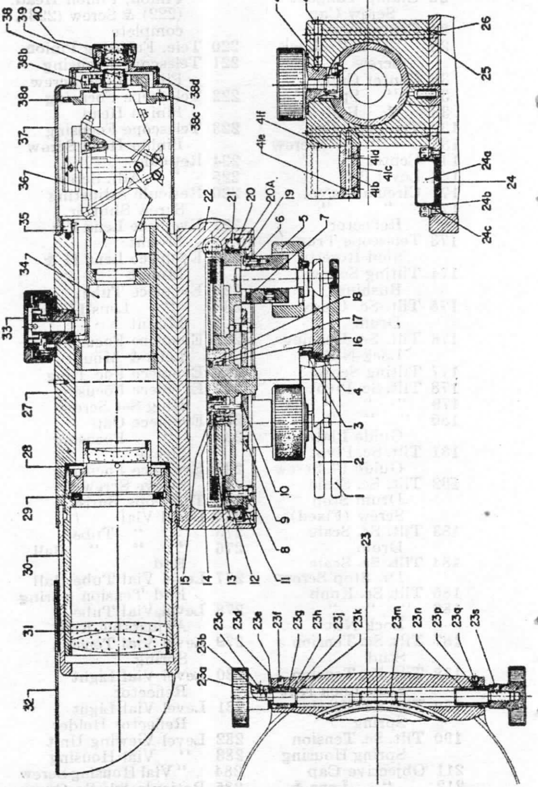
5210-1 Tripod Plate
2 Leveling Head
3 " Screw Head
4 " " Stem
5 " " Shoe
6 " " Cap
8 Half Ball
9 " " Lock Screw

15 Clamp
18 " Gib
19 " Screw
20 " " Pin
21 " Tangent Screw
21A " " "
Pivot Pin

5210-22 Clamp Tangent Screw Tension Screw
23 Clamp Tangent Screw Plunger
24 Clamp Tangent Screw Spring
25 Clamp Tangent Screw Cap
34 Center Nut
35 " " Lock Screw
36 Center Cap
37 " Spring
38 " Ball
130 Trunnion Cap
131 " " Screw
145 Center
146 Level Bar
171 Circular Level
172 " " Reflector
173 Telescope Trunnion Rosette
174 Tilting Screw Bushing
175 Tilt. Sc. Index Drum
176 Tilt. Sc. Bushing Lock Nut
177 Tilting Screw
178 Tilt. Sc. Pivot
179 " " " Ball
180 " " " Guide Plate
181 Tilt. Sc. Pivot Guide Pl. Screw
182 Tilt. Sc. Scale Drum Stop Screw (Fixed)
183 Tilt. Sc. Scale Drum
184 Tilt. Sc. Scale Dr. Stop Screw
185 Tilt. Sc. Knob
186 " " " Lock Nut
187 Tilt. Sc. Tension Stud
188 Tilt. Sc. Tension Stud Lock Nut
189 Tilt. Sc. Tension Spring
190 Tilt. Sc. Tension Spring Housing
211 Objective Cap
212 " Lens & Mount
213 Sunshade
214 Tele. Draw Tube
215 Telescope Focusing Lens
216 Telescope Focusing Lens Mount
217 Tele. Focusing Lens Mount Lock Screw
218 Tele. Focusing Lens Mount Lock Ring
219 Telescope Focusing Pinion, Pinion Head (222) & Screw (223), complete
220 Tele. Focusing Pinion
221 Telescope Focusing Pinion Lock Screw
222 Telescope Focusing Pinion Head
223 Telescope Focusing Pinion Head Screw
224 Reticule
225 " Adj. Screw
226 Reticule Adjusting Screw Shutter
227 Eyepiece Lens I & Mount
228 Eyepiece Lens II & Mount
229 Eyepiece Tube
230 " Lens III & Mount
231 Eyepiece Focusing Lens & Mount
232 Eyepiece Foc. Ring
233 Eyepiece Focusing Ring Set Screw
234 Eyepiece Cap
235 " Focusing Sleeve
236 Eyepiece Focusing Sleeve Screw
265 Telescope Barrel
274 Level Vial
275 " " Tube
276 " " " Ball End
277 Level Vial Tube Ball End Tension Spring
278 Level Vial Tube Adjustable End
279 Level Vial Tension Spring
280 Level Vial Light Reflector
281 Level Vial Light Reflector Holder
282 Level Viewing Unit
283 " Vial Housing
284 " Vial Housing Screw
285 Reticule Adj. Sc. Cover
286 Bubble Adj. Lock Scr.
287 " " Screw
288 Mirror Attach. Screw
289 Screw for Bubble Adjusting Hole

When ordering parts, state Serial No. of instrument.

ZEISS Ni 2
SELF-LEVELING LEVEL



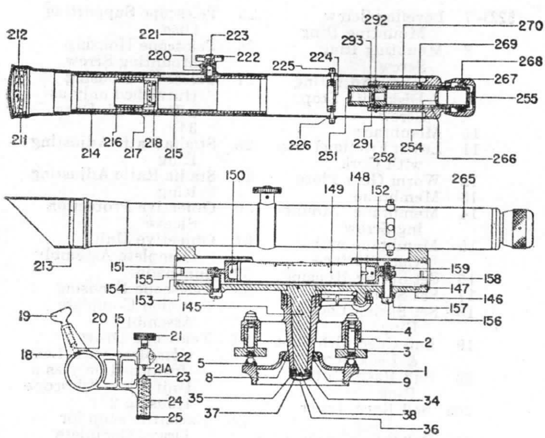
5223-1	Lower Foot Plate	5	Leveling Screw, Complete Assembly
2	Upper Foot Plate	6	Leveling Screw Assembly Fastening Screw
3	Tension Spring		
4	Foot Plate Lock Ring		

ZEISS Ni 2
SELF-LEVELING LEVEL

5223- 7	Leveling Screw Mounting Ring	
8	Mounting Ring Screw	
9	Friction Adjusting Disk with Stop Screw	
10	Membrane	
11	Lower Friction Plate with Cork	
12	Worm Gear Plate	
13	Membrane	
14	Membrane Mounting Screw	
15	Membrane with Cork Surface	
16	Set Spring Housing	
17	Set Spring	
18	Set Spring Lock Ring	
19	Ball Cage with Shoe & Lock Screw	
20	Ball Race, Outer Ring	
20a	Ball Race, Inner Ring	
21	Ball (Mention Quantity Required When Ordering)	
22	Box Housing for Telescope	
23	Lateral Drive, Complete Assembly	
23a	Knob	
23b	Leather Shoe	
23c	Leather Shoe Screw	
23d	Spring Washer	
23e	Plastic Washer	
23f	Right Bearing Set Screw	
23g	Right Bearing	
23h	Plastic Washer	
23j	Metal Washer	
23k	Spring Washer	
23m	Worm	
23n	Left Bearing	
23p	Coil Spring	
23q	Coil Spring Screw	
23s	Left Knob Set Screw	
24	Circular Vial & Housing Complete Assembly	
24a	Circular Vial	
24b	Mount	
24c	Adjusting Screw	
25	Telescope Supporting Disc	
26	Telescope Housing Mounting Screw	
27	Telescope Housing (furnished only as a Unit with Draw 34)	
28	Stadia Ratio Adjusting Ring	
29	Stadia Ratio Adjusting Ring	
30	Objective Protection Sleeve	
31	Objective Unit, Complete Assembly	
32	Sunshade	
33	Telescope Focusing Pinion Complete Assembly	
34	Telescope Draw Complete with Lens (furnished only as a Unit with Telescope Housing 27)	
35	Excentric Stop for Draw, Complete	
36	Compensator Unit, Complete Assembly	
37	Ocular, Complete Assembly	
38	Reticule, Complete Assembly	
38a	Reticule Centering Mount	
38b	Reticule Adjusting Screw	
38c	Reticule Centering Mount Screw	
38d	Reticule Screw Cover	
39	Eyepiece Cap with Diopter Scale	
40	Eyepiece Cap Lock Screw	
41a	Prism (not shown)	
41b	Mount	
41c	Lock Plate	
41d	Prism Plate Screw	
41e	Observation Prism Assembly Mounting Screw	
41f	Intermediate Disk	
42	Cover Screw	
43	Focusing Pinion Lock Screw	

When ordering parts, state Serial No. of instrument.

K&E PARAGON®
DUMPY LEVEL



5216- 1 Tripod Plate
2 Leveling Head
3 " Screw Head
4 " " Stem
5 " " Shoe
8 Half Ball
9 " " Lock Screw
15 Clamp
18 " Gib
19 " Screw
20 " " Pin
21 Clamp Tangent Screw
21A " Tangent Screw Pivot Pin
22 " Tangent Screw Tension Screw
23 " Tangent Screw Plunger
24 " Tangent Screw Spring
25 " Tangent Screw Cap
34 Center Nut
35 Center Nut Lock Screw
36 Center Cap
37 " Spring
38 " Ball
145 Center
146 Level Bar
147 " " End Cap
148 Telescope Level Vial Tube & Ends complete
149 Telescope Level Vial only
150 Telescope Level Vial Tube End Lock Screw
151 Telescope Level Pivot
152 " " Tube End Position Pin
153 Telescope Level Tension Screw
154 Telescope Level Tension Screw Spring
155 Telescope Level Tension Screw Stud
156 Telescope Level Adjusting Screw
157 Telescope Level Adjusting Screw Bushing
158 Telescope Level Adj. Sc. Washer
159 Telescope Level Adjusting Screw Nut
211 Objective Cap

5216-212 Objective Lens & Mount
213 Sunshade
214 Telescope Draw Tube
215 " Focusing Lens
216 Telescope Focusing Lens Mount
217 Telescope Focusing Lens Mount Lock Screw
218 Tele. Focusing Lens Mount Lock Ring
219 Telescope Focusing Pinion, Pinion Head (222) and Screw (223) complete
220 Telescope Focusing Pinion
221 Telescope Focusing Pinion Lock Screw
222 Telescope Focusing Pinion Head
223 Telescope Focusing Pinion Head Screw
224 Reticule (See 74 0300)
225 " Adjusting Screw
226 Reticule Adjusting Screw Shutter
251 Reticule Lens I & Mount
252 Reticule Lens II & Mount
254 Reticule Lens III & Mount
255 Reticule Lens IV & Mount
265 Telescope Barrel
266 Eyepiece Body
267 " Focusing Ring
268 Eyepiece Focusing Ring Lock Screw
269 Eyepiece Cam Screw
270 " Draw Tube
291 Front Aperture
292 Tension Spring
293 Ring, Eyepiece Guide

When ordering parts, state Serial No. of instrument.

MAINTENANCE, LUBRICATION AND DISASSEMBLY OF LEVELING INSTRUMENTS

(Except the Zeiss Self-Leveling Level)

In the maintenance of levels, the following are accomplished as described for transits on pages 23, 24, 27, 28.

1. Precautions for taking the instrument apart.
2. To remove the reticule.
3. Preparation for Arctic temperatures.

A level is lubricated in the same manner as a transit (see page 23), except that only the following points need be lubricated:

1. Bearing surface and shoulder of center.
2. Spring and plunger of clamp.
3. Threads of clamp screw, tangent screw and leveling screws.
4. Collar and surface of clamp.
5. Surface of half ball, and upper surface and thread of tripod plate.

If the level is a tilting instrument the following points should also be lubricated:

1. Micrometer screw.
2. Telescope trunnion bearings.
3. Tilting screw compression spring.

TO DISASSEMBLE THE LEVEL

If the level is a tilting instrument, first remove the telescope from the trunnion bearings as follows:

1. Unscrew tension stud lock nut (188) and tension spring housing (190). The tension spring should fall out.

2. Unscrew telescope trunnion bearing cap screws (131) and remove caps (130), noting matching numbers.

3. Lift out telescope.

4. Then proceed as for a Dumpy Level.

If the instrument is a Dumpy Level:

1. Remove level bar and center in the same way that the alidade and the circle assembly are removed on a transit.

2. Remove clamp mechanism as described for the transit (page 25).

3. Remove half ball and leveling screws as described for the transit on page 25.

All surfaces that need to be cleaned and lubricated are now exposed. Re-assemble the instrument in reverse order.

LEVEL ADJUSTMENTS

TILTING LEVEL ADJUSTMENTS

First read the general directions under "Adjustments" on pages 28-30.

Object. To make the coincidence of the ends of the bubble occur when the line of sight is horizontal.

Test. Make the test for the peg adjustment as described for the telescope level of the transit.

Adjustment. After the target has been set, bring the line of sight on it by turning the micrometer screw.

There are three capstan head screws at the back of the bubble housing. Loosen the two outside screws. Turn the middle screw until the ends of the bubble are in coincidence. Retighten the two outside screws.

No other adjustments are necessary.

ZEISS SELF-LEVELING LEVEL ADJUSTMENTS

Before it is assumed that adjustments are necessary, it is essential to make sure that any apparent need for adjustment is actually due to the condition of the instrument and is not caused by deficiencies in the test. To test an instrument properly, observe the following precautions:

1. Choose a firm support for the instrument. Usually this can be found only outdoors. The floor of a building, even when made of concrete, will deflect when the observer moves around the instrument.

2. If possible, choose a cloudy day. If the sun is shining, the work must be carried out in the shade, but in good light.

3. The circular bubble should be centered at once, and then the instrument must have time to accommodate itself to temperature and to eliminate hysteresis in the pendulum support. This requires 30 minutes to an hour, depending on how great a temperature difference exists between the place of storage and the outdoor temperature.

4. Be on the lookout for *creep* when adjusting the circular level. Creep is caused by tripod settlement, or by the temperature of the instrument changing. This is particularly apt to happen if the instrument has just been brought out-of-doors or is exposed to body or other radiant heat. After setting a bubble or the line of sight, let it stand a few seconds to see that no movement occurs.

5. The line of sight of a Zeiss Level seldom gets out of adjustment. Adjustment should not be undertaken except as the result of several sets of tests made after the circular level has been carefully adjusted.

To Adjust the Friction of the Leveling Screws. After considerable use the leveling screws may become slightly loose where they are threaded into the tribrach or leveling head. This play is not serious when using the instrument as a level. However, if the instrument has a horizontal circle and it is used to measure angles, play in the leveling screws will affect the accuracy of this measurement. To eliminate the play, turn each leveling screw clockwise until a small screw can be seen on the side of the leveling screw bushing. The leveling screw is threaded into the bushing. The screw is located in that portion of the bushing which is toward the vertical center line of the instrument. It can be seen by looking across the hold down plate outward toward the bushing.

Tightening this screw increases the compression of a small spring, which in turn, applies pressure to the screw threads. Avoid tightening the screw to such an extent that the leveling screw is difficult to turn.

To Replace the Plastic Washers On the Tangent Screws. Hold the left-hand screw stationary and unscrew the right-hand screw until it comes off. Pull out the two screws and replace the washers.

1. ***Object.*** To make the circular bubble center when the azimuth axis is vertical.

This adjustment is of great importance on the Zeiss Level. The accuracy of the instrument is considerably increased when the azimuth axis is as nearly vertical as it is possible to set it with the circular bubble. The compensator mechanism is designed so that the compensator is at the center of its movement when the azimuth axis is vertical. The accuracy with which the compensator corrects for the residual tilt of the telescope is greatest when the compensator is at its center of movement.

Test. Turn the telescope in azimuth until it is parallel with a pair of leveling screws. Center the bubble precisely in the ring with the leveling screws. Turn the telescope 180° in azimuth until it is parallel with the same pair of leveling screws. The bubble should return to center. If it does not, adjustment is required.

Adjustment. In the circular level mount, on the latest models, there are four slotted-capstan head adjusting screws. The outer edge of the circular level mount is a spherical surface, and is precisely fitted in a recess in the box housing. With a screwdriver or adjusting pin loosen or moderately tighten all four screws until they are seated. Repeat the test as the bubble may be moved further out of adjustment.

If the bubble fails to center, bring it halfway toward the center with the leveling screws. To bring it the rest of the way, loosen the slotted-capstan head screw that lies in the direction of desired bubble movement. Tighten the opposite screw until the bubble is in line with the other two adjusting screws. A final adjustment of these two adjusting screws should then bring the bubble to the center. Turn the telescope 180° in azimuth until it is parallel to the same pair of leveling screws. If the bubble fails to center, repeat the adjustment. When the adjustment is complete all of the screws must be firm but not tight. The bubble should remain exactly centered in the ring as the telescope is turned in every direction. If it does not, repeat this adjustment. On earlier models, it is first necessary to unscrew the lock ring at the base of the observation prism and remove the prism unit. If the instrument is not equipped with an observation prism unscrew the adjusting-screw-guard ring which surrounds the circular level. This will expose three slotted head adjusting screws. The circular vial is supported by a resilient washer which forces it upward against the screws. With a screw driver loosen or moderately tighten all three screws until they are seated. Repeat the test as the bubble may be moved further out of adjustment. If the bubble fails to center bring it half way toward the center with the leveling screws and the balance of the way by tightening the most logical adjusting screws until the bubble is precisely centered. Do not loosen any one of them. Turn the telescope 180° in azimuth until it is parallel to the same pair of leveling screws. If the bubble fails to center, repeat the adjustment.

When the adjustment is complete all of the screws must be firm but not tight. The bubble should remain exactly centered in the ring as the telescope is turned in every direction. If it does not, repeat this adjustment.

2. ***Object.*** To make the line of sight level.

Test. Make the test for the peg adjustment as described for the telescope level for the transit.

Adjustment. After the target has been set, unscrew the reticule cover. This is a circular cap 1⁵⁄₁₆ inch in diameter at the end of the telescope just in front of the eyepiece. A small capstan head screw will be exposed just above the eyepiece. This raises and lowers the cross lines against a spring loading. Bring the cross line on the target by regulating this screw.

No other adjustments are necessary.

DUMPY LEVEL ADJUSTMENTS

First read the general directions under "Adjustments" on pages 28-30.

For convenience, the bubble should center when the azimuth axis is placed in the direction of gravity. This relationship makes it unnecessary to relevel the instrument more than a slight touch, for any observation. But if the adjustment necessary to obtain this relationship is made, then the complete peg adjustment must be carried out immediately, as the bubble will no longer center when the line of sight is horizontal.

The Level Tube

1. ***Object.*** To make the bubble center when the azimuth axis is placed in the direction of gravity.

Test. Roughly level over each of the two pairs of opposite leveling screws, then center the bubble over one pair. Turn the instrument 180° in azimuth The bubble should center.

Adjustment. Bring the bubble half-way toward the center with the leveling screws. Center the bubble with the capstan adjusting screw or nut or, on some dumpy levels, with the opposing nuts at one end of the tube.

The Cross Line Reticule

2. ***Object.*** To make the horizontal cross line lie in a plane perpendicular to the azimuth axis.

Test. Aim at some well defined point and turn the telescope slightly left and right with the tangent screw. The horizontal cross line should remain on the point.

Adjustment. Loosen slightly two adjacent reticule adjusting screws. Tap the sides of the screws until the cross line is rotated to its correct position. Tighten the same screws.

3. ***Object.*** To make the line of sight level when the bubble is centered.

Test. Make the test for the peg adjustment as described for the telescope level of the transit.

Adjustment. After the target has been set, focus on the rod and center the bubble. Bring the horizontal cross line on the target with the reticule adjusting screws. Loosen a side screw. Move the upper and lower screws by small increments. Finally tighten the side screw previously loosened.

PLANE TABLE ALIDADES

Plane table surveys made with adequate telescopic alidades are the best means of mapping small areas and of filling in details between survey control points. They are also of great importance as an adjunct to aerial mapping in certain areas. Aerial mapping is impossible over areas lacking objects that appear on the photographs. Large areas of sand or uniform vegetation are examples. Dense deciduous forest areas can be mapped only when the leaves are off the trees, and dense conifer forests cannot be mapped by aerial methods. Certain political and private boundaries do not appear on the photographs, and deep valleys are often concealed.

The accuracy of aerial maps depends in part on the density of survey control, particularly vertical control. Control points are usually selected only after the photographs have been taken. It is always necessary to tie these points to sparsely distributed basic control points established before the photographs are taken. Plane table leveling and traverse have been used extensively for this purpose.

Plane table mapping has three important advantages over other types of ground mapping:

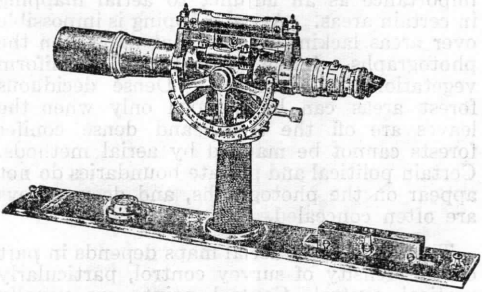
1. All direction measurements are instantly recorded on the map. The intervening processes of recording field notes and plotting them are eliminated.

2. The map is constructed at once, in the field, so that no permanent records are necessary other than the map itself.

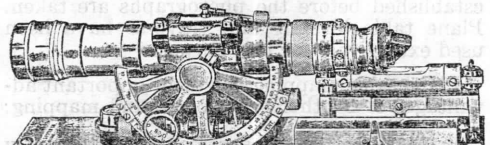
3. The topographer sees the ground that he is mapping. He can draw a more perfect representation of the ground and yet use fewer field observations.

CONVENTIONAL ALIDADES

Conventional alidades of the type exemplified by K&E PARAGON Geological Survey Alidade No. 76 0020 and K&E PARAGON Expedition Alidade 76 0030 are well known.



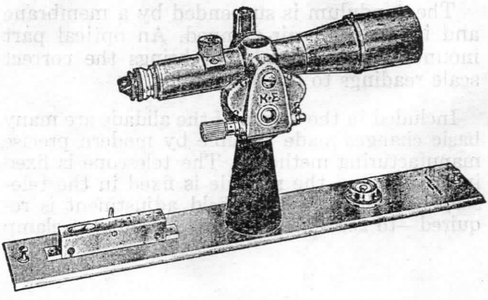
K&E PARAGON® Geological Survey Alidade 76 0020



K&E PARAGON® Expedition Alidade 76 0030

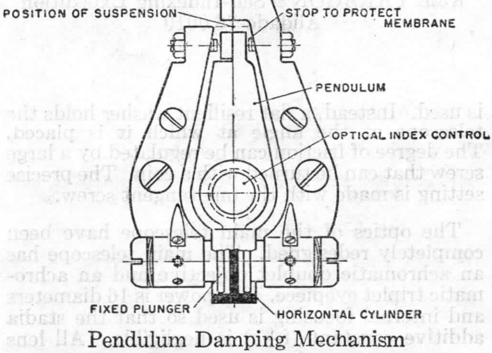
K&E PARAGON® SELF-INDEXING ALIDADES

In cooperation with the U. S. Geological Survey, K&E has developed a radically new alidade, the K&E PARAGON Self-Indexing Alidade.



K&E PARAGON® Self-Indexing Geological Survey Alidade 76 0000

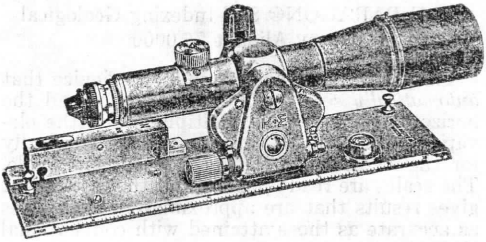
This instrument has a pendulum device that *automatically* sets the indices used to read the horizontal and vertical multipliers and the elevation angle scale. It thus corrects automatically for the slight residual tilts of the plane table. The scales are read *optically* and the instrument gives results that are approximately four times as accurate as those attained with conventional alidades.



Pendulum Damping Mechanism

The pendulum is suspended by a membrane and its swing is air-damped. An optical part mounted in the pendulum brings the correct scale readings to the index.

Included in the design of the alidade are many basic changes made possible by modern precise manufacturing methods. The telescope is fixed in its axle and the reticule is fixed in the telescope, so that only one field adjustment is required—to zero-in the index. No tangent clamp

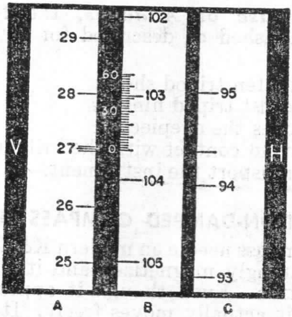


K&E PARAGON® Self-Indexing Expedition Alidade 76 0010

is used. Instead, a flat resilient washer holds the telescope at the angle at which it is placed. The degree of friction can be regulated by a large screw that can be turned with a coin. The precise setting is made with the one tangent screw.

The optics of the main telescope have been completely redesigned. The main telescope has an achromatic doublet objective and an achromatic triplet eyepiece. The power is 16 diameters and internal focusing is used so that the stadia additive constant (f+c) is negligible. All lens surfaces are coated except the first and last. The focusing knob is on top for convenience. Open finder sights are provided.

View through Scale-Reading Eyepiece



A. Vertical Scale reads 27.0

B. Elevation Angle Scale reads 103° 42′ (See page 104)

C. Horizontal Multiplier reads 94.4

The optical scale-reading eyepiece provides a view of the scales as shown in the illustration. All three scales are visible simultaneously. No vernier is required and all three scales can be read from a single point. The light which illuminates the scales is collected by a large, almost semi-spherical lens. This eliminates the need for a mirror that must be regulated for each sight, as conventionally used on optically read instruments.

The compass is of the induction-damped type.

THE USE OF CONVENTIONAL ALIDADES

Space does not permit a description of mapping with an alidade and plane table. The reader is referred to the many excellent available texts that cover this subject.

In the use of Alidades, the following are accomplished as described for transits on pages 12-16:

1. To tighten tripod shoes.
2. To adjust tripod hinges.
3. To focus the eyepiece.
4. To avoid contact with the instrument.
5. To transport the instrument.

INDUCTION-DAMPED COMPASS NEEDLE

The compass needle on modern K&E alidades is very strongly magnetized and it is damped by induction. Even though it appears to be sluggish, it actually moves freely. It is much more sensitive, accurate and dependable than the conventional compass needle.

Test for Sensitivity of Needle

Center the needle by aiming the alidade in azimuth. Swing the needle off center by bringing a steel key or other magnetic object near the needle momentarily. Note where the needle comes to rest. If it does not return exactly to its original position, the pivot is damaged and must be replaced.

THE STADIA ARC AND THE VERTICAL ARC GRADUATIONS

K&E Alidades Nos. 76 0020 and 76 0030 are equipped with the K&E Stadia Arc No. 74 0510. The use of these arcs facilitates stadia surveying by eliminating measurements of the vertical angle and the use of tables. For a more detailed description of stadia surveying see page 102.

THE USE OF K&E PARAGON® SELF-INDEXING ALIDADES 76 0000 & 76 0010

The Self-Indexing Alidade has a number of features that make it so different from conventional alidades that K&E includes these instructions for its use.

The Strap and Clasp. Mildew-proof, damp-resistant webbing is used for the strap. This material never drys out and breaks as leather does. It was chosen by the U. S. Geological Survey after exhaustive tests to determine the material that would give the best and longest service. The clasp, when closed, seems loose. However, it will not open by itself. It is made this way so that when the instrument is carried, the strap will not become taut until its center is 2 or 3 inches above the case. This gives enough freedom to reduce the strain on the strap and case and to give plenty of room for the fingers.

The Grip. The resilient plastic gives a nearly perfect grip and does away with the wrapped cord grip that frequently loosened.

The Circular Level. The circular level has two circles. The inner circle is used for accurate leveling. The outer circle is a safety device. When the bubble is within the outer circle, the pendulum that sets the index is sure to be free to swing.

The Compass. The strong magnetism of the needle makes it dip more than conventional needles. To adjust the dip, loosen the four screws at the sides of the compass box cover.

Slide the cover upwards and lift off the needle, holding it by its center. Loosen the lifter screw so that the needle will swing free when replaced. Move the weight until the needle will balance when placed on the pivot.

To Aim the Telescope Vertically. There is no clamp to hold the telescope in position. The slope of the telescope is retained by a special spring-friction device. Aim the telescope by hand and make the final adjustment with the tangent screw. The open sights on the top of the telescope facilitate aiming.

The degree of friction can be regulated by turning the large screw at the right-hand end of the elevation axis. A coin will fit the slot in the screw.

The Tangent Screw. The tangent screw will move the telescope through a range of over $\pm 5°$. The center and limits of the range are marked for the convenience of the observer so that he can center the screw when he desires. The marks are on the tangent screw collar over which the knurled head of the tangent screw turns. Red circles around the collar show the limits of range; a black circle around the collar shows the center of range.

If desired, the tangent screw can be reversed so that it can be operated from the front of the instrument. To make this change, unscrew the cap mounted on the standard in line with the tangent screw. A coin or screw driver may be used. A spring and plunger should come out with the cap. If they do not, turn the instrument objective end down and tip it until they come out. Unscrew the tangent screw assembly. Replace the collar and the tangent screw before replacing the spring, plunger and cap.

To Read the Vertical Arcs.* Once the instrument is aimed, the arcs can be read immediately. No index level need be set, as the automatic indexing feature takes over. The arcs are read at the eyepiece located at the top of the left-hand standard. While looking down through the eyepiece, focus it by turning it until the graduations are clear.

The field of view appears as shown in the figure on page 63. There are two vertical black bands in the field of view. To the right of the narrower band is a single line marked "H." This is index for the horizontal stadia multiplier. At the left of the wide band is a paired-line index marked "V" for the vertical stadia scale. At the right edge of the wide band is a scale which is the index for the zenith angle arc.

The horizontal multiplier is read directly; in this case 94.4. The vertical scale is read 27.0 and 50 is subtracted from it giving − 23.0. To avoid a minus reading the vertical multiplier values are arbitrarily increased by 50. Thus, 50 must be subtracted from each reading to obtain the true value.

The zenith distance is the angle measured down from the zenith to the line of sight. It is therefore the complement of the vertical angle. To find the vertical angle, subtract the zenith distance from 90°. When a minus sign results, the vertical angle is minus.

To read the zenith distance, first read the number which is adjacent to the small scale, 103. This gives the number of degrees. The small scale reads in minutes at intervals of two minutes. Read this scale at the point where the degree mark coincides. In this example the

*If this is attempted indoors, turn the right-hand side of the instrument toward a window.

reading is 42. The complete reading is therefore 103°42′. The vertical angle is then computed:

	90°00′
Zenith Distance	−103°42′
Vertical Angle	−13°42′

While reading the arcs, be careful not to disturb the plane table. If it is deflected, the slope of the line of sight will be changed and thus move above or below the point of aim. The automatic index will then give the reading for this new slope and not the slope desired.

To Make an Observation. Two methods are recommended for making observations, the stadia arc method and the zenith angle method. An example of each is given. In both, assume that the elevation of the instrument is 525.7. Note that the stadia additive constant is negligible in this instrument so that it does not appear in the computations.

The Stadia-Arc Method. Determine the stadia intercept (5.30 for example). Set the vertical stadia scale at the nearest exact value (27.0). Read the rod at center horizontal cross line (4.7). Read the horizontal multiplier (94.4).

Make the following computations, using an ordinary slide rule for the multiplications.

5.30(94.4)	= 500	Hor. Dist.
27.0 − 50	= −23.0	
5.30(−23.0)	= −121.9	Diff. Elev.

Instrument Elevation	525.7
Difference in Elevation	−121.9
	403.8
Rod	4.7
Elevation	399.1

The Zenith-Distance Method. Determine the stadia intercept (5.30). Read the Zenith Distance (103°42′) and the rod (4.7). Make the following computations, using a stadia slide rule for the multiplications.

$$90° - 103°42' = -13°42'$$

Set the slide index at 530
Set the indicator at 13°42′ for H and read 500
Set the indicator at 13°42′ for V and read 121.9

Compute the elevation as before.

It may be convenient for you to make up a table of vertical angles equivalent to Zenith Distances from 80° to 90°. Most plus vertical angles fall within this range. Values of minus vertical angles are merely the Zenith Distance minus 90°.

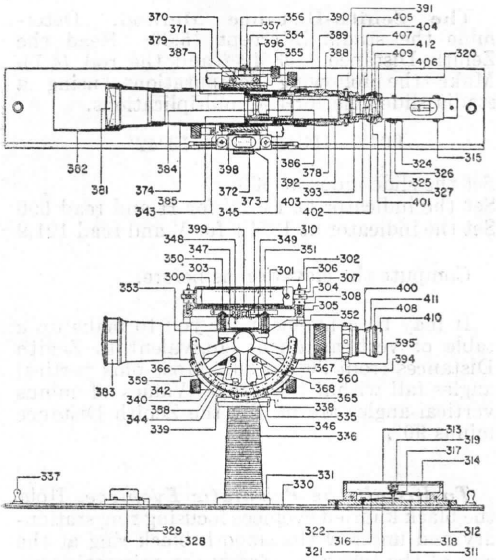
To Install the Prismatic Eyepiece. Hold the black knurled eyepiece focusing ring stationary and unscrew the smooth black ring at the end of the telescope. Screw the prismatic eyepiece in its place.

Adjustments. There is only one field adjustment. This is described under "Field Adjustments" pages 84-86. First read general directions under "Adjustments" on pages 28-30.

Shop Adjustments. There are certain shop adjustments that may be necessary if the instrument is damaged. To make them, refer to "Disassembly and Adjustments" page 86.

CARE OF ALIDADES

Same as for transits (pages 16-17).

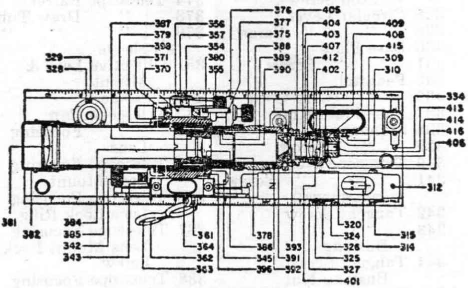


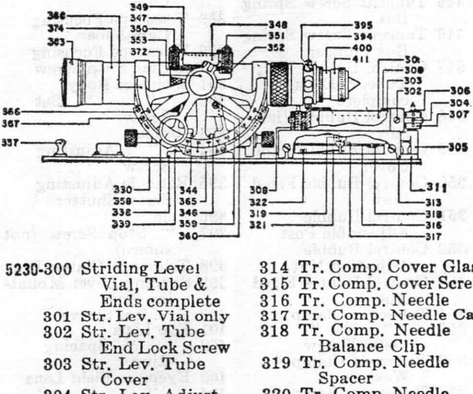
5225-300 Striding Level Vial, Tube and Ends complete
301 Str. Lev. Vial only
302 Str. Lev. Vial Tube End Lock Screw
303 Str. Lev. Tube Cover
304 Stri. Level Adj. Screw
305 Str. Lev. Bracket
306 Striding Level Post
307 Striding Level Adjusting Nut
308 Str. Lev. Fixed Nut
309 Str. Lev. Bracket Lock Screw (Not shown. See 76 0030)
310 Striding Level Spring Release
311 Trough Compass Base
312 Tr. Comp. Base Screw
313 Tr. Comp. Cover
314 Tr. Comp. Cover Glass
315 Tr. Comp. Cover Screw
316 Tr. Comp. Needle
317 Tr. Comp. Needle Cap
318 Trough Compass Needle Balance Clip
319 Trough Compass Needle Spacer
320 Trough Compass Needle Spacer Screw
321 Trough Compass Needle Lifter
322 Trough Compass Needle Lifter Screw
323 Trough Compass Needle Lifter Cam (not shown)
324 Trough Compass Needle Lifter Lever
325 Tr. Comp. Needle Lifter Lever Washer
326 Tr. Comp. Needle Lifter Lever Screw

5225-327 Trough Compass Needle Lifter Lever Stop Screw
328 Circular Level
329 " " Screw
330 Base Plate
331 " " Screw
335 Pedestal
336 " Grip Cord
337 Base Plate Knob
338 Standard
339 " Screw
340 Telescope Stop
341 " " Screw (not shown)
342 Tangent Screw
343 " " Bushing
344 Tangent Screw Bushing Nut
345 Tangent Screw Spring Box
346 Tangent Screw Spring Box Plunger
347 Control Bubble Vial, Tube, & Ends complete
348 Control Bubble Vial only
349 Control Bubble Tube Cover
350 Control Bubble Fixed Post
351 Control Bubble Adjustable Post
352 Control Bubble Adjusting Nut
353 Control Bubble Fixed Nut
354 Telescope Clamp
355 " " Clamp Screw
356 Telescope Clamp Washer
357 Telescope Clamp Washer Screw
358 Vernier Arc
359 " " Bearing Bracket
360 Vernier Arc Bearing Bracket Screw
365 Vertical Arc Vernier
366 Stadia Index
367 Vernier & Index Screw
368 Vertical Arc
369 " " Screw (not shown)
370 Trunnion Cap
371 " " Screw
372 Rosette
373 Spacing Washer
374 Telescope Barrel
378 " Draw Tube
379 " " " Sleeve
381 Objective Lens & Mount
382 Sunshade
383 Telescope Cap
384 " Focusing Lens
385 Telescope Focusing Lens Mount
386 Telescope Focusing Lens Lock Ring
387 Telescope Focusing Lens Mount Lock Screw
388 Telescope Focusing Cam
389 Telescope Focusing Cam Shoe
390 Telescope Focusing Cam Shoe Screw
391 Eyepiece Body
392 " " Set Screw
393 Reticule
394 " Adjusting Screw
395 Reticule Adjusting Screw Shutter
396 Axle
397 " Stop Screw (not shown)
398 Telescope Clamp Ring
399 Striding Level Mounting Stud
400 Eyepiece Sleeve
401 Eye Lens
402 " " Spacing Ring
403 Eyepiece Field Lens
404 " " " Spacing Ring
405 Eyepiece Field Lens Lock Ring
406 Eyepiece Mount
407 " Cam Screw
408 " Focusing Ring
409 Eyepiece Focusing Ring Lock Screw
410 Eyepiece Cap
411 " Diopter Scale
412 Eyepiece Diopter Scale Screw

When ordering parts, state Serial No. of instrument.

K&E PARAGON®
EXPEDITION ALIDADE





5230-300 Striding Level Vial, Tube & Ends complete
301 Str. Lev. Vial only
302 Str. Lev. Tube End Lock Screw
303 Str. Lev. Tube Cover
304 Str. Lev. Adjusting Screw
305 Str. Lev. Bracket
306 Str. Lev. Post
307 Str. Lev. Adj. Nut
308 Str. Lev. Fix. Nut
309 Str. Lev. Bracket Lock Screw
310 Str. Lev. Spring Release
311 Trough Compass Base
312 Tr. Comp. Base Screw
313 Tr. Comp. Cover
314 Tr. Comp. Cover Glass
315 Tr. Comp. Cover Screw
316 Tr. Comp. Needle
317 Tr. Comp. Needle Cap
318 Tr. Comp. Needle Balance Clip
319 Tr. Comp. Needle Spacer
320 Tr. Comp. Needle Spacer Screw
321 Tr. Comp. Needle Lifter
322 Tr. Comp. Needle Lifter Screw
323 Tr. Comp. Needle Lifter Cam (not shown)
324 Tr. Comp. Needle Lifter Lever
325 Tr. Comp. Needle Lifter Washer
326 Tr. Comp. Needle Lifter Screw

5230-327 Trough Compass Needle Lifter Stop Screw

328 Circular Level

329 " " Screw

330 Base Plate

332 Striding Level Bracket Stud (not shown)

334 Striding Level Bracket Stop Screw

337 Base Plate Knob

338 Standard

339 " Screw

342 Tangent Screw

343 " " Bushing

344 Tangent Screw Bushing Nut

345 Tangent Screw Spring Box

346 Tangent Screw Spring Box Plunger

347 Control Bubble Vial, Tube, & Ends complete

348 Cont. Bub. Vial only

349 Cont. Bub. Tube Cover

350 Cont. Bub. Fixed Post

351 Cont. Bub. Adjustable Post

352 Cont. Bub. Adjusting Nut

353 Cont. Bub. Fixed Nut

354 Telescope Clamp

355 " " Clamp Screw

356 Telescope Clamp Washer

357 Telescope Clamp Washer Screw

358 Vernier Arc

359 " " Bearing Bracket

360 Vernier Arc Bearing Bracket Screw

361 Magnifier Frame Holder

362 Magnifier Frame

363 " Glass

364 " Frame Clamp Screw

365 Vertical Arc Vernier

366 Stadia Index

367 Vernier and Index Screw

368 Vertical Arc

369 " " Screw (not shown)

370 Trunnion Cap

371 " " Screw

372 Rosette

374 Telescope Barrel

375 Gradienter Screw

376 " " Drum

377 Gradienter Index

378 Draw Tube

379 " " Sleeve

380 Gradienter Index Screw

381 Objective Lens & Mount

382 Sunshade

383 Telescope Cap

384 " Focusing Lens

385 Telescope Focusing Lens Mount

386 Telescope Focusing Lens Lock Ring

387 Telescope Focusing Lens Mount Lock Screw

388 Focusing Cam

389 " " Shoe

390 " " " Screw

391 Eyepiece Body

392 " " Set Screw

393 Reticule

394 " Adjusting Screw

395 Reticule Adjusting Screw Shutter

396 Axle

397 Axle Stop Screw (not shown)

398 Telescope Clamp Ring

399 Striding Level Mounting Stud (not shown)

400 Eyepiece Sleeve

401 Eye Lens

402 " " Spacing Ring

403 Eyepiece Field Lens

404 " " " Spacing Ring

405 Eyepiece Field Lens Lock Ring

406 Eyepiece Mount

407 " Cam Screw

408 " Focusing Ring

409 Eyepiece Focusing Ring Lock Screw

411 Eyepiece Diopter Scale

412 " " " Screw

413 Eyepiece Prism

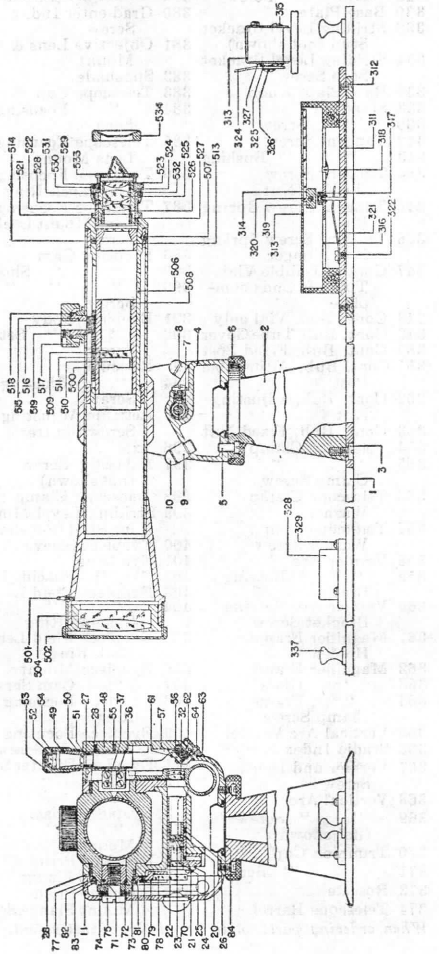
414 " " Mount

415 Eyepiece Prism Mount Flange

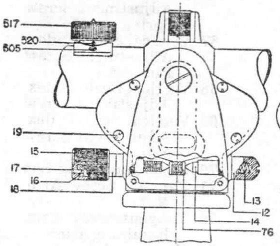
416 Eyepiece Prism Mount Flange Screw

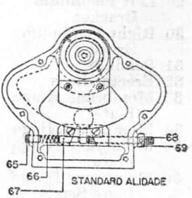
When ordering parts, state Serial No. of instrument.

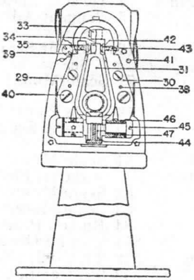
K&E PARAGON®—SELF-INDEXING
GEOLOGICAL SURVEY ALIDADE

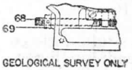


K&E PARAGON®—SELF-INDEXING
GEOLOGICAL SURVEY ALIDADE









5226-1 Base Plate
2 Pedestal
3 Base to Pedestal Screw
4 Standard
5 Standard Mounting Screw
6 Protective Housing
7 Opening Adjustment Screw
8 Right Bumper Mount
9 Left Bumper Mount
10 Telescope Bumper
11 Right Cover
12 Tangent Screw Plunger Bushing
13 Tangent Screw Spring
14 Tangent Screw Spring Plunger
15 Tangent Screw Cap
16 Tangent Screw
17 Tangent Screw Cap Screw
18 Tangent Screw Bushing
19 Right & Left Cover to Standard Screw
20 Regulator Lens Mount Tube
21 Regulator Lens
22 Regulator Lens Mount
23 Regulator Lens Mount
24 Regulator Tube Plate
25 Regulator Tube Plate Screw
26 Regulator Lens Mount Screw

5226-27 Standard Plate
28 Friction Plug
29 Left Pendulum Bracket
30 Right Pendulum Bracket
31 Pendulum
32 Erector Lens
33 Membrane Hinge Plate
34 Membrane Hinge
35 Membrane Hinge Plate
36 Membrane Hinge Plate Screw
37 Membrane Hinge Plate Screw
38 Plate to Standard Pin
39 Left Cover to Standard Screw
40 Bracket & Plate to Standard Screw
41 Left Cover Pin
42 Pendulum Bracket Bumper
43 Bumper Screw
44 Pendulum Piston
45 Pendulum Screw
46 Piston Spring Washer
47 Piston Set Screw
48 Left Cover
49 Focusing Tube
50 Reticule
51 Reticule Lock Ring
52 Eyepiece Lens
53 Focusing Tube Cap
54 Eyepiece Lens Lock Ring
55 Focusing Tube Set Screw
56 Mirror Mount
57 Scale Mirror
58 Right Front Mirror Spring †
59 Left Front Mirror Spring †
60 Side Front Mirror Spring †

†Not shown

61 Mirror Spring Screw
62 Mirror Mount Screw
63 Mirror Mount Cover
64 Mirror Mount Cover Screw
65 Vertical Scale Index Adjustment Screw
66 Vertical Scale Index Adjustment Screw Spring
67 Vertical Scale Index Adjustment Screw Plunger
68 Vertical Scale Index Adjustment Screw
69 Vertical Scale Index Adjustment Screw Nut
70 Light Gathering Lens
71 Tangent Screw Arm Nut
72 Tangent Screw Arm Retaining Ring
73 Tangent Screw Arm
74 Tension Plate
75 Tangent Adjusting Screw
76 Tangent Screw Arm Screw
77 Scale Mount
78 Scale
79 Scale Plate
80 Plate to Scale Mount Screw
81 Scale Mount to Barrel Pin
82 Scale Mount Washer
83 Scale Mount Nut
84 Button Plug
311 Trough Compass Base
312 Tr. Comp. Base Screw
313 Tr. Comp. Cover
314 Tr. Comp. Cover Glass
315 Tr. Comp. Cover Screw
316 Tr. Comp. Needle
317 Tr. Comp. Needle Cap
318 Tr. Comp. Needle Balance Clip
319 Tr. Comp. Needle Spacer
320 Tr. Comp. Needle Spacer Screw
321 Tr. Comp. Needle Lifter
322 Tr. Comp. Needle Lifter Screw
323 Tr. Comp. Needle Cam (Not shown)
324 Tr. Comp. Needle Lifter Lever

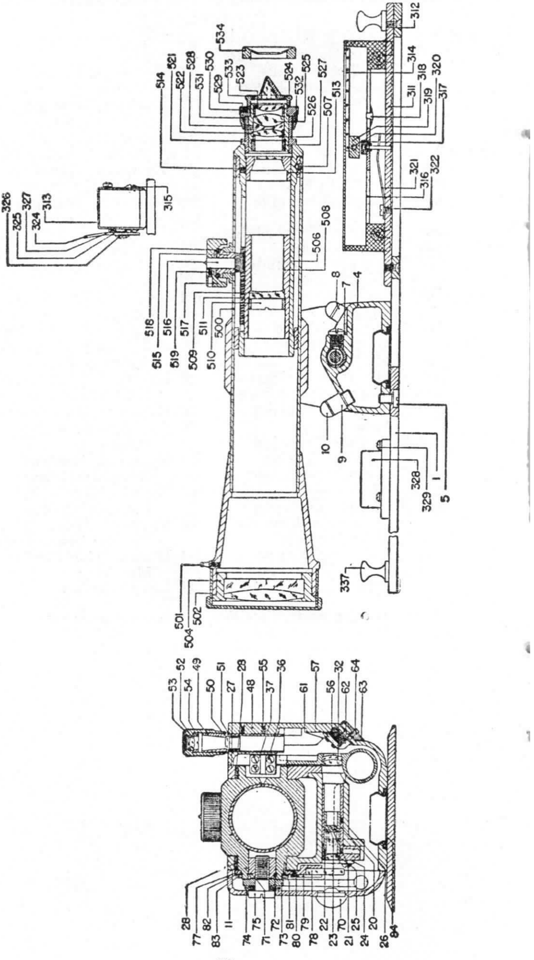
K&E PARAGON®—SELF-INDEXING

GEOLOGICAL SURVEY ALIDADE

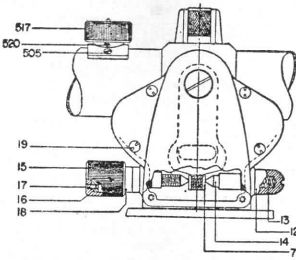
5226-325 Tr. Comp. Needle Lifter Leve. Washer
326 Tr. Comp. Needle Lifter Lever Screw
327 Tr. Comp. Needle Lifter Lever Stop Screw
328 Circular Level
329 Circular Level Screw
337 Base Plate Knob
500 Telescope Barrel & Axle
501 Telescope Front Sight
502 Telescope Cap
503 Telescope Sunshade (Not Shown)
504 Objective Lens & Mount
505 Pinion Saddle to Barrel Screw
506 Body Tube
507 Body Tube Set Screw
508 Telescope Draw Tube
509 Telescope Focusing Lens
510 Telescope Focusing Lens Lock Ring
511 Telescope Focusing Pinion Rack
512 Telescope Focusing Pinion Rack Screw (Not Shown)
513 Reticule & Mount
514 Reticule Mount Set Screw
515 Telescope Pinion Mount
516 Telescope Focusing Pinion
517 Telescope Focusing Pinion Head
518 Telescope Focusing Pinion Tension Ring
519 Telescope Focusing Knob Set Screw
520 Telescope Focusing Pinion Mount Set Screw
521 Eyepiece Sleeve
522 Eyepiece Mount
523 Eye Lens
524 Eye Lens Spacing Ring
525 Eyepiece Field Lens
526 Eyepiece Field Lens Spacing Ring
527 Eyepiece Field Lens Lock Ring
528 Eyepiece Cam Screw
529 Eyepiece Focusing Ring
530 Eyepiece Focusing Ring Lock Screw
531 Eyepiece Focusing Diopter Scale
532 Eyepiece Focusing Diopter Scale Screw
533 Holder With Prism Mount
534 Eyepiece Cap

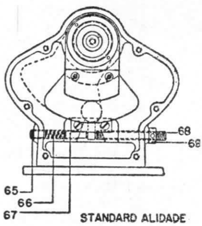
When ordering parts, state Serial No. of instrument.

K&E PARAGON®—SELF-INDEXING
EXPEDITION ALIDADE

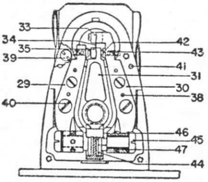


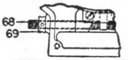
K&E PARAGON®—SELF-INDEXING
EXPEDITION ALIDADE





STANDARD ALIDADE





GEOLOGICAL SURVEY ONLY

5231-1 Base Plate
4 Standard
5 Standard Mounting Screw
7 Opening Adjustment Screw
8 Right Bumper Mount
9 Left Bumper Mount
10 Telescope Bumper
11 Right Cover
12 Tangent Screw Plunger Bushing
13 Tangent Screw Spring
14 Tangent Screw Spring Plunger
15 Tangent Screw Cap
16 Tangent Screw
17 Tangent Screw Cap Screw
18 Tangent Screw Bushing
19 Right & Left Cover tc Standard Screw
20 Regulator Lens Mount Tube
21 Regulator Lens
22 Regulator Lens Mount
23 Regulator Lens Mount
24 Regulator Tube Plate
25 Regulator Tube Plate Screw
26 Regulatoı Lens Mount Screw
27 Standard Plate
28 Friction Plug
29 Left Pendulum Bracket
30 Right Pendulum Bracket
31 Pendulum
32 Erector Lens
33 Membrane Hinge Plate
34 Membrane Hinge

5231· 35 Membrane Hinge Plate
36 Membrane Hinge Plate Screw
37 Membrane Hinge Plate Screw
38 Plate to Standard Pin
39 Left Cover to Standard Screw
40 Bracket & Plate to Standard Screw
41 Left Cover Pin
42 Pendulum Bracket Bumper
43 Bumper Screw
44 Pendulum Piston
45 Pendulum Screw
46 Piston Spring Washer
47 Piston Set Screw
48 Left Cover
49 Focusing Tube
50 Reticule
51 Reticule Lock Ring
52 Eyepiece Lens
53 Focusing Tube Cap
54 Eyepiece Lens Lock Ring
55 Focusing Tube Set Screw
56 Mirror Mount
57 Scale Mirror
58 Right Front Mirror Spring †
59 Left Front Mirror Spring †
60 Side Front Mirror Spring †

†Not shown

61 Mirror Spring Screw
62 Mirror Mount Screw
63 Mirror Mount Cover
64 Mirror Mount Cover Screw
65 Vertical Scale Index Adjustment Screw
66 Vertical Scale Index Adjustment Screw Spring
67 Vertical Scale Index Adjustment Screw Plunger
68 Vertical Scale Index Adjustment Screw
69 Vertical Scale Index Adjustment Screw Nut
70 Light Gathering Lens
71 Tangent Screw Arm Nut
72 Tangent Screw Arm Retaining Ring
73 Tangent Screw Arm
74 Tension Plate
75 Tangent Adjusting Screw
76 Tangent Screw Arm Screw
77 Scale Mount
78 Scale
79 Scale Plate
80 Plate to Scale Mount Screw
81 Scale Mount to Barrel Pin
82 Scale Mount Washer
83 Scale Mount Nut
84 Button Plug
311 Trough Compass Base
312 Tr. Comp. Base Screw
313 Tr. Comp. Cover
314 Tr. Comp. Cover Glass
315 Tr. Comp. Cover Screw
316 Tr. Comp. Needle
317 Tr. Comp. Needle Cap
318 Tr. Comp. Needle Balance Clip
319 Tr. Comp. Needle Spacer
320 Tr. Comp. Needle Spacer Screw
321 Tr. Comp. Needle Lifter
322 Tr. Comp. Needle Lifter Screw
323 Tr. Comp. Needle Cam (Not Shown)
324 Tr. Comp. Needle Lifter Lever
325 Tr. Comp. Needle Lifter Lever Washer
326 Tr. Comp. Needle Lifter Lever Screw
327 Tr. Comp. Needle Lifter Lever Stop Screw
328 Circular Level
329 Circular Level Screw
337 Base Plate Knob

5231-500 Telescope Barrel & Axle
501 Telescope Front Sight
502 Telescope Cap
503 Telescope Sunshade (Not Shown)
504 Objective Lens & Mount
505 Pinion Saddle to Barrel Screw
506 Body Tube
507 Body Tube Set Screw
508 Telescope Draw Tube
509 Telescope Focusing Lens
510 Telescope Focusing Lens Lock Ring
511 Telescope Pinion Rack
512 Telescope Focusing Pinion Rack Screw (Not Shown)
513 Reticule & Mount
514 Reticule Mount Set Screw
515 Telescope Pinion Mount
516 Telescope Focusing Pinion
517 Telescope Focusing Pinion Head
518 Telescope Focusing Pinion Tension Ring
519 Telescope Focusing Knob Set Screw
520 Telescope Focusing Pinion Mount Set Screw
521 Eyepiece Sleeve
522 Eyepiece Mount
523 Eye Lens
524 Eye Lens Spacing Ring
525 Eyepiece Field Lens
526 Eyepiece Field Lens Spacing Ring
527 Eyepiece Field Lens Lock Ring
528 Eyepiece Cam Screw
529 Eyepiece Focusing Ring
530 Eyepiece Focusing Ring Lock Screw
531 Eyepiece Focusing Diopter Scale
532 Eyepiece Focusing Diopter Scale Screw
533 Holder With Prism Mount
534 Eyepiece Cap

When ordering parts, state Serial No. of instrument.

MAINTENANCE, LUBRICATION AND DISASSEMBLY OF ALIDADES

76 0020 & 76 0030

In the maintenance of alidades, the following are accomplished as described for transits on pages 23, 24, 27, 28:

1. Precautions for taking the instrument apart.
2. To remove the reticule.
3. Preparation for Arctic temperatures.

The alidade is lubricated in the same manner as a transit except that only the following points need be lubricated:

1. Telescope axle bearings.
2. Clamp springs and plungers of both tangent motions.
3. Threads of clamp screw and the two tangent screws.

TO DISASSEMBLE THE ALIDADE

1. Remove tangent screws, unscrew spring boxes and remove springs and plungers. Note where each belongs.
2. Unscrew trunnion cap screws and remove caps.
3. Lift out telescope.
4. Unscrew clamp screw.

All surfaces that need to be cleaned and lubricated are now exposed. Re-assemble the instrument in reverse order. Make sure that the telescope bearing caps are replaced according to the matching numbers.

ALIDADE ADJUSTMENTS

First read the general directions under "Adjustments" on pages 28-30.

The circular levels on K&E alidades require no adjustment.

ADJUSTMENT OF CONVENTIONAL ALIDADES

The Cross Line Reticule

1. ***Object.*** To rotate the reticule until the vertical cross line is in a plane perpendicular to the elevation axis.

Proceed as described under Transit Adjustment 3 on page 31.

2. ***Object.*** To make the line of sight coincide with the axis of the collars.

Test. Release the telescope, so that it may be rotated, by loosening the telescope clamp ring (398) that surrounds the telescope at the forward end of the supporting sleeve. Make sure that after it is released the telescope is turned clockwise, when viewed from the objective end, against the stop.

Aim at a leveling rod or other vertical graduated scale 100 feet or more distant. Center the striding level bubble with the tangent screw and read the rod.

Rotate the telescope 180°, center the bubble and read the rod. The reading should be the same.

Adjustment. Loosen a side reticule adjusting screw. Then, by turning the vertical reticule adjusting screws by small increments, bring the line of sight to a point half way between the two readings. Tighten the side screw.

Rotate the telescope 90°, center the bubble, and adjust the other cross line to the same reading.

Each adjustment may interfere with the other, so that checks must be made back and forth until both lines point at the mid-point reading when the bubble is centered.

The Striding Level

3. ***Object.*** To make the striding bubble

center when the axis of the collars is horizontal.

Test. Center the bubble with the tangent screw. Reverse the striding level. The bubble should center.

Adjustment. Move the bubble half way toward the center with the tangent screw. Center it with the opposing nuts at one end of the level tube.

The Vernier Control Level

4. *Object.* To make the vernier control level bubble center when the line of sight is horizontal, and the vernier reads 30°.

Test. Center the striding level bubble with the tangent screw.

Set the vernier at 30° with its tangent screw. The bubble should center.

Adjustment. Center the bubble with the capstan screw or, on some types, with the opposed nuts, at the end of the bubble tube.

FIELD ADJUSTMENT OF SELF-INDEXING ALIDADES 76 0000 & 76 0010

1. *Object.* To make the zenith distance read 90° when the line of sight is horizontal.

Two methods are recommended, the collimator method and the peg method. The collimator method is the better of the two but it requires a level instrument in good adjustment.

The Collimator Method. Set up the alidade on a plane table and set up a level instrument in good adjustment as close to it as possible. Choose a location so that a well illuminated background is behind the level. Regulate the height of the level so that the two instruments are at very nearly the same elevation. Focus the level on some point 800 feet or more distant.

Without changing the focus, aim it approximately at the center of the plane table and carefully center the spirit level.

Stand on the opposite side of the plane table from the level and move the eye until a round spot of light is seen through the level. Place the alidade telescope barrel on the line established by the spot of light and pointed toward the level telescope. The spot of light should appear in the alidade telescope. It will look like a very hazy white circle if the alidade is not in focus or, if the alidade is nearly in focus, the background *seen through the level* may appear. Regulate the focus until the cross lines of the level are seen, and carefully focus on them. If the two instruments are properly in line, the field of view through the level will be a clear-cut circle approximately in the center of the field of view of the alidade.

Test. Bring the central horizontal cross line of the alidade exactly on the central horizontal cross line of the level. Due to the collimator action of the level, the line of sight of the alidade will be parallel to that of the level even if the two instruments are not exactly alined with each other. Accordingly, the line of sight of the alidade will be exactly level and the reading should be exactly 90°.

Adjustment. To adjust the reading, loosen the capstan lock nut just to the right of the tangent screw mechanism at the rear of the instrument and regulate the capstan screw.

The Peg Method. Select two supports for the alidade about 200 feet apart and at nearly the same elevation. Two plane tables are excellent. Construct a small target that will stand on the plane table at exactly the same height as the center of the friction adjusting screw on the left end of the telescope axle.

Test. Level the instrument on one support and place the target on the other. Aim at the target and record the zenith distance reading. Mark the horizontal position of the center of the instrument and the position of the target and interchange them. Aim at the target with this arrangement and record the second zenith distance. The average of the two zenith distances should be exactly 90°.

Adjustment. To adjust the reading, loosen the capstan lock nut just to the right of the tangent screw mechanism at the rear of the instrument and regulate the capstan screw. If the average of the readings is not 90°, change the reading at the second position in a direction toward 90° by an amount equal to the error of the average.

	Example 1	Example 2
First reading	88° 20′	92° 32′
Second reading	91° 48′	87° 26′
Sum	180° 08′	179° 58′
Average	90° 04′	89° 59′
Error 04′		*Error 01′*
2nd Reading 91° 48′		*2nd Reading 87° 26′*
Set at	91° 44′	87° 27′

DISASSEMBLY AND SHOP ADJUSTMENTS—SELF-INDEXING ALIDADES

76 0000 & 76 0010

DISASSEMBLY

To Remove the Blade. Unscrew the four screws underneath the blade that are threaded upward into the pedestal.

Object. To align the line of sight with the edge of the blade. This adjustment is not necessary unless the blade has been removed or when two or more alidades are to be used on the same manuscript or map.

Test. Place the instrument on a plane table and carefully level the plane table. Make up a target with two short vertical lines 1½ inch apart, designed so that the right-hand line can be seen by the naked eye and the other through the telescope. Mount the target so that it is nearly in line with the surface of the plane table and at least 25 feet distant. Aim the line of sight at the left-hand target. Eye along the right-hand edge of the blade. The right-hand target should be on line.

If this test is to be made several times, it is best to set up a permanent jig that will hold the blade in a definite position. A permanent mark can then be established on which the line of sight should fall.

Adjustment. Loosen the four screws underneath the blade that screw up into the pedestal. The holes in the blade are oversize so that the pedestal can be rotated through a small angle. Adjust as required and tighten the screws.

To Remove the Standards from the Pedestal. At the top of the pedestal is cemented a large rubber washer. Work this loose and move it down the pedestal. Four Allen-head screws will be exposed which thread upward into the base of the standards. Remove these screws.

To Remove the Telescope Eyepiece for Cleaning. Unscrew and remove the knurled-screw ring at the eyepiece end next to the telescope barrel. Rotate the eyepiece counterclockwise until a set screw can be seen in the side of the eyepiece sleeve. Remove this screw. This screw serves as a pawl which engages the spiral focusing groove. Slide out the assembly. In reassembly, this pawl must be engaged in the groove.

To Remove the Focusing Knob and Pinion. This is mounted on the top of the telescope. Loosen the set screw on the right side of the focusing-knob-pinion housing. Pull out the knob. To replace the pinion, carefully push it into the housing, rotating the knob back and forth slightly so that the teeth of the pinion will engage in the rack. Hold the knob so that the set screw will engage in the hole. Tighten the set screw.

To Remove the Scale-Reading Eyepiece. This is the black knurled cylinder at the top of the left-hand standard. Loosen the set screws at the side of the eyepiece. Pull out the eyepiece.

THE OPTICAL SYSTEM

The adjustment of the optical system is a delicate and pains-taking operation. Since it requires the removal of certain cover plates which expose sensitive parts, it must be performed in a dust-free room. Under no circumstances should the main left-hand cover plate be removed. This exposes the pendulum mechanism. The pendulum mechanism cannot be disassembled or repaired except by a *specially trained* instrument repairman. The Keuffel & Esser Co. has instrument repairmen trained for this work at their main factory in Hoboken, N. J.

1. ***Object.*** To regulate the focus of the scale reading eyepiece so that, when the minute scale is in focus, the slope scales will also be in focus.

Adjustment. Focus the eyepiece on the minute scale by rotating the eyepiece in the usual way. Loosen the two set screws located one above the other on the side of the left-hand standard. Move the whole eyepiece mount up and down until the slope scales are in focus. Make sure that both the minute and the slope scales are in focus simultaneously. When they are properly focused, no parallax will appear when the eye is moved up and down.

CAUTION

Before tightening the two set screws, move the telescope up or down until the index line on the elevation angle scale reads 90°. At this point the graduation mark at the 50 reading on the "V" scale should be centered between the paired index lines. The 100 graduation mark on the "H" scale should be directly under the horizontal index line. If this does not occur, rotate the scale reading eyepiece sleeve clockwise or counter-clockwise until this condition is met. Recheck the eyepiece for proper focus. Tighten the set screws.

2. ***Object.*** To make the index lines parallel to the slope-scale markings and to center them so that they extend across the markings.

Adjustment. Follow the same procedure as noted in the Caution portion above.

3. ***Object.*** To adjust the elevation angle scale so that it reads 90° when the telescope is level.

Adjustment. Place the alidade on an approximately horizontal surface. Aim the line of sight at a level collimator (a surveying level will serve).

Fine Adjustment. Some instruments are equipped with an opposed screw & lock nut located at the lower right end of the standard. In this case, loosen both capstan head lock nuts and regulate both screws simultaneously. If the instrument is not equipped as above, the adjusting screw will be at the objective end of the lower part of the standard. Loosen the lock nut and rotate the screw until the proper adjustment is made.

Coarse Adjustment. If the fine adjustment is not sufficient to eliminate the error, proceed as follows:

On the left-hand main cover plate is a small cover plate about ½ inch long which is held in place by a screw. Remove this plate. Five screws are underneath it. The three small screws push and the two large screws pull on the support of a small mirror. By tightening and loosening these screws, the required adjustment is made.

The two small screws on the right-hand side, when turned in opposite directions to each other, move the index line to the left or right, depending upon the sequence used in turning. The small left-hand screws, operated in conjunction with the larger left-hand center screw, move it up or down.

When the adjustment is completed, all screws should be firm.

4. ***Object.*** **A.** To regulate the apparent swing of the pendulum so that it gives the correct reading when the blade is tilted to any angle within the pendulum's range of correction.

B. To regulate the apparent length of the slope scale.

Preparation. Remove the spring and plunger that oppose the main tangent screw. To do this, unscrew the cap mounted on the standard in line with the tangent screw. A coin or screw driver may be used. A spring and plunger should come out with the cap. If they do not, turn the instrument objective end down and tip it until they come out.

Grind out the center of the blade of a small screw driver so that a V-shaped notch is formed which will fit the screws. Remove the six screws located around the perimeter of the cover plate on the right-hand standard. Lift off the plate.

Unscrew the large slope-friction adjusting screw at the right-hand end of the elevation axis. Remove this screw and with it both the rubber and brass washers. Lift off the tangent screw arm.

With a spanner wrench, unscrew and remove the lock ring and the washer which hold the scale mount.

Lift off the scale mount carefully. Note the pin which holds the mount in the proper position. The pin may come out with the scale mount, if it does not, let it remain. If it does come out, in assembly the pin must be replaced in the same hole.

A small lever will be exposed. This lever is actuated either by two opposed screws or by a single screw and an opposed spring and plunger. Remove the spring and plunger or the opposing screw. This is done by loosening the capstan head lock nut and unscrewing the Allen-head screw located at the base of the standard on the eyepiece side.

In the same manner, back off the other screw located at the base of the standards on the objective side. Remove the two screws that hold a small plate which retains the lever.

The lever is part of and at the end of a horizontal cylinder which is a mount for two small lenses. Carefully extract the lens mount. Loosen two set screws in the lens mount. One is threaded into the side of the cylinder and the other is parallel to it and threaded into the lower end of the lever. Tighten the set screws until they provide a slight friction which will tend to hold in position the two lens cells within the cylinder.

Push the lens cell nearest the arc about $\frac{1}{32}$ inch towards the arc.

Completely re-assemble all parts including the cover plate, tangent-screw and opposing-spring assembly.

***Test.* A.** Aim the line of sight into a level collimator. A surveying level will serve. Note the reading. Adjust the support of the blade until the zenith distance reads approximately 25 minutes. Re-aim the line of sight at the collimator. The zenith distance reading should be the same as before. If it is not, remove the cover plate & follow the adjustment procedure below.

Adjustment. Remove the cover plate, move the lens mount nearest the arc to the left if the angle reading is too large and vice-versa. Replace the cover plate. Check by tilting the blade about 25 minutes in the opposite direction.

Test. B. With the tangent screw, aim the telescope so that the zero end of the scale coincides with a degree mark. The 60 minute mark should coincide with the next smaller degree mark.

Adjustment. Remove the cover screw at the right of the center in the base of the standards on the eyepiece side.

One small lens cell will be exposed which contains the lens to be adjusted. Around the cell is a groove. The cell can be moved left or right by engaging a small screw driver in the groove.

Move the cell to the left or right until the vernier is the correct length.

Note whether or not the focus of the scale is still clear when observed through the eyepiece. If any parallax exists, adjust the scale-reading eyepiece sleeve up or down until parallax is eliminated.

When these adjustments are complete, disassemble, remove the mount that contains the lens cells and tighten the set screws.

Reassemble all parts and recheck all adjustments. Particularly, check the adjustment of the scale reading eyepiece.

THREE-WIRE LEVELING

Short Form of Field Notes for Yard Rod

+ Rod	Stad.	− Rod	Stad.	Stad.	Elev.	Sta.
3.897(1)		0.734			206.481	BM 61
	72(4)		76			
3.825(2)		0.658				
	74(5)		77			
3.751(3)	146(7)	0.581	153(8)			
11.473(6)		1.973(9)		− 7(10)	+9.500(11)	
2.694		1.248			215.981	TP 1
	63		62			
2.631		1.186				
	62		61			
2.569	125	1.125	123			
7.894		3.559		+ 2	+4.335	
3.174		2.648		− 5	220.316	TP 2
	55		60			
3.119		2.588				
	52		60			
3.067	107	2.528	120			
9.360		7.764		−13	+1.596	
				−18	221.912	BM 62
28.727	378	13.296	396			

Explanation. In this short form of field notes only five columns are used on the left-hand page of the field notebook, and two on the right.

(1), (2), (3) are wire readings.
(4) = (1) − (2), (5) = (2) − (3), (6) = (1) + (2) + (3), (7) = (4) + (5), (10) = (7) − (8), (11) = (6) − (9)

Sums. The sum 28.727 should be computed by adding all the rod readings and the sum 378 by adding all the half stadia intercepts. Similarly for 13.296 and 396. When properly combined, they are used to check the values for the final benchmark, viz:

	Elev.	Stad.
	28.727	378
	−13.296	−396
	+15.431	− 18
BM 61	206.481	0
BM 62	221.912	− 18

STADIA MEASUREMENTS

Purpose. Stadia provides a method of measuring distances and differences in elevation by merely sighting a rod. It is very rapid, and the accuracy is better than is necessary for even large scale mapping. Stadia is always used for measurements with a plane table and it is nearly always used for locating topography with a transit. Stadia is often employed exclusively for complete traverses as well as for ties to other control.

Theory. Two supplementary horizontal lines called stadia lines are placed at equal distances above and below the central horizontal cross line of the instrument. When a graduated rod is sighted, the length of rod between the stadia lines can be observed. This is called the stadia intercept, S.

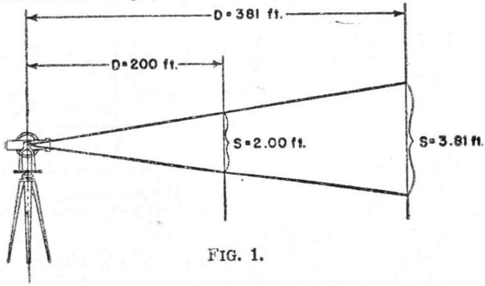


FIG. 1.

In modern K&E internal focusing instruments the distance between the stadia lines is such that, when the telescope is horizontal and the rod is vertical, the distance D from the center of the instrument to the rod is equal to **100 times the stadia intercept.** (Fig. 1), i. e.,

$$D = 100S \qquad (1)$$

In Level No. 75 0020, D is equal to 333 times the stadia intercept. No. 75 0000 is furnished with this intercept, when so ordered.

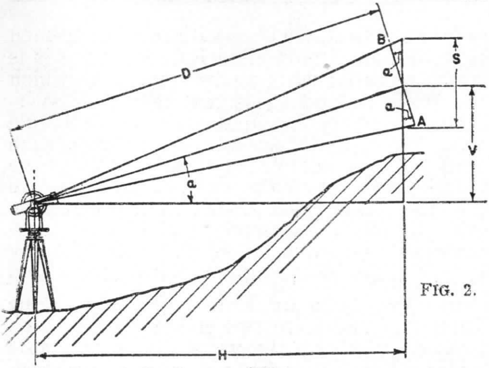


FIG. 2.

Inclined Sights. When the sight is inclined as in Fig. 2, the stadia intercept S must be multiplied by the cosine of the vertical angle a to obtain AB perpendicular to D.

From (1) $\quad D = 100AB$

Therefore $\quad D = 100S \cos a \quad (2)$

and $\quad H = D \cos a = S\,(100 \cos^2 a) \quad (3)$

$V = D \sin a = S\,(100 \sin a \cos a) \quad (4)$

Stadia Computing Devices. Various devices are used to solve these formulas. Three are described below.

Stadia Tables. Stadia tables list the values in the parentheses in eqs. (3) and (4) for various values of a. Using a, the proper values are found in the table and multiplied by S to obtain the values of H and V. Some tables list corrections which, when multiplied by S and subtracted from $100S$, give values of H.

The stadia tables in this booklet (Tables A and B) give very accurate results and require only one opening of the book. They extend to vertical angles up to 10°. Larger vertical angles are so seldom encountered that reductions can be made for them directly from the formulas without loss of time.

Stadia Slide Rules. A well made stadia slide rule will give results which are more accurate than stadia observations. The 10-inch K&E Kissam Stadia Slide Rule No. 68 1486 is more accurate than a stadia traverse in which the foresights and backsights have been averaged. Except for very unusual values, this rule gives H. V. and horizontal corrections, each with the position of the decimal point. The values never run off the scale. When tables are used the necessary multiplications alone require an equal number of settings. If none of these devices are available, an ordinary slide rule may be used although it lengthens the computation.

Stadia Circle or Arc. All K&E Plane Table Alidades have two special scales which automatically give the values found in stadia tables. K&E Transits may be so equipped. The values obtained must be multiplied by *S*. Since the spacing of the graduations is irregular, no vernier can be used. They are less accurate than the tables or the stadia slide rules and they are not as fast as the slide rules. Nevertheless they are frequently used because of their convenience. To avoid minus readings, the readings for vertical heights have been arbitrarily increased by 50 on all K&E instruments. Thus, 50 must be subtracted from each reading to obtain the true value. On K&E conventional alidades, 30° has been added to vertical angle readings. Thus, 30° must be subtracted to obtain the vertical angle. On K&E Self-Indexing Alidades, the vertical angle readings have been replaced by zenith distance readings. The zenith distance readings must be subtracted from 90° to obtain vertical angles.

Example	Zenith Distance	Corresponding Vertical Angle
	68	22
	108	– 18

Rods Used. Ordinary self-reading leveling rods with targets can be used up to 800 feet. Special stadia rods with graduations that are more easily read are used for longer distances.

Point Sighted on Rod. The difference in elevation V that is obtained by stadia, extends from the center of the instrument and the point sighted on the rod. To simplify the corrections necessary to obtain ground elevations, it is best to sight at a target set at the *h. i.* which is the height of the instrument center above the station over which the instrument is set up. V then equals the difference between the two ground elevations. Often a certain mark (usually the 5 ft. mark) is always sighted throughout the survey. V is then the vertical height from a point 5 ft. below the instrument center.

When differences in elevation are small, horizontal observations are used. Distances can be computed mentally from the stadia intercepts and elevations are handled as in leveling.

A Stadia Observation. As a rule, a stadia observation is performed by the following steps:

1. The cross lines are brought on the target at the *h. i.* or on the five foot mark, or the telescope is leveled, depending on the method in use.

2. The lower stadia line is then immediately placed on the nearest foot mark and the stadia intercept is obtained by subtracting the lower line reading from the upper line reading.

3. The telescope is returned to the original position and the rodman is started off to the next point.

4. The instrument readings are taken.

Observations with the Stadia Arc. To obtain better accuracy with a stadia arc, many engineers prefer to use a slightly different procedure after completing Steps 1 and 2 above. For Step 3 the telescope is changed in elevation just enough to cause the nearest graduation of the vertical stadia arc to coincide exactly with the index. The position of the central cross line on the rod is then recorded. The difference in elevation, from the ground at the instrument to the ground at the rod, is then computed thus:

$$\text{h.i.} + V - \text{Rod Reading}$$

The Accuracy of Stadia Measurements. A single stadia observation has an accuracy of about 1/300 in distance and about 0.06 feet in elevation per hundred feet of length. A stadia traverse in which the intercepts and the vertical angles are observed in both directions along each course has an accuracy of about 1/500 and an elevation closure of about 0.8 feet $\times \sqrt{\text{miles}}$. Under unusual conditions it may be worth while to introduce special procedures to obtain high accuracy. The instruments must be calibrated very carefully, no approximation can be used in computation, each observation must be repeated many times, and refraction must be carefully avoided. With similar care accuracies as high as 1/2000 have been recorded.

Calibration of a Stadia Telescope. The formula for internal focusing instruments, $D = 100\,S$, changes slightly with changing focus and varies slightly from instrument to instrument. These variations are negligible except for very accurate measurements. For such determinations a correction curve should be constructed for the instrument to be used by measuring exact stadia intercepts at various known distances. The following distances are recommended: 25, 50, 100, 200, 400, 800, 1600 feet. Plot the curve on semi-logarithmic graph paper.

Formulas for External Focusing Instruments. On external focusing instruments, the distance X (Fig. 3), which is proportional to the stadia intercepts, is measured from the exterior principal focus of the lens. To obtain a value for D the distances f and c must be added. Their sum (and hence the total correction) is about one foot.

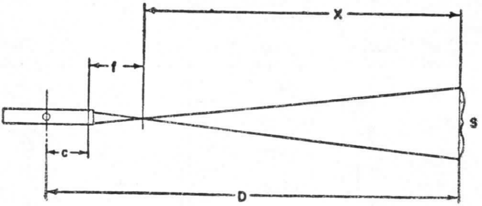


FIG. 3.

The resulting formulas are therefore:

$$D = 100\,S + 1 \qquad (5)$$
$$H = 100\,S \cos^2 a + \cos a \qquad (6)$$
$$V = 100\,S \cos a \sin a + \sin a \qquad (7)$$

Since a is usually less than 10 deg., multiplying the last term in eq. (6) and in eq. (7) by $\cos a$ will not appreciably change the values of H and V. These equations can therefore be written:

$$H = (S + .01)\,100 \cos^2 a \qquad (8)$$
$$V = (S + .01)\,100 \sin a \cos a \qquad (9)$$

Accordingly, all stadia computing devices can be used with external focusing instruments by substituting for S the value $S + .01$.

FORMULAS TO USE WITH VERTICAL ANGLES GREATER THAN 10°

	Internal Focusing	External Focusing
Hor. Dist.	$100S\cos^2 a$	$100(S + 0.01)\cos^2 a$
Vert. Ht.	$100S\sin a\cos a$	$100(S + 0.01)\sin a\cos a$

Where: S = stadia intercept; a = vertical angle

TABLE A

HORIZONTAL CORRECTIONS FOR STADIA INTERCEPT 1.00 FT.

Vert. Angle	Hor. Cor. for 1.00 ft.	Vert. Angle	Hor. Cor. for 1.00 ft.	Vert. Angle	Hor. Cor. for 1.00 ft.
0°00′		5°36′		8°02′	
	0.0 ft.		1.0 ft.		2.0 ft.
1°17′		5°53′		8°14′	
	0.1 ft.		1.1 ft.		2.1 ft.
2°13′		6°09′		8°26′	
	0.2 ft.		1.2 ft.		2.2 ft.
2°52′		6°25′		8°38′	
	0.3 ft.		1.3 ft.		2.3 ft.
3°23′		6°40′		8°49′	
	0.4 ft.		1.4 ft.		2.4 ft.
3°51′		6°55′		9°00′	
	0.5 ft.		1.5 ft.		2.5 ft.
4°15′		7°09′		9°11′	
	0.6 ft.		1.6 ft.		2.6 ft.
4°37′		7°23′		9°22′	
	0.7 ft.		1.7 ft.		2.7 ft.
4°58′		7°36′		9°33′	
	0.8 ft.		1.8 ft.		2.8 ft.
5°17′		7°49′		9°43′	
	0.9 ft.		1.9 ft.		2.9 ft.
5°36′		8°02′		9°53′	
					3.0 ft.
				10°03′	

Results from Table A are correct to the nearest foot at 1000 feet and to the nearest 1/10 foot at 100 feet, etc.

With a slide rule, multiply the stadia intercept by the tabular value and subtract the product from the horizontal distance.

Example. Vertical angle, 4°22′; stadia intercept, 3.58 ft.

Corrected Hor. Dist. =

$$358 - (3.58 \times 0.6) = 356 \text{ ft.}$$

Table B gives the vertical heights for a stadia intercept of 1.00 ft. With a slide rule, multiply the stadia intercept by the tabular value.

Example. Vertical angle, 4°22′; stadia intercept, 3.58 ft.

Vertical Height = 3.58×7.59 = **27.2 ft.**

TABLE B

VERTICAL HEIGHTS FOR STADIA INTERCEPT 1.00′

Min.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
0	0.00	1.74	3.49	5.23	6.96	8.68	10.40	12.10	13.78	15.45
2	0.06	1.80	3.55	5.28	7.02	8.74	10.45	12.15	13.84	15.51
4	0.12	1.86	3.60	5.34	7.07	8.80	10.51	12.21	13.89	15.56
6	0.17	1.92	3.66	5.40	7.13	8.85	10.57	12.27	13.95	15.62
8	0.23	1.98	3.72	5.46	7.19	8.91	10.62	12.32	14.01	15.67
10	0.29	2.04	3.78	5.52	7.25	8.97	10.68	12.38	14.06	15.73
12	0.35	2.09	3.84	5.57	7.30	9.03	10.74	12.43	14.12	15.78
14	0.41	2.15	3.89	5.63	7.36	9.08	10.79	12.49	14.17	15.84
16	0.47	2.21	3.95	5.69	7.42	9.14	10.85	12.55	14.23	15.89
18	0.52	2.27	4.01	5.75	7.48	9.20	10.91	12.60	14.28	15.95
20	0.58	2.33	4.07	5.80	7.53	9.25	10.96	12.66	14.34	16.00
22	0.64	2.38	4.13	5.86	7.59	9.31	11.02	12.72	14.40	16.06
24	0.70	2.44	4.18	5.92	7.65	9.37	11.08	12.77	14.45	16.11
26	0.76	2.50	4.24	5.98	7.71	9.43	11.13	12.83	14.51	16.17
28	0.81	2.56	4.30	6.04	7.76	9.48	11.19	12.88	14.56	16.22
30	0.87	2.62	4.36	6.09	7.82	9.54	11.25	12.94	14.62	16.28
32	0.93	2.67	4.42	6.15	7.88	9.60	11.30	13.00	14.67	16.33
34	0.99	2.73	4.47	6.21	7.94	9.65	11.36	13.05	14.73	16.39
36	1.05	2.79	4.53	6.27	7.99	9.71	11.42	13.11	14.79	16.44
38	1.11	2.85	4.59	6.32	8.05	9.77	11.47	13.17	14.84	16.50
40	1.16	2.91	4.65	6.38	8.11	9.83	11.53	13.22	14.90	16.55
42	1.22	2.97	4.71	6.44	8.17	9.88	11.59	13.28	14.95	16.61
44	1.28	3.02	4.76	6.50	8.22	9.94	11.64	13.33	15.01	16.66
46	1.34	3.08	4.82	6.56	8.28	10.00	11.70	13.39	15.06	16.72
48	1.40	3.14	4.88	6.61	8.34	10.05	11.76	13.45	15.12	16.77
50	1.45	3.20	4.94	6.67	8.40	10.11	11.81	13.50	15.17	16.83
52	1.51	3.26	4.99	6.73	8.45	10.17	11.87	13.56	15.23	16.88
54	1.57	3.31	5.05	6.79	8.51	10.22	11.93	13.61	15.28	16.94
56	1.63	3.37	5.11	6.84	8.57	10.28	11.98	13.67	15.34	16.99
58	1.69	3.43	5.17	6.90	8.63	10.34	12.04	13.73	15.40	17.05
60	1.74	3.49	5.23	6.96	8.68	10.40	12.10	13.78	15.45	17.10

HOW TO SET OFF THE MAGNETIC DECLINATION

The magnetic declination is the angle measured from the true north to the direction of the compass needle. A 12° west declination is present when the needle points 12° west of true north. The declination is different in different localities, and in any locality it is continually changing. The U. S. Coast and Geodetic Survey publishes charts from which the declination can be estimated for any time or place in the United States.

When the compass circle is set in its normal position, the needle gives the magnetic bearing of the line of sight. This is shown in Fig. 1 with the instrument pointed to the true north. The compass circle can be rotated by turning the capstan head pinion (near the south or west mark) so that the needle will give the true bearing of the line of sight.

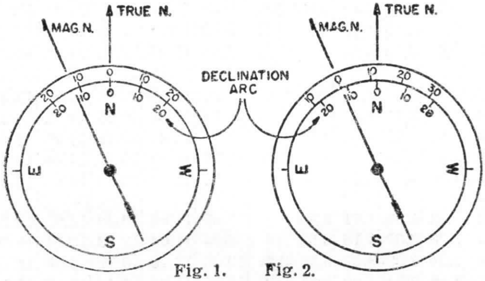


Fig. 1. Fig. 2.

The extent of rotation of the circle is measured *by the declination arc* in the base of the compass box next to the north part of the circle.

To set the circle for a declination of 12° west, turn the pinion clockwise and hence the circle counter-clockwise until the zero of the circle coincides with 12° to the left of N on the declination arc. The result is shown in Fig. 2. The instrument will now read true bearings for all points of the compass. The procedure is the same in the southern hemisphere.

UNITS OF MEASURE

LENGTH

U. S. SYSTEM

1 mile (mi)	=	5280 feet
1 chain (ch)	=	66 feet
1 rod (rd)	=	16.5 feet
1 yard (yd)	=	3 feet
1 foot (ft)	=	12 inches (in)
1 nautical mile	=	6076.1155– feet
1 fathom (fm)	=	6 feet

METRIC SYSTEM

1 kilometer (km)	=	1000 meters
1 meter (m)	=	1000 millimeters
1 millimeter (mm)	=	1000 microns
1 micron (μ)	=	1000 millimicrons
1 millimicron (mμ)	=	1000 millionth microns (μμ)
1 meter	=	10 decimeters
1 decimeter (dm)	=	10 centimeters (cm)
1 millimicron	=	10 angstroms (A)

CONVERSION 1959-FOOT SYSTEM AND METRIC SYSTEM

1 kilometer	=	0.62137119 + miles
1 meter	=	3.2808399 – feet
1 meter	=	39.370079 – inches
1 mile	=	1.609344 kilometers
1 foot	=	0.3048 meters
1 inch	=	25.4 millimeters

AREA and VOLUME

1959-FOOT SYSTEM

1 sq. mile	=	640 acres
1 acre (A)	=	10 sq. ch.
1 acre	=	43560 sq. ft.

METRIC SYSTEM

1 sq. kilometer	=	100 hectares (ha)
1 hectare	=	100 ares
1 are	=	100 sq. meters

CONVERSION 1959-FOOT SYSTEM AND METRIC SYSTEM

1 hectare	=	2.4710538 + acres
1 cu. meter	=	1.30795 + cu. yards
1 cu. cm.	=	0.0610237 + cu. in.
1 acre	=	0.40468564 + hectares
1 cu. yard	=	0.764555 – cu. meters
1 cu. inch	=	16.3870 + cu. cm.

Note. In 1959, the Foot System was redefined by agreement among officials of the nations where it is used, as follows: 1 yard = 0.9144 International Meter exactly. This reduced the lengths of units of the existing United States Foot System approximately 2 parts in 1,000,000. The then existing United States system was defined as follows: 39.37 inches = 1 International Meter and the foot in that system is now called the American Survey Foot. The American Survey Foot is still used by the U. S. Coast and Geodetic Survey and therefore applies to all the horizontal and vertical control nets in the United States. This exception is essential, as all data in feet published by that Bureau are the result of conversion from International Meters according to the definition 39.37 inches = 1 International Meter.

TABLE C

CONVERSION OF TIME TO ARC

HOURS OF TIME INTO ARC

T.	A.	T.	A.	T.	A.	T.	A.	T.	A.	T.	A.
hrs.	°	hrs.	°	hrs.	°	hrs.	°	hrs.	°	hrs.	°
1	15	5	75	9	135	13	195	17	255	21	315
2	30	6	90	10	150	14	210	18	270	22	330
3	45	7	105	11	165	15	225	19	285	23	345
4	60	8	120	12	180	16	240	20	300	24	360

MINUTES OF TIME TO ARC
SECONDS OF TIME TO ARC

Min. *Sec.*	° ′	′ ″	Min. *Sec.*	° ′	′ ″	Min. *Sec.*	° ′	′ ″
1	0	15	21	5	15	41	10	15
2	0	30	22	5	30	42	10	30
3	0	45	23	5	45	43	10	45
4	1	0	24	6	0	44	11	0
5	1	15	25	6	15	45	11	15
6	1	30	26	6	30	46	11	30
7	1	45	27	6	45	47	11	45
8	2	0	28	7	0	48	12	0
9	2	15	29	7	15	49	12	15
10	2	30	30	7	30	50	12	30
11	2	45	31	7	45	51	12	45
12	3	0	32	8	0	52	13	0
13	3	15	33	8	15	53	13	15
14	3	30	34	8	30	54	13	30
15	3	45	35	8	45	55	13	45
16	4	0	36	9	0	56	14	0
17	4	15	37	9	15	57	14	15
18	4	30	38	9	30	58	14	30
19	4	45	39	9	45	59	14	45
20	5	0	40	10	0	60	15	0

HUNDREDTHS OF A SECOND OF TIME TO ARC

100ths of sec. of time s.	.00 ″	.01 ″	.02 ″	.03 ″	.04 ″	.05 ″	.06 ″	.07 ″	.08 ″	.09 ″
0.00	0.00	0.15	0.30	0.45	0.60	0.75	0.90	1.05	1.20	1.35
.10	1.50	1.65	1.80	1.95	2.10	2.25	2.40	2.55	2.70	2.85
.20	3.00	3.15	3.30	3.45	3.60	3.75	3.90	4.05	4.20	4.35
.30	4.50	4.65	4.80	4.95	5.10	5.25	5.40	5.55	5.70	5.85
.40	6.00	6.15	6.30	6.45	6.60	6.75	6.90	7.05	7.20	7.35
0.50	7.50	7.65	7.80	7.95	8.10	8.25	8.40	8.55	8.70	8.85
.60	9.00	9.15	9.30	9.45	9.60	9.75	9.90	10.05	10.20	10.35
.70	10.50	10.65	10.80	10.59	11.10	11.25	11.40	11.55	11.70	11.85
.80	12.00	12.15	12.30	12.45	12.60	12.75	12.90	13.05	13.20	13.35
.90	13.50	13.65	13.80	13.95	14.10	14.25	14.40	14.55	14.70	14.85

TABLE D

TEMPERATURE CORRECTIONS FOR STEEL TAPES BASED ON COEF. OF EXP. OF 0.00000645 PER DEGREE

For these tempera- tures subtract correction	Correction per 1000 ft.	For these tempera- tures add correction	For these tempera- tures subtract correction	Correction per 1000 ft.	For these tempera- tures add correction
68°F.	.00000	68°F.	28°F	.25800	108°F.
67	.00645	69	27	.26445	109
66	.01290	70	26	.27090	110
65	.01935	71	25	.27735	111
64	.02580	72	24	.28380	112
63	.03225	73	23	.29025	113
62	.03870	74	22	.29670	114
61	.04515	75	21	.30315	115
60	.05160	76	20	.30960	116
59	.05805	77	19	.31605	117
58	.06450	78	18	.32250	118
57	.07095	79	17	.32895	119
56	.07740	80	16	.33540	120
55	.08385	81	15	.34185	121
54	.09030	82	14	.34830	122
53	.09675	83	13	.35475	123
52	.10320	84	12	.36120	124
51	.10965	85	11	.36765	125
50	.11610	86	10	.37410	126
49	.12255	87	9	.38055	127
48	.12900	88	8	.38700	128
47	.13545	89	7	.39345	129
46	,14190	90	6	.39990	130
45	.14835	91	5	.40635	
44	.15480	92	4	.41280	
43	.16125	93	3	.41925	
42	.16770	94	2	.42570	
41	.17415	95	1	.43215	
40	.18060	96	0	.43860	
39	.18705	97	− 1	.44505	
38	.19350	98	− 2	.45150	
37	.19995	99	− 3	.45795	
36	.20640	100	− 4	.46440	
35	.21285	101	− 5	.47085	
34	.21930	102	− 6	.47730	
33	.22575	103	− 7	.48375	
32	.23220	104	− 8	.49020	
31	.23865	105	− 9	.49665	
30	.24510	106	−10	.50310	
29	.25155	107	−11	50955	

Example: Measured distance at 29°F. = 782.36
Correction − 25155 x .782 = −.20
Corrected Length = 782.16

CORRECTION FOR MERIDIAN CONVERGENCE

Apply when traverse angles are checked by celestial observation.

$C = \Delta\lambda \sin \phi$ $\qquad$ $C'' = 52.13 \text{ m} \tan \phi$

where: C is angular convergence, $\Delta\lambda$ is long. diff., ϕ is mean lat., m is distance east or west in miles.

CORRECTION FOR SLOPE

Square the difference in height of the two ends and divide by twice the slope measurement. Subtract the result from the slope measurement.

Slope meas. 100 ft. Diff. in ht. 12 ft.

$$100 - \frac{144}{200} = 99.28 \text{ ft. (error 0.003 ft.)}$$

CORRECTION FOR CURVATURE and REFRACTION IN LEVELING

The correction equals $-.000209\ S^2$ where S is the number of hundreds of feet in the sight.

Length of sight 220 ft. Rod reading = 8.276
Correction: $-.000209\ (2.2)^2 = -.001$
Corrected reading = 8.275

PROBABLE ERROR

If d_1, d_2, d_3, etc. are the discrepancies of various results from the mean, and if Σd^2 = the sum of the squares of these differences, and n = the number of observations, then the Probable Error is computed thus:

$$\text{P.E. Mean} = \pm 0.6745 \sqrt{\frac{\Sigma d^2}{n(n-1)}}$$

$$\text{P.E. One Obser.} = \pm 0.6745 \sqrt{\frac{\Sigma d^2}{n-1}}$$

MEASUREMENT EQUIVALENTS

π	= 3.1415927−	log = 0.49714987
1 radian	= 57.295780− deg.	log = 1.75812263
1 radian	= 3437.7468− min.	log = 3.53627388
1 radian	= 206264.81− sec.	log = 5.31442513
1 degree	= 0.017453293− rad.	log = 8.24187737 − 10
1 minute	= 0.000290888+ rad.	log = 6.46372612 − 10
1 second	= 0.000004848+ rad.	log = 4.68557487 − 10

TRIGONOMETRIC FORMULAS

$\frac{\sin A}{\cos A}=\tan A \qquad \sin^2 A+\cos^2 A=1 \qquad \tan^2 A+1=\sec^2 A$

$$\sin A=\frac{1}{\csc A}=\cos(90°-A)=\frac{\tan A}{\pm\sqrt{\tan^2 A+1}}$$

$$\cos A=\frac{1}{\sec A}=\sin(90°-A)=\frac{1}{\pm\sqrt{\tan^2 A+1}}$$

$$\tan A=\frac{1}{\cot A}=\cot(90°-A)=\frac{\sin A}{\pm\sqrt{1-\sin^2 A}}=\frac{\pm\sqrt{1-\cos^2 A}}{\cos A}$$

$\sin(A\pm B)=\sin A\cos B\pm\cos A\sin B$

$\cos(A\pm B)=\cos A\cos B\mp\sin A\sin B$

$\tan(A\pm B)=\frac{\tan A\pm\tan B}{1\mp\tan A\tan B} \qquad \cot(A\pm B)=\frac{\cot A\cot B\mp1}{\cot B\pm\cot A}$

$\sin(A\pm90°)=\pm\cos A \qquad \cos(A\pm90°)=\mp\sin A$

$\sin(180°\pm A)=\mp\sin A \qquad \cos(180°\pm A)=-\cos A$

$\sin A+\sin B=2\sin\frac{1}{2}(A+B)\cos\frac{1}{2}(A-B)$

$\sin A-\sin B=2\cos\frac{1}{2}(A+B)\sin\frac{1}{2}(A-B)$

$\cos A+\cos B=2\cos\frac{1}{2}(A+B)\cos\frac{1}{2}(A-B)$

$\cos A-\cos B=-2\sin\frac{1}{2}(A+B)\sin\frac{1}{2}(A-B)$

$\sin 2A=2\sin A\cos A$

$\cos 2A=\cos^2 A-\sin^2 A=1-2\sin^2 A=2\cos^2 A-1$

$\tan 2A=\frac{2\tan A}{1-\tan^2 A} \qquad \cot 2A=\frac{\cot^2 A-1}{2\cot A}$

$\sin\frac{1}{2}A=\pm\sqrt{\frac{1}{2}(1-\cos A)} \qquad \cos\frac{1}{2}A=\pm\sqrt{\frac{1}{2}(1+\cos A)}$

$$\tan\frac{1}{2}A=\frac{1-\cos A}{\sin A}=\frac{\sin A}{1+\cos A}=\frac{1}{\cot\frac{1}{2}A}$$

SOLUTION OF OBLIQUE TRIANGLES

Angles are A, B, C. Sides opposite are a, b, c respectively.

Case I given a, B, C.

$$A = 180° - (B + C) \qquad b = \frac{a}{\sin A}\sin B$$

$$c = \frac{a}{\sin A}\sin C$$

Case II given a, b, A.

$$\sin B = \frac{\sin A}{a} b \qquad C = 180° - (A + B)$$

$$c = \frac{a}{\sin A}\sin C$$

Case III given a, b, C.

$$A + B = 180° - C$$

$$\tan \tfrac{1}{2}(A - B) = \frac{a - b}{a + b}\tan \tfrac{1}{2}(A + B)$$

$$A = \tfrac{1}{2}(A + B) + \tfrac{1}{2}(A - B)$$
$$B = \tfrac{1}{2}(A + B) - \tfrac{1}{2}(A - B)$$

$$c = \frac{a}{\sin A}\sin C$$

Case III given a, b, C: *alternate method.*

$$c^2 = a^2 + b^2 - 2ab\cos C$$

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc} \quad \text{or} \quad \sin A = \frac{\sin C}{c} a$$

$$\cos B = \frac{a^2 + c^2 - b^2}{2ac} \quad \text{or} \quad \sin B = \frac{\sin C}{c} b$$

$$\text{or} \quad B = 180 - (A + C)$$

Case IV given a, b, c.

$$\text{let } s = \tfrac{1}{2}(a + b + c)$$

$$\text{and } r = \sqrt{\frac{(s - a)(s - b)(s - c)}{s}}$$

$$\tan \tfrac{1}{2}A = \frac{r}{s - a} \quad \tan \tfrac{1}{2}B = \frac{r}{s - b} \quad \tan \tfrac{1}{2}C = \frac{r}{s - c}$$

Case IV given a, b, c: *alternate method.*

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc} \qquad \cos B = \frac{a^2 + c^2 - b^2}{2ac}$$

$$\cos C = \frac{a^2 + b^2 - c^2}{2ab} \quad \text{or} \quad C = 180° - (A + B)$$

$$\text{Area} = \tfrac{1}{2}bc\sin A = \frac{a^2 \sin B \sin C}{2\sin A}$$

$$= \sqrt{s(s - a)(s - b)(s - c)}$$

CELESTIAL OBSERVATIONS

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I. THE PRINCIPLES UPON WHICH CELESTIAL OBSERVATIONS ARE BASED

A. CONCEPTS

1. The Celestial Sphere. To simplify the computations necessary for the determinations of the direction of the meridian, of latitude, and of longitude or time, certain concepts of the heavens have been generally adopted. They are the following:

a. The earth is stationary.

b. The heavenly bodies have been projected outward, along lines which extend from the center of the earth, to a sphere of infinite radius called the ***celestial sphere.***

The celestial sphere has the following characteristics:

a. Its center is at the center of the earth.

b. Its equator is on the projection of the earth's equator.

c. With respect to the earth, the celestial sphere rotates from east to west about a line which coincides with the earth's axis. Accordingly, the poles of the celestial sphere are at the prolongations of the earth's poles.

d. The speed of rotation of the celestial sphere is 360° 59.14′ per 24 hours.

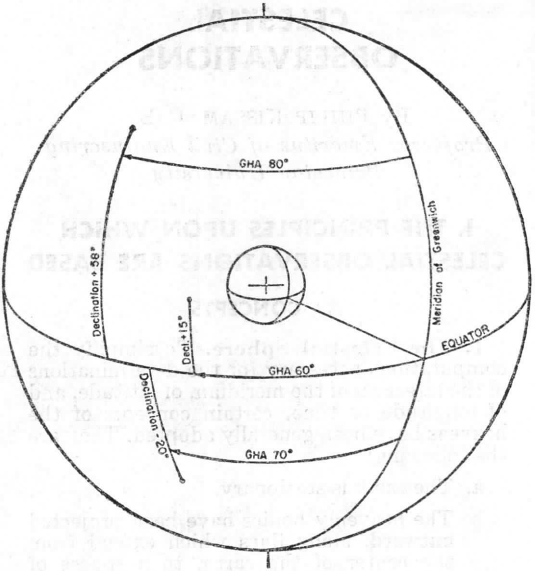

Fig. 1.

e. With the important exception of bodies in the solar system, which change position slowly, all heavenly bodies remain practically fixed in their positions on the celestial sphere, never changing more than negligible amounts in 24 hours, and accordingly are often called *fixed stars.*

2. The Position of a Heavenly Body. (Fig. 1) The position of any heavenly body with respect to the earth, at any moment, is given by its ***declination*** (d) and its ***Greenwich Hour Angle*** (*GHA*)*.

* The position of a heavenly body in the celestial sphere is given by its declination and right ascension. The concept of right ascension is unnecessary in this discussion and is omitted for simplicity.

3. Declination. A plus declination is the angular distance measured north from the equator. An angular distance measured south from the equator is a minus declination. A declination therefore is equivalent to a latitude.

Table 1 can be used to obtain the sun's declination at any moment of time throughout the year, Table 3 gives the declination of Polaris at ten-day intervals, and Table 13 gives the declinations of twenty-six selected stars.

4. Greenwich Hour Angle. The *GHA* is the angle measured from the meridian of Greenwich westward to the meridian over which the body stands at any moment. Up to 180°, a *GHA* is equivalent to west longitude, and thereafter it continues up to 360°. Thus the *GHA's* of all heavenly bodies are always *increasing* as the heavens move toward the west. Table 1 lists the *GHA* of Polaris at the moment of Greenwich midnight (0^h) for each day of the year. Since the angular speed of rotation of the celestial sphere is known, the increase in the *GHA* that occurs after Greenwich midnight can be computed for any time of day. Table 5 is a multiplication table which facilitates this computation.

5. Time. The word *time* has two meanings that are often confused, ***elapsed time*** and ***moment of time.***

The measure of elapsed time used throughout this treatise is the familiar hour of which there are 24 in a day. Elapsed time, so measured, is more accurately called Mean Solar Time (*MST*), Mean Time (*MT*), or Civil Time (*CT*).

A moment of time is given by the year, the day of the month and the elapsed time since midnight (0^h) at the beginning of the day named. It must be further defined by the meridian from which it is reckoned. Accordingly, ***Greenwich Civil Time*** (*GCT*), often called ***Universal Time,*** is civil time reckoned from the moment of midnight at the Greenwich meridian; and 75th meridian time (Eastern Standard Time, *EST*), for example, is civil time reckoned from midnight at the 75th meridian. ***Local Civil Time*** (*LCT*) is civil time reckoned from the precise meridian of longitude where an observation is taken. To convert a moment of time, reckoned from any meridian, to *GCT*, one hour is added for every 15° of west longitude and one hour is subtracted for every 15° of east longitude. Obviously, when the value of the longitude is not evenly divisible by 15°, fractional hours will result.

Examples:

1 AM *EST*	=	6^h *GCT*
2 PM *EST*	=	19^h *GCT*
10 PM *EST*	=	3^h *GCT* (the next day)
4 AM 76°W *LCT*	=	$9^h\ 4^m$ *GCT*
10 AM 30°E *LCT*	=	8^h *GCT*

6. Tables and Charts. This book contains all the tables necessary for observations on the sun, on Polaris and on twenty-six selected stars. For other stars the reader is referred to "The American Nautical Almanac" published for each year by the U. S. Naval Observatory and available from the Superintendent of Documents, Washington, D. C.

Note that the word *apparent* is often found preceding data in tables. It means that the data given are those which would result if the observation were made at the center of the earth. Since all computations are based on this premise and all observations are corrected accordingly, these are the data to use. When the word *apparent* is omitted it is understood to be there.

Two star charts are provided; Fig. 6, which shows the northern sky, and Fig. 10, which shows the sky when looking south.

7. The Sun. As the earth traverses its yearly path, the background of the celestial sphere behind the sun changes slightly from day to day. Viewed from the earth, the sun apparently completes a circuit around the celestial sphere once in the course of a year. Accordingly the rate of increase in the *GHA* of the sun differs slightly from the rate of increase of the *GHA* of the fixed stars, which move very nearly with the celestial sphere.

Since the earth's axis slants with respect to the plane of the earth's path around the sun, the sun moves north and south on the celestial sphere as the earth moves along its path. This causes the sun's declination to change more rapidly than do the nearly constant declinations of fixed stars. In the course of a year the sun's declination ranges almost 23½° each way north and south of the equator. For these reasons, special tables are necessary for the sun.

The sun does not make its daily passage around the earth at a constant rate. For this reason it is impossible to base elapsed time on the daily passage of the sun. The 24 hour unit used for the day is based on the *average* rate of movement of the sun. In fact the sun is sometimes ahead of and sometimes behind noon *LCT* by an amount which varies from zero to about 16 minutes. (See next section.)

8. The Equation of Time is the *GHA* of the sun minus the *GHA* of noon *LCT*. But for all practical purposes it may be defined as the elapsed time by which the sun precedes noon *LCT*. A minus value indicates that the sun follows noon *LCT*. For example, the following data can be true.

Moment of Time	Position of Sun	Equation of Time
12^h *GCT*	*GHA* 3° 8.4′	$+12^m\ 33.6^s$
12^h *GCT*	*GHA* 356° 37.1′	$-13^m\ 31.6^s$

Table 1 can be used to find the value of the equation of time for any moment of time throughout the year.

9. True Solar Time is, for all practical purposes, a moment of time measured in civil hours but based on the sun's passage for the day in question. Noon (12^h) true solar time on any day and at any meridian is the moment the sun crosses that meridian that day. Accordingly, at any given meridian:

$$\text{or}\begin{cases}\text{True Solar Time} = \text{Local Civil Time} \\ \qquad\qquad\qquad + \text{ Equation of Time} \\ \text{Local Civil Time} = \text{True Solar Time} \\ \qquad\qquad\qquad - \text{ Equation of Time}\end{cases} \quad (1)$$

B. THE TRIGONOMETRY INVOLVED

10. A Spherical Triangle. A ***great circle*** is the trace on a sphere of a plane which passes through the center of the sphere. A ***spherical triangle*** is the figure on a sphere bounded by the arcs of three great circles. It has six parts: three sides and three angles. When any three parts are known, the other three can be found. Both sides and angles are measured in angular units, usually in degrees and minutes. The length of a side is measured by the angle at the center of the sphere between the radii extended to its ends. The size of an angle is measured by the dihedral angle between the planes of the great circles which form it. It may also be measured by the angle between the tangents to the great circles at their intersection.

Any three points on a sphere may be joined by great circles to form a triangle in which no part is greater than 180°. Such a triangle is the one always considered in this text.

11. The Principles. Fig. 2 illustrates the spherical trigonometry involved in every observation for position or for true north. It represents the conditions that exist at the moment of observation. P is a pole of the celestial sphere (in this case the north pole),*

***The south pole may be used, but the signs of the latitude and the declination must then be reversed. To avoid confusion, the symbol P in this text is always taken as the north pole.**

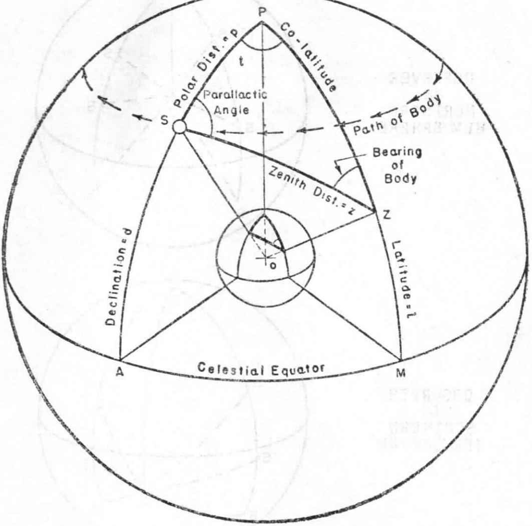

Fig. 2.

S is the celestial body observed (the arrows represent the path of the body) and *Z* is the observer's zenith. The lines joining them are arcs of great circles.

12. The Zenith. The observer's zenith is a point on the celestial sphere found by projecting the center of the instrument at the time of observation upward along the direction opposite to that of gravity.

13. The Astronomical Triangle. (Fig. 2.) The triangle *PZS* is known as the ***astronomical triangle.*** It may be formed west of the meridian as shown, or east of the meridian if the body is so located. It is a true spherical triangle formed by great circles, and spherical

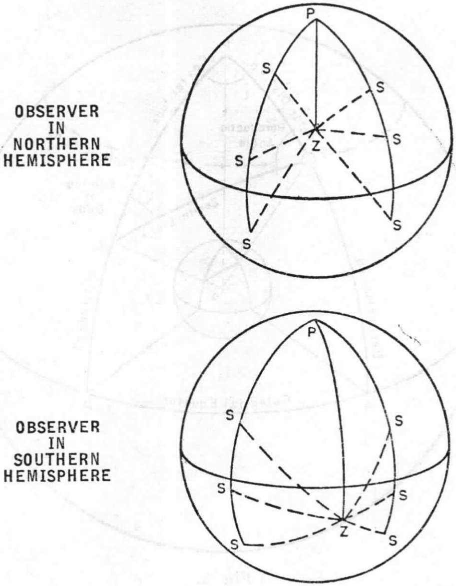

Fig. 3.

trigonometric formulas apply. When Z or S, or both, are in the southern hemisphere, other arrangements are created. Fig. 3 shows the twelve possibilities. Note that no angle or side is greater than 180°. All forms of the triangle are solved by the same formulas but the results of the solutions do not indicate whether the body is east or west of the meridian. This can be determined from the *LHA* described in the next paragraph. The six parts of the triangle are named and described below.

14. Angle *t* is known as the ***meridian angle***. The ***Local Hour Angle*** (*LHA*) of a body is the angle measured westward around the axis of the celestial sphere from the meridian of the observation to the meridian of the body. The arc MA represents the LHA. Obviously

$$LHA = GHA - \text{West Longitude} \ldots\ldots\ldots (2)$$
$$LHA = GHA + \text{East Longitude} \ldots\ldots\ldots (2a)$$

When the LHA is less than 180°, the body is west of north and:

$t = LHA$

When the LHA is greater than 180°, the body is east of north and:

$t = 360° - LHA$

15. Angle *Z* is the bearing* of the body S, since it is equal to the horizontal angle between the north direction of the observer's meridian and the direction of the body. It is measured east or west of north according to the position of the PZS triangle.

16. Angle *S* is the parallactic angle. It is usually unnecessary to use the value of this angle.

17. Side *PS* (p) is the *polar distance*. It is equal to 90° minus the declination (d) of the body S. In the formulas used for many observations sin d is substituted for cos p, etc.

18. Side *PZ* is the *co-latitude* of Z. It is equal to 90° minus the latitude (l) of the observer. The formulas are often written using sin l substituted for cos co-latitude, etc.

19. Side *ZS* (z) is the *zenith distance* of the body S. It is equal to 90° minus true altitude (h). The true altitude can be found in the field by observing the altitude of a body and correcting the result for *refraction* and *parallax*, as described in the next section.

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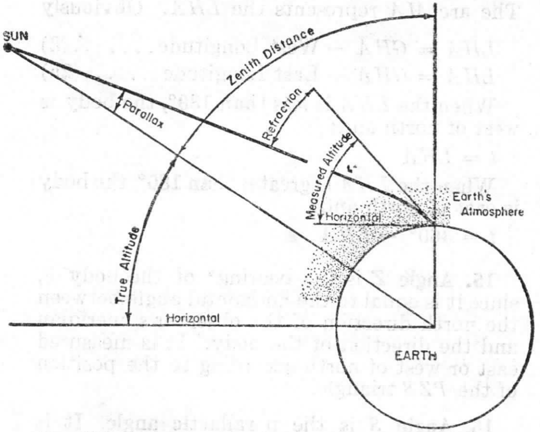
*The term *bearing* is used here in preference to *azimuth* since the angle measured from the north may be either east or west. It may exceed 90° but it is always less than 180°.



True Altitude = Measured Altitude — Refraction + Parallax

Fig. 4.

20. Refraction and Parallax. Fig. 4 shows the effect of refraction and of parallax. The true altitude is obtained by the following formula:

$$\text{True Altitude} = h = \text{Measured Altitude} - \text{Refraction} + \text{Parallax} \quad (3)$$

The value of the refraction is affected by the altitude and to a lesser degree by the air density. Its effect can be estimated for the measured altitude and the ground temperature and barometric pressure or elevation. The sun's parallax is very small (never more than 0.2′) and the parallax of the stars is infinitesimal. Table 2 gives the values of refraction and the sun's parallax at a certain temperature and barometric pressure. Table 2a gives factors for correcting those values for actual temperature and barometric pressures (or elevations).

C. FIELD METHODS

21. Operations. The field operations consist of measuring vertical and horizontal angles to celestial bodies and recording the precise time that a body is sighted. Horizontal angles must, of course, be measured from an *azimuth mark* on the ground.

Usually several observations are made in a group, the angles and times averaged, and only the averages used in computation. At least two groups should be averaged and computed separately for a check. As a rule no single group should include observations made more than ten minutes apart, because of the curvature of the path of the body. The methods of observing are identical to ordinary surveying methods with the following additional requirements.

a. Pointing on a star. At dusk a star can be observed without special equipment. When the sky is so dark that the cross hairs cannot be seen, a flashlight should be pointed diagonally into the objective lens. The position of the flashlight can be regulated so that the stray light gives sufficient background to show the cross lines but is not so bright that the star is obliterated. K & E No. 74 0560 Reflector Sunshade provides the proper illumination when a flashlight is played on it from the side.

b. Illumination of azimuth mark. While any light will serve as a mark at night, it is best to provide an illuminated background for a plumb bob or other signal placed over the station. The cross lines can then be seen against the background without illuminating the instrument.

c. Pointing on the sun. The sun should not be observed through a telescope without protection for the eye. Methods for pointing on the sun are described in Section 30.

d. Set up. If the ground is springy, the tripod should be supported on firm stakes. Leveling must be extremely accurate to avoid serious errors. If the instrument is equipped with a telescope level, after leveling with the plate bubbles, proceed as follows.

Step 1. Set the vernier at zero, turn the instrument in azimuth until the telescope is in line with a pair of opposite leveling screws and center the telescope bubble with the vertical motion.

Step 2. Turn 180° in azimuth. If the bubble fails to center, correct half the error with the leveling screws, and the other half with the tangent screw.

Step 3. Repeat Steps 1 and 2 until the bubble remains in the center.

Step 4. Turn 90° in azimuth. Center the bubble with the leveling screws.

Step 5. Test the leveling at 0°, 90°, 180°, and 270°.

If the telescope is without a level, perfect the leveling until the plate level that is parallel to the telescope remains in the same position in the tube at all azimuths.

e. Recording time. For certain observations, time must be recorded within two or three seconds. For these observations the watch correction should be determined to the nearest second before, and preferably also after, the field work. Before comparison, the minute hand should be set so that it coincides exactly with a minute mark when the second hand is at zero. Accurate time is best obtained from radio time signals.

During the observation the transitman calls "tit" when his pointing is perfected. The recorder reads first the second, then the minute and the hour. When no recorder is available, a stop watch is of great assistance. The observer starts the stop watch when the pointing on the body is correct and stops it when the second hand of the timing watch is on a 10 seconds mark. The reading of the stop watch is subtracted from that of the timing watch.

Example: If the stop watch is stopped at 6 seconds when the timing watch read 8:42:30, the stop watch was evidently started at 8:42:24. Therefore, the time of observation was 8:42:24.

II. DETERMINATION OF TRUE BEARING

METHOD 1. BY OBSERVATION OF POLARIS AT ELONGATION

22. Description. True north can be determined by a Polaris observation at elongation when accurate time is not available. The method is simple and, with care, should give results within ±0.5 minutes. However, it often must be performed at inconvenient hours.

Polaris follows a circular path around the pole similar to that shown by the arrows in Fig. 2. Viewed from the earth, the path is circular and the motion is counterclockwise. The points in the path where Polaris is furthest west or furthest east are called *western* and *eastern elongation* respectively. When the parallactic angle S is 90° the star is at elongation.

23. Directions for Observation. Required to determine the bearing of a mark B from transit station A. (See Sec. 21). The instrument must be in perfect adjustment unless the star can be observed with the telescope both direct and reversed as mentioned below.

From observation of the sky or by means of Fig. 5 or Table 8, estimate the time of that elongation which occurs during dark. Set up at A. Set the horizontal vernier at zero. Sight B with the lower motion. Point on Polaris with the upper motion.

Before $\begin{Bmatrix}\text{western}\\ \text{eastern}\end{Bmatrix}$ elongations the star will be moving $\begin{Bmatrix}\text{down}\\ \text{up}\end{Bmatrix}$ and also moving toward the $\begin{Bmatrix}\text{west}\\ \text{east}\end{Bmatrix}$.

Follow the star until the $\begin{Bmatrix}\text{westward}\\ \text{eastward}\end{Bmatrix}$ movement ceases and the only movement is vertical. Read the horizontal vernier. The motion east or west is imperceptible for about 10 minutes. It therefore may be possible to repeat the angle with the telescope reversed — thus increasing the accuracy and eliminating errors of instrument adjustment.

24. Example. Date, Oct. 18, 1969; latitude (from map), 40° 20′; clockwise angle from mark B to Polaris, 75° 20′. Use the following formula or Table 7.

$$\text{Bearing of Polaris (in minutes)} = \frac{\text{Polar Distance (in minutes)}}{\text{cos Latitude}} \quad \ldots\ldots (4)$$

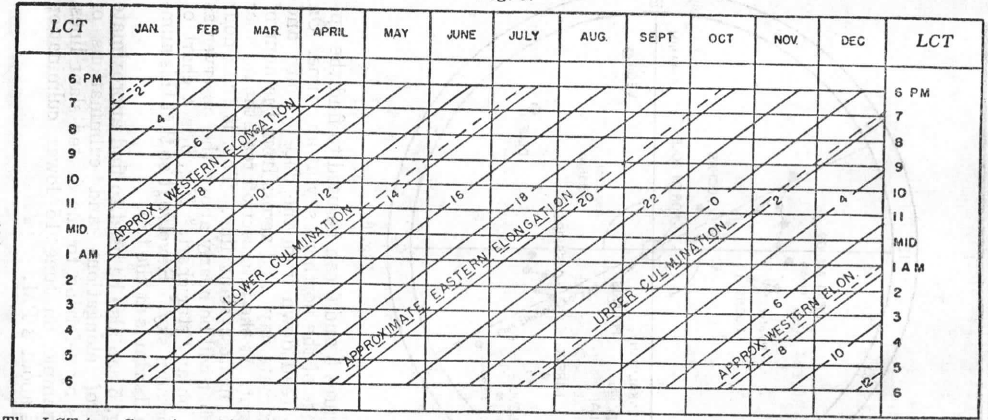
From Table 3 polar distance Polaris Oct. 18, 1969 = 0° 52.42′

$$Z = \frac{52.42'}{0.7623} = 68.8' \quad = 1^\circ\, 08.8'$$

From Table 7 azim. = 1° 08.8′

Bearing AB = N76°28.8′ W (if elong. was western)
= N74°11.2′ W (if elong. was eastern)

Fig. 5.



The *LCT* (see Sec. 5) used in the chart is substantially correct for any year. To convert watch time to *LCT*, add to the watch time 4 minutes for every degree of longitude that the observation is east of the meridian from which the watch time is reckoned. Subtract if west. Example: watch 10:00 *CST* (90th mer.); observation 87° W. Long. 10:00 + 3x4 = 10:12 (*LCT*). This conversion is necessary only when watch time and *LCT* differ substantially.

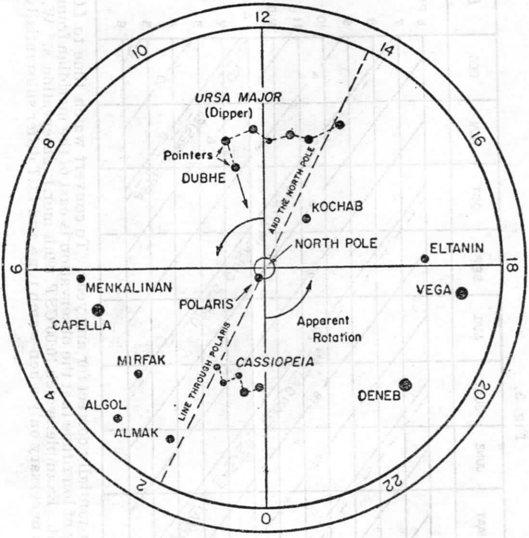


Fig. 6.

Figures 5 and 6 can be used to find the appearance of the northern sky at any time. On Fig. 5 read down from the date (month and approximate day) and across from the hour of the night. At the intersection read the number of the nearest slant line. This is the "hour line" that will be nearly above the observer as shown on any star chart. Fig. 6 is a chart of the northern sky. Revolve it so that this number on its rim is at the top.

Fig. 5 can also be used to find approximate times of elongations and culminations of Polaris by referring to the dotted slant lines. For example, on June 15 lower culmination occurs about 8 PM.

METHOD 2. BY OBSERVATION OF POLARIS AT ANY TIME

25. Description. The method described below is designed for accurate observation. It is quick and convenient, and the computations are simple. It can be made at any time from dusk to dawn. Twilight is recommended. Pointings can be made on the star at that time while the instrument can be set up and the angles read by daylight. Polaris can be easily seen through the telescope an hour before sunset. To find the star, focus on a point 800 feet or more away so that the star will be in focus when brought into the field of view. Estimate its place in the sky with respect to the pole to ± ¼° by means of Fig. 5. The telescope can be pointed to the pole by setting the vertical circle at the latitude and the compass needle at the magnetic bearing of the pole. By correcting these settings, according to its estimated position, the star can be brought into the field of view. A signal should be placed on the ground under the star about 30 feet from the instrument, to aid in finding the star again.

26. Directions for Observation. Required to determine the bearing of mark B from transit station A. Determine the watch correction to the nearest second. (See Sec. 21). Set up at A. Turn the angle from B to the star, using six repetitions of the angle, three with the telescope in its normal position and three in its reversed position, i.e. 3DR. Record the time to the nearest second each time the cross line is brought on the star. Average the time and divide the total angle by six. At least two separate observations should be made.

27. Example. Time of observation May 5, 1969; watch reading, 8:28:23 PM, 90th Meridian time; watch known to be 0:02:03 slow; latitude (from map) N42°22.6′; longitude (from map) W92° 58.3′; clockwise angle, mark to star 25°53.0′.

Find the *LHA* and *t* (see Sec. 14) as shown below.

Watch time	8:28:23 PM
Watch correction (slow is plus)	2:03 slow
Standard time (90th meridian)	8:30:26 PM
Correction to 24 hour basis	+ 12
90th meridian time	20:30:26
Correction for time zone	+ 6
GCT (Sec. 5)	26:30:26
GCT May 6, 1969	2:30:26
GHA (Sec. 2) 0^h May 6, 1969 Table 1	193° 27.5′
Correction for $2^h 30^m$ (Table 5)	+ 37 36.2
Correction for 26^s (Table 5)	+ 6.5
GHA	231° 10.2′
Less west longitude (from map)	− 92 58.3
LHA (Sec. 14)	138° 11.9′
$t = LHA$ or $360 - LHA$ (use smaller)	138° 11.9′

28. Computation. The bearing of Polaris (Z) (Sec. 15) is found from the formula:

$$Z = \frac{\sin t}{\cos h} p \quad \dots\dots\dots\dots (5)$$

where

t (Sec. 14) is the meridian angle just computed above.

h (Sec. 20) is the true altitude. It is usually obtained from the known latitude l, using Table 6, and then it need not be observed.

p (Sec. 17) is the polar distance.

Four optional procedures for the computation are given below. Procedure A is the solution which is familiar to K&E Solar Ephemeris users. Procedures B, C and D are added to give a more precise solution under different conditions of latitude and instrumentation.

Procedure A

Table 10 gives values of Z for selected values of LHA and l when $p = 0° 52.40'$. By a two-way interpolation the value of Z can be found from the known values of LHA and l. Table 11 gives the correction to be applied for values of p other than $0° 52.40'$.

Example.

$LHA =$	$l = 42°$	$42° 22.6'$	$44°$
135°	49.4′	49.7′	51.0′
138° 12′		46.8′	
140°	44.9′	45.2′	46.3′

From Table 3, p for May 6 = 52.64′; from Table 11, the correction for $p = 52.60'$ and $Z = 46.8'$ is $+ 0.2'$. Therefore

$$Z = 46.8' + 0.2' = 47.0'$$

Procedure B

For a precise computation, if the station is between N. Lat. 25° and N. Lat. 50° (latitudes of U. S. A.), use the formula

$$Z = \frac{\sin t}{\cos h} p \quad \text{where}$$

Z (Sec. 15) is the bearing of Polaris expressed in minutes of arc with a computational accuracy of $\pm 0.02'$.

t (Sec. 14) is the meridian angle to the nearest minute.

h (Sec. 20) is the true altitude to the nearest minute from Table 6.

p (Sec. 17) is the polar distance expressed in minutes to the nearest 0.02′.

Example.

p (Sec. 17) for Polaris (Table 3, May 6, 1969)	52.64′
l (from map)	42° 22.6′
Correction (Table 6, t = 138.2°)	— 39.2′
h (Sec. 20)	41° 43.4′

$$Z = \frac{\sin 138° 12'}{\cos 41° 43'} \times 52.64' = \frac{0.6665}{0.7464} \times 52.64'$$

$$= 47.00'$$

Procedure C

For latitudes below 25° or above 50° where Polaris can be observed, greater accuracy can be achieved by measuring h directly, rather than by using a correction of l, provided the instrument has a full vertical circle. Use the same formula (Eq. 5) as above, but observe the altitude and the temperature and obtain the true altitude h by correcting for refraction. The altitude should be observed once direct at the first pointing on Polaris and once reversed at the last pointing on Polaris. The average is used. Assume the average measured altitude is 21° 10.0′, the temperature is 70°, and the barometer is 30.5 in.

$$\text{Measured altitude} = \quad 21°\ 10.0'$$

$$\text{Less refraction correction}$$

$$-2.46 \times 0.96 \times 1.03 \quad (\text{Table 2}) = -\quad 2.4$$

$$h = \quad 21°\ 07.6'$$

Procedure D

When procedure C cannot be followed because the instrument has no vertical circle, use the following formula. (For cot p see Table 3).

$$Z \text{ in minutes} = \frac{(3438)\sin t}{\cos l \cot p - \sin l \cos t} \quad (6)$$

Example.

Z (minutes)

$$= \frac{(3438)\sin 138°\ 12'}{\cos 42°23' \cot p - \sin 42°23' \cos 138°\ 12'}$$

$$= \frac{(3438)\ (.6665)}{(.7387)\ (65.30)\ -\ (.67)\ (-.75)}$$

$Z = 47.00'$

To compute the bearing of the Mark. (Fig. 7). Having computed Z by any one of the above four procedures, continue as follows:

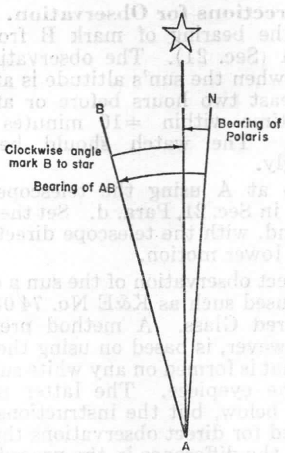


Fig. 7.

Since *LHA* is less than 180°, the star is west of north. Using the value 0°47.0′, the bearing of mark B is computed as follows. (See Sec. 14).

Clockwise angle mark B to star	25° 53.0′
Bearing of Polaris	+N 0° 47.0′ W
Bearing of AB	N 26° 40.0′ W

Note: When neither accurate time nor longitude are available, the *GHA* and the *t* of Polaris can be obtained by the method outlined on page 152.

METHOD 3. BY THE ALTITUDE OF THE SUN

29. Description. The bearing of a line can be determined to within ±2′ by an observation on the sun. The average of several such observations will, of course, give a higher accuracy.

30. Directions for Observation. Required to find the bearing of mark B from transit station A (Sec. 21). The observation should be made when the sun's altitude is at least 20° and at least two hours before or after noon. Correct time within ±10 minutes must be observed. The watch should be checked accordingly.

Set up at A using the telescope level as described in Sec. 21, Para. d. Set the *A* vernier at zero and, with the telescope direct, sight B, using the lower motion.

For direct observation of the sun a dark filter must be used such as K&E No. 74 0575 Prism and Colored Glass. A method preferred by many, however, is based on using the image of the sun that is formed on any white surface held behind the eyepiece. The latter method is described below, but the instructions can also be followed for direct observations through the telescope, the difference in the procedure being obvious.

To Sight the Sun. Have the recorder hold the back (white) page of the field book about six inches behind the eyepiece. With the upper and vertical clamps free, turn the telescope until its shadow on the page is circular. As the telescope is moved into this position, the sun's image will flash across the page. Bring the image within the shadow of the telescope and clamp both motions. Approximately center the sun in the shadow with the tangent screws. Adjust the distance between the field book page and the eyepiece until the cross lines can be seen most effectively. Focus the eyepiece until the images of the cross lines which appear on the sun's disc are clear cut, and focus the objective until the edge of the sun's image is sharp.

Identify the center horizontal cross line. It will be noticed that, as the sun's image is moved

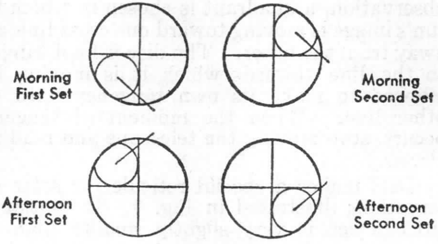


Fig. 8.

with the tangent screws, the cross lines remain stationary with respect to the shadow of the telescope. The center horizontal cross line will remain in the center of the shadow, while the stadia lines will be found at the top and bottom respectively.

To make the observations, the sun's image may be centered on the cross lines or brought tangent to them. The first method is simpler to perform, the second method is more accurate. If the second method is used, half of the observations should be made with the sun in one quadrant and the other half with the sun in the opposite quadrant. The mean of the results will then be the same as that which would have been obtained had the cross lines been centered. (See Fig. 8.)

While either pair of opposite quadrants may be used, the scheme illustrated in Fig. 8 is recommended. When using an erecting instrument, the sun's image moves in the same direction as a shadow that is cast by the sun. Fig. 8 shows this motion. If it is turned upside down Fig. 8 will illustrate an observation with an inverting instrument. In the southern hemisphere the horizontal components of the sun's motion will be in the opposite direction from those shown in Fig. 8. To make the observation, a quadrant is chosen in which the sun's image is moving toward one cross line and away from the other. The disc is kept tangent to the line towards which it is moving but allowed to make its own tangency with the other line. When the moment of tangency occurs, stop moving the telescope and read the circles.

K&E makes a special reticule for solar observations illustrated in Fig. 9. It contains a circle which is very slightly smaller than the

Fig. 9.

GLASS RETICULE for direct solar observation, with cross and short stadia lines and solar circle. The semi-diameter of the circle is 15′ 45″.

sun's image so that it can be centered very accurately on the sun's disc. When this reticule is used, the pointings are more accurate than when the sun's image is brought tangent to the cross lines. In addition, the difficulty of choosing the correct quadrants is eliminated, and there is no danger that a stadia line might be used in error.

Make three pointings with the telescope direct and three with the telescope reversed, without moving the circle and therefore without using the lower motion. Read the *A* vernier and the vertical angle vernier both to the nearest vernier division at each pointing. Record the time of the first and last pointings. Finally sight mark B with the telescope reversed and read the *A* vernier. It should read 180° within ± 1 minute. Add ± 180° to all reversed pointings.

Find the averages respectively of the horizontal readings, the vertical readings, and the time. Correct the horizontal readings by the average of the two readings on the mark B. Take the air temperature or estimate it.

31. Computation. Formula for machine computation.*

$$\cos Z = \frac{\sin d - \sin h \sin l}{\cos h \cos l} \quad \ldots\ldots (7)$$

Formula for logarithmic computation.*

$$\cos Z = \frac{\sin d}{\cos h \cos l} - \tan h \tan l$$

where Z (Sec. 15) is the sun's bearing. It may be greater than 90°. A minus value of $\cos Z$ indicates a value of Z greater than 90°. If the observation was taken in the morning the bearing is east of north and vice versa. d (Sec. 17) is the declination taken from Table 1, to the nearest 0.1′. h (Sec. 20) is the measured altitude to the nearest 0.1′ corrected for refraction and parallax. l is the latitude to the nearest 0.1′ taken from the map.

Five place tables give sufficient accuracy.

32. Example. Assume latitude (from map) N38° 10.1′, temperature 70° F., elevation 600 ft., the field notes are: Date: May 6, 1969

All horizontal angles clockwise.
Watch on Central Time.

Transit at A, Pointing	B at start	0° 00′
	B at end	0° 00′
	Correction	0° 00′

Pointing Sun

	Hor. Ang.	Vert. Ang.	Time
Direct	157° 54.0′	33° 48.0′	3:40 PM
	158° 10.5′	33° 26.5′	
	158° 23.0′	33° 12.0′	
Reversed	159° 05.5′	32° 50.0′	
	159° 18.0′	32° 31.0′	
	159° 34.0′	32° 09.0′	3:50 PM
Aver.	158° 44.2′	32° 59.4′	3:45 PM
Correction	0.0		
	158° 44.2′		

* If frequent Sun Observations are made, special trigonometric tables that readily solve this formula are available in the booklet "Shoot the Sun", published by State Publishing Co., Helena, Mont.

Standard time 90th meridian	3:45 PM
Correction for 24 hour basis	+ 12
90th meridian time	15:45
Correction for time zone	+ 6
GCT (Sec. 5)	21:45
Sun's d 0^h May 6, 1969 (Table 1)	+16° 25.5′
Change since 0^h; 21.75 × 0.70 +	15.2
Sun's d	+16° 40.7′
Measured altitude	32° 59.4′
Refraction and parallax (Table 2)	
−(1.48) (.96) (.99) + .13 =	− 1.3
True altitude, h	32° 58.1′

$$\cos Z = \frac{\sin 16° \ 40.7' - \sin 32° \ 58.1' \sin 38° \ 10.1'}{\cos 32° \ 58.1' \cos 38° \ 10.1'}$$

$$\cos Z = \frac{(.28700) - (.54418)\ (.61797)}{(.83897)\ (.78620)}$$

$$\cos Z = -0.07473$$

$$Z = 94° \ 17.1'$$

See Fig. 2.

Sun's bearing	S 85° 42.9′ W
Clockwise angle B to sun	158° 44.2′
Bearing of mark B	S 73° 01.3′ E

33. Use in Southern Hemisphere. The formula can be used without change for observations in the southern hemisphere. South latitude as well as south declination must be taken as minus. Z will be measured from the north, as before.

METHOD 4. BY USE OF THE SOLAR ATTACHMENT

34. Description. By use of the solar attachment, the transit can be made to solve the astronomical triangle automatically. Thus, by direct observation of the sun, the line of sight can be brought into the plane of the local meridian. The accuracy is limited to about ± 2 minutes.

III. THE DETERMINATION OF LATITUDE

35. Description. The latitude of the point of observation is required for several methods of determining a true bearing. For these observations, when it cannot be accurately determined from a map, latitude must be determined in the field.

Latitude can be determined, without accurate time and independent of other observations, by measuring the altitude of the sun or a star when it reaches its culmination.

Directions for Observation. The instrument must be in good adjustment. Choose a time when any star, or the sun, is approaching a point north or south of the point of observation. Follow the body with the cross lines to the point of maximum (or minimum) altitude.* When this point is reached, stop moving the cross lines and record the altitude.

Computation. The observed altitude is corrected for refraction (and for semi-diameter and parallax if the sun is observed) and the zenith distance (Sec. 20) is derived from it. The formulas used are the following:

$$z = 90° - h \ldots\ldots\ldots\ldots (8)$$

Then at upper culmination $l = d + z \ldots\ldots (9)$

at lower culmination $l = (180° - d) + z$

where l is the latitude, d is the declination (Sec. 3) and z the zenith distance. The signs

*A maximum occurs at *upper culmination*, a minimum at *lower culmination*. Lower culmination can be observed only on bodies having a declination which, when added to the latitude of the observer, gives a value numerically larger than 90°.

of each of these terms must be carefully taken into account as follows:

South latitudes are minus.
South declinations are minus.

Zenith distances of bodies north of the observer are minus in both north and south hemispheres.

Note: In Eq. 9 the parenthesis $(180° - d)$ is computed as though d were plus. The result is then given the actual sign of d.

One of the twenty seven stars for which data are available passes the meridian nearly every hour. (See Fig. 10. For identification see Sec. IV.) It is unnecessary, therefore, to predetermine when the observation must be made. If it is desired to observe Polaris or the sun, it is convenient to estimate the proper time to make the observation. The time of upper or lower culmination of Polaris can be estimated from Fig. 5. The time of upper culmination of the sun is noon, True Solar Time. It is estimated as follows, when approximate longitude is available:

GCT of True Solar Noon

$$= 12 \text{ hours} + \text{West Longitude} - \text{Equation of Time} \quad (10)$$

Example of estimating the time of the sun's upper culmination. Assume longitude approximately W102°; observation to be made May 6, 1969.

Noon, True Solar Time	12.0 hrs.
Less equation of time (Sec. 8) Table 1	− 0.1
LCT	11.9
Add W. Long. converted to hours (Sec. 5) $\frac{102}{15}$ =	+ 6.8
GCT (Sec. 8) of True Solar Noon at W102°	18.7
Zone Correction to Mountain Time (105th meridian)	− 7.0
Mountain time	11.7

Example of a sun observation. Assume that the observation described above resulted in the following observed altitude of the sun's upper limb (top), temperature 50° F., barometer 29.6 in.

Observed altitude		58° 29.7′
Refraction and parallax cor. (Table 2) − 0.59 + 0.07		− 0.5
Altitude upper limb		58° 29.2′
Less sun's semi-diameter May 6, 1969 (Table 4)		− 15.9
True altitude h		58° 13.3′
$z = 90 - h$ (z is taken as plus when body is south of observer)		+31° 46.7′
Sun's d 0^h May 6, 1969 (Table 1)	+16° 25.5′	
Change since 0^h; 18.7 ×.70	+ 13.1	
Sun's d		+16° 38.6′
Latitude		+48° 25.3′

Example of a Polaris observation. Assume observation on Polaris at lower culmination May 6, 1969; temperature 50°; elevation 1000 ft.; observed altitude 35° 21.9′.

Observed Altitude	35° 21.9′
Refraction correction (Table 2) − 1.35 × 1.00 × 0.98	− 1.3
True altitude, h	35° 20.6′
$z = 90 - h$ (z is taken as minus when body is north of observer)	−54° 39.4′
Polaris d May 6, 1969 (Table 3). 90° − 0° 52.64′ = + 89° 07.4′	
180° − d (lower cul.)	+90° 52.6′
Latitude	+36° 13.2′

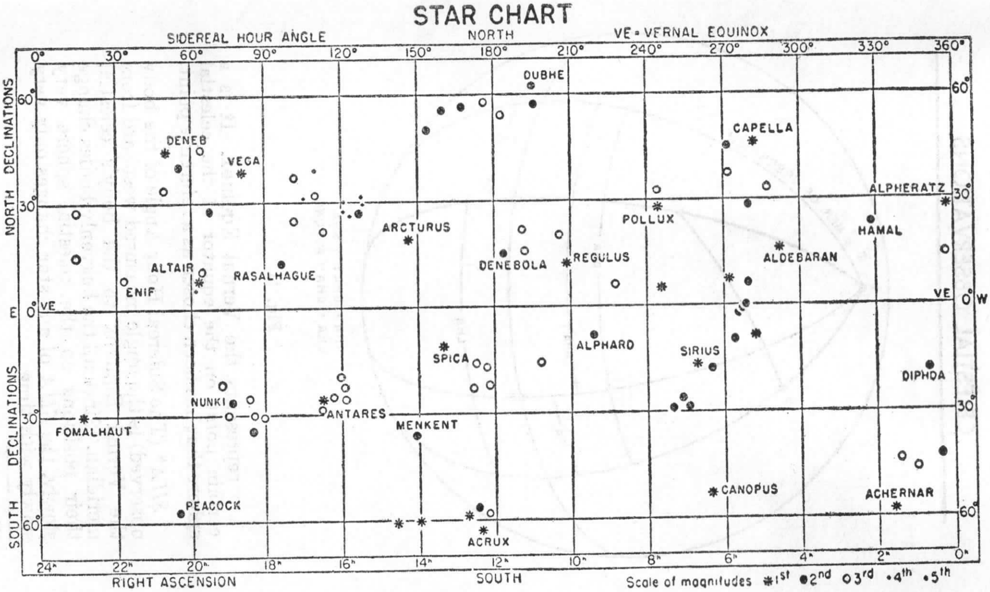
IV. SUPPLEMENTARY OBSERVATIONS

Since K&E surveying instruments are used in many parts of the world where Polaris cannot be observed and other difficulties are encountered, this supplement has been prepared to cover the usual problems faced. It includes methods of determining a true bearing by observing stars other than Polaris, and by observations on Polaris at any time when accurate time and longitude are unavailable. To complete the description of celestial observations, it also gives a method of determining longitude.

Identification. Fig. 10 is arranged to show the appearance of the heavens. The declinations are marked along the edges. The declination which is directly above the observer is equal to the latitude. Hours are marked from 0 to 24 along the bottom. The hour line, which is overhead at any time, can be found by Fig. 5 or computed from the following formula: Hour line overhead = local PM time $+ 2 \times$ (number of months since March 22) . . (11)

For example; at 10 PM on December 4, the hour line overhead is $10 + 2 \times 8.4 = 26.8$. Rejecting 24 hours, this gives 2.8 or nearly 3 hours.

Data Available in this Booklet. The necessary data are available in this booklet for twenty six stars. The stars are shown in Fig. 10 and the data are listed in Table 13. Certain terms, not always familiar to engineers, are used. They are illustrated in Fig. 11.



STAR CHART
SIDEREAL HOUR ANGLE
NORTH
VE = VERNAL EQUINOX
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
360°
NORTH DECLINATIONS
SOUTH DECLINATIONS
60°
30°
0°
E
W
VE
DUBHE
CAPELLA
DENEB
VEGA
ALPHERATZ
POLLUX
HAMAL
ARCTURUS
ALDEBARAN
DENEBOLA
REGULUS
ALTAIR
RASALHAGUE
ENIF
ALPHARD
SIRIUS
SPICA
DIPHDA
NUNKI
ANTARES
MENKENT
FOMALHAUT
CANOPUS
ACHERNAR
PEACOCK
ACRUX
24h
22h
20h
18h
16h
14h
12h
10h
8h
6h
4h
2h
0h
RIGHT ASCENSION
SOUTH
Scale of magnitudes
1st
2nd
3rd
4th
5th

Fig. 10.

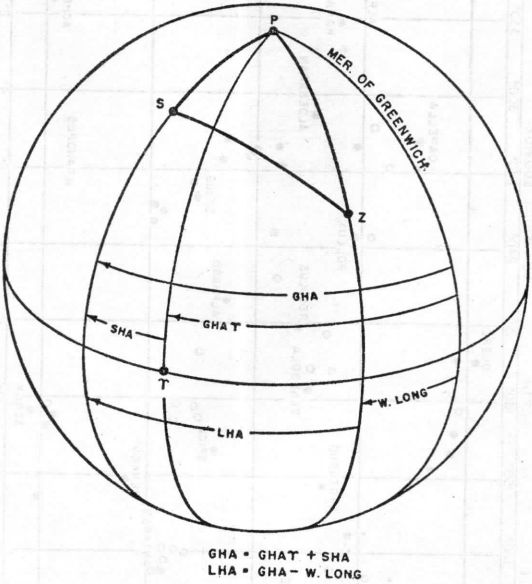


Fig. 11.

♈ represents the Vernal Equinox. It is a certain point on the equator of the celestial sphere that has been chosen as a reference point.

*SHA** (The Sidereal Hour Angle of the body observed) is the angle measured westward from the Vernal Equinox to the body's celestial meridian. Since all the heavenly bodies change their positions on the celestial sphere very slowly, the *SHA* of any star changes only very slowly with time.

***SHA = 360°— Right Ascension (expressed in degrees)**

GHA ♈ (The Greenwich Hour Angle of the Vernal Equinox) is the angle, at the moment of observation, measured from the Greenwich meridian westward to the Vernal Equinox.

Obviously, the *GHA* of any celestial body is determined from the following formula:

$$GHA = SHA + GHA\ ♈$$

Table 13 gives the *SHA* and the declination of each of twenty-six stars at the first of each month throughout the year. Under each month is listed a correction. The correction for the date of observation should be interpolated and added algebraically to the *SHA* or Decl. given at the left.

Example. To find the declination of Acrux on Apr. 17, 1969.

(Decl.)	S 62° 55′
Correction (interpolated)	+ 1.0
	S 62° 56.0′

Table 12 gives the *GHA* of ♈ for each date at 0^h *GCT*. By using Table 5, the *GHA* can be brought up to the moment at which the observation was made.

Example. To find the *GHA* of Aldebaran on Jan. 3, 1969, at 2:31:48 *GCT*.

From Table 13, *SHA*	291° 27.7′
GHA ♈0^hJan.3, 1969 (Table 12)	102° 26.4′
Correction for 2^h31^m (Table 5)	37° 51.2′
Correction for 48^s (Table 5)	12.0′
GHA (sum, rejecting 360°)	71° 57.3′

TRUE BEARING WITHOUT POLARIS

Description. In high northern latitudes, when Polaris is too near the zenith to be observed, and in southern latitudes where Polaris cannot be seen, the most accurate method of determining a true bearing is by observations of the altitudes of stars.

The method consists of simultaneously observing the horizontal angle from a mark to a star and the star's altitude. The procedure for this operation is the same as that for finding true north by the altitude of the sun as described on page 137. Each observation consists of six direct and six reversed pointings with the horizontal circle in the same position. Time does not have to be recorded, as the declinations of the stars do not change rapidly enough to make it necessary. The method is not very accurate, especially in high latitudes, and therefore many observations must be taken. The stars chosen should be nearly on the ***prime vertical***, that is, nearly east or west from the observer and preferably 25° to 30° above the horizon. They should be observed in pairs, one east and one west, at about the same altitude. This process eliminates the effect of errors in estimating refraction.

Directions for Observation. Choose two bright stars, one in the east and one in the west, at altitudes of about 25° to 30°. Unless they can be immediately recognized, make sketches showing the positions of the stars that surround them, to aid in later identification. Complete several observations of each star, alternating between the two.

To identify the stars, find the point in the chart which was overhead during the observation. Three to five hours east and west from this point, and slightly toward the equator, are the parts of the sky where the stars observed will be found. Identify them from the sketches. Any bright, unwinking body not shown on the chart is probably a planet. Planets require special corrections.

Computations. The computations for one star are shown. Those for other stars are similar. Use the formula given on page 141. (Eq. 7). In this case Z (Sec. 15) is the star's true bearing from the north. Assume, star observed NUNKI (in east), June 3, 1969; latitude S40° 20′ (from map), clockwise horizontal angle from mark B to star, 125° 10′; vertical angle 35° 55.7′, temperature 40°, barometer 28.1 inches.

d Nunki June 3, 1969 (Table 13)	−26° 20.3′
Measured altitude	35 55.7
Refraction correction (Sec. 21) (Table 2) − 1.32 × 1.02 × .95 =	− 1.3
True altitude, *h* (Sec. 20)	35° 54.4′

$$\cos Z = \frac{\sin(-26°20.3') - \sin(35°54.4')\sin(-40°20.0')}{\cos 35°54.4' \cos(-40°20.0')}$$

$$\cos Z = \frac{(-.44367) - (.58647)(-.64723)}{(.80997)(.76229)}$$

$$\cos Z = -0.10380$$

$$Z = 95°\,57.5'$$

Star's bearing (Sec. 14)	S 84° 02.5′ E
Clockwise angle B to star	125° 10.0′
Bearing mark B	N 29° 12.5′ W

True Bearing by a Southern Circumpolar Star. Stars that are near the poles are called circumpolar stars. In the southern hemisphere the nearest bright star to the pole is about 30° distant from it. Several such stars exist, and an observation for true bearing can be made on one of them in exactly the same way as the observation on Polaris, which is made in the northern hemisphere. The field work is identical. The computation must be based on the following formula:

$$\tan Z = \frac{\sin t}{\cos l \cot p - \sin l \cos t} \quad \text{. . (11)}$$

Whichever star is nearest elongation (Sec. 23) should be chosen. A star that is on an hour line about 6 hours from the overhead position is nearly at elongation.

OBSERVATION TO DETERMINE t

When an observation is made on Polaris or on a southern circumpolar star, if either longitude, accurate time, or both, are unavailable, the angle t of the circumpolar can be found by an observation on a star near the prime vertical, as follows:

Observe the altitude and take the time of each pointing. The horizontal angle is not required. Using the average altitude corrected for refraction and the average time, compute angle t for the east west star by the following formula:

$$\cos t = \frac{\sin h - \sin d \sin l}{\cos d \cos l} \quad \ldots. \ (12)$$

Since the SHA of each star is given in table 13 the difference between SHA's can be computed. The difference in t is the same as the difference in SHA. Thus if the value of t for the east west star at the time of the observation is known, the value of t for the circumpolar at that moment can be computed by applying the difference of the SHA's. The change in t that occurred between the times of the two observations can be computed by Table 5.

The SHA of Polaris is not given in Table 13. To find it, use the equation:

$$SHA = GHA - GHA \ \Upsilon.$$

Example. Assume that neither longitude nor time had been available for the example given in Sec. 27, and that instead, the star Pollux had been observed in the west. *Required to obtain* **t** *of Polaris.*

Time of observation of Polaris May 5, 1969; 8:49:47 PM (approx. C. S. T.); latitude N42° 22.6′ by method in Sec. III.

Time of observation of Pollux 9:10:04 (by the same watch); measured altitude 40° 11.0′; temperature 60°; barometer 29.8 inches.

In the formula given above, h is the altitude corrected for refraction, d is the declination of east or west star taken from Table 13, l is the latitude. All are taken to the nearest 0.1′. Five places of decimals is sufficient.

Measured altitude	40° 11.0
Less refraction correction (Table 2)	
$-1.14 \times .98 \times 1.01$	− 1.1′
True altitude h	40° 09.9′

$$\cos t = \frac{\sin 40°\,09.9' - \sin 28°\,06.3' \sin 42°\,22.6'}{\cos 28°\,06.3' \cos 42°\,22.6'}$$

$$\cos t = \frac{.64499 - (.47109)(.67400)}{(.88209)\ (.73873)}$$

$\cos t = .50256$

$t = 59°\ 49.8'$ (Pollux)

LHA Pollux 59° 49.8′ (see Sec. 14)

1. *GHA* Polaris 0^h *G* May 6, 1969 (Table 1)	193° 27.5′
	360° 00.0′
	553° 27.5′
2. *GHA* ♈ 0^h *G* May 6, 1969 (Table 12)	223° 40.4′
3. *SHA* Polaris all day May 6, 1969, (1) − (2)	329° 47.1′
4. *SHA* Pollux all day May 6, 1969 (Table 13)	244° 08.5′
5. Cor. to be added to *LHA* Pollux to obtain *LHA* Polaris (3) − (4)	85° 38.6′
6. *LHA* Pollux at 9:10:04 by watch (above)	59° 49.8′
7. *LHA* Polaris at 9:10:04 by watch (5) + (6)	145° 28.4′
8. Elapsed time between observations 8:49:47 − 9:10:04 = − 0:20:17	
9. Correction for elapsed time (Table 5)	− 5° 05.1′
10. t for Polaris at 8:49:47 by watch	140° 23.3′

Having obtained t for Polaris the computation for the bearing can be made as before.

TO FIND LONGITUDE

To find longitude except from a map, accurate time must be available. When it is available, an observation such as described for Pollux above will give longitude if the time of each pointing on the star is recorded.

Example. Assume that the correct *GCT* (see Sec. 27 for computation of *GCT*) for the observation of the altitude of Pollux was 2:53:39, May 6, 1969.

SHA Pollux May 6, 1969 (Table 13)	244° 08.5′
GHA ♈ 0^h *G* May 6, 1969 (Table 12)	223° 40.4′
Correction for 2^h 53^m (Table 5)	43° 22.1′
Correction for 39^s (Table 5)	9.8′
GHA Pollux (add four above)	511° 20.8′
Rejecting 360°	151° 20.8′
Less *LHA* as computed	59° 49.8′
West Longitude	91° 31.0′

TABLES and EXAMPLES

Basic astronomical data for the K&E Solar Ephemeris was taken from publications of the U. S. Naval Observatory, Washington, D. C.

The tables and examples in this ephemeris, which are based upon the varying positions of celestial bodies, have been prepared under the supervision and direction of Assoc. Prof. G. B. Lyon of the Geotechnical Engineering Department, School of Civil Engineering, Cornell University.

Table 1 is a photographic reproduction of electronic digital computer output with page headings added prior to printing. Tables 3, 6, 7, 8, and 10 were also produced by computer.

TABLE 2

REFRACTION AND SUN'S PARALLAX

(To be applied to observed altitudes. See page 126)
Bar. = 29.6 in. Temp. = 50° F

Measured Altitude		Refraction	Sun's Par.	Measured Altitude		Refraction	Sun's Par.
°	′	′	′	°	′	′	′
7	30	6.88	0.15	17	30	3.02	0.14
7	40	6.75	0.15	18	00	2.93	0.14
7	50	6.62	0.15	18	30	2.85	0.14
8	00	6.50	0.15	19	00	2.77	0.14
8	10	6.37	0.15	19	30	2.70	0.14
8	20	6.25	0.15	20	00	2.62	0.14
8	30	6.13	0.15	21	00	2.48	0.14
8	40	6.02	0.15	22	00	2.36	0.14
8	50	5.92	0.15	23	00	2.25	0.14
9	00	5.82	0.15	24	00	2.15	0.14
9	10	5.72	0.15	25	00	2.05	0.14
9	20	5.63	0.15	26	00	1.96	0.13
9	30	5.53	0.15	27	00	1.88	0.13
9	40	5.43	0.15	28	00	1.80	0.13
9	50	5.34	0.15	29	00	1.73	0.13
10	00	5.26	0.15	30	00	1.66	0.13
10	20	5.10	0.15	32	00	1.53	0.13
10	40	4.95	0.14	34	00	1.42	0.12
11	00	4.81	0.14	36	00	1.32	0.12
11	20	4.67	0.14	38	00	1.23	0.12
11	40	4.54	0.14	40	00	1.15	0.11
12	00	4.42	0.14	42	00	1.07	0.11
12	30	4.25	0.14	44	00	1.00	0.11
13	00	4.09	0.14	46	00	0.93	0.10
13	30	3.93	0.14	48	00	0.86	0.10
14	00	3.78	0.14	50	00	0.80	0.09
14	30	3.65	0.14	55	00	0.67	0.08
15	00	3.53	0.14	60	00	0.55	0.07
15	30	3.42	0.14	65	00	0.45	0.06
16	00	3.32	0.14	70	00	0.35	0.05
16	30	3.22	0.14	80	00	0.17	0.03
17	00	3.12	0.14	90	00	0.00	0.00

The refraction values in Table 2 are corrected by multiplying them by the multipliers in Table 2a when the barometric pressure and the temperature differ from those on which Table 2 is based, i. e. 29.6 inches and 50° F.

If the barometric pressure is not known, it may be estimated from the elevation of the locality in accordance with the values given in Table 2a. Otherwise the elevations are disregarded.

TABLE 2a

To correct Table 2. See Examples below.

MULTIPLIERS FOR OBSERVED BAROMETRIC PRESSURE OR ELEVATION

Bar. (Inches)	Elev. (Feet)	Multi-plier	Bar. (Inches)	Elev. (Feet)	Multi-plier
30.5	−451	1.03	25.4	+4535	0.86
30.2	−181	1.02	25.1	4859	0.85
30.0	00	1.01			
			24.8	5186	0.84
29.9	+ 91	1.01	24.5	5518	0.83
29.6	366	1.00	24.2	5854	0.82
29.3	643	0.99			
29.0	924	0.98	23.9	6194	0.81
			23.6	6538	0.80
28.7	1207	0.97	23.3	6887	0.79
28.4	1493	0.96	23.0	7239	0.78
28.1	1783	0.95			
			22.7	7597	0.77
27.8	2075	0.94	22.4	7960	0.76
27.5	2371	0.93	22.1	8327	0.75
27.2	2670	0.92			
			21.8	8700	0.74
26.9	2972	0.91	21.5	9077	0.73
26.6	3277	0.90	21.2	9460	0.72
26.3	3586	0.89			
26.0	3899	0.88	20.9	9848	0.71
			20.6	10242	0.70
25.7	4215	0.87	20.3	10642	0.69
25.4	4535	0.86	20.0	11047	0.68

MULTIPLIERS FOR TEMPERATURE

Temp. Deg. F	Multi-plier	Temp. Deg. F	Multi-plier	Temp. Deg. F	Multi-plier
−20	1.16	+30	1.04	+ 80	0.94
−10	1.13	+40	1.02	+ 90	0.93
0	1.11	+50	1.00	+100	0.91
+10	1.08	+60	0.98	+110	0.90
+20	1.06	+70	0.96	+120	0.88

Example. Sun: Meas. Alt. = 30°; Bar. = 26 in. or Elev. 3900 ft.; Temp. 70° F.
Refraction = 1.66′ (0.88) (0.96) = 1.40′. Parallax = 0.13′.
True Alt. = 30° 00.00′ − 1.40′ + 0.13′ = 29° 58.73′.

Example. Star: Meas. Alt. = 25°; Bar. = 24.5 or Elev. 5518 ft.; Temp. 10° F.
Refraction = 2.05′ (0.83) (1.08) = 1.84′.
True Alt. = 25° 00.00′ − 1.84′ = 24° 58.16′.

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