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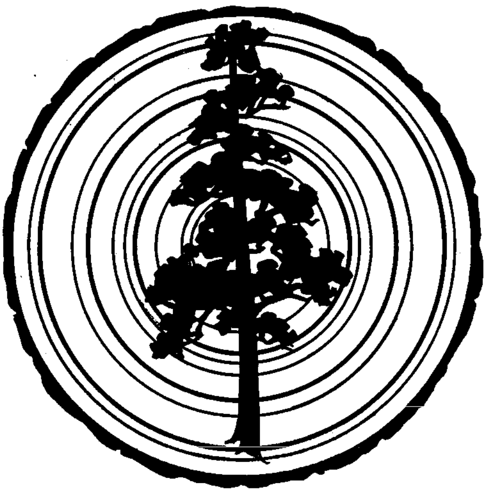

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NOTES ON THE TECHNIQUE OF TREE-RING ANALYSIS. V: PRACTICAL INSTRUMENTS*

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G. CURVE PLOTTING AND CYCLIC ANALYSIS

Dendrochronology or Tree-Ring Analysis received generous aid from the Carnegie Institution of Washington whose special interest was the cyclic and climatic effects in tree-ring growth. This aid began through Dr. F. E. Clements in 1918 as a part of his "Ecological Work" and continued many years as "Climatological Research." It was concluded in 1935-1937 by a 3-year grant for cooperative work between the Carnegie Institution and the University of Arizona. This was arranged by Dr. J. C. Merriam, President of the Institution with the participation of the Division of Plant Biology under Dr. H. A. Spoehr who aided with work-rooms and facilities in his Laboratory at Palo Alto.

As part of this work a volume on cycles was published in 1936 and in that year and 1937 a cycloscope more complete and efficient than any previous form was designed and constructed. The completed instrument was exhibited at the Institution headquarters in Washington, D. C. in April, 1937. It has not heretofore been described. For this most important aid we give a sincere expression of thanks to the Carnegie Institution of Washington and to its President at that time, Dr. J. C. Merriam with the feeling that this aid will help the future of this work even more than it did its past.

Cyclic analysis is a form especially designed for tree-ring investigations. The original purpose in 1913 was to produce a rapid and efficient method of searching for the 11-year cycle or other cycles in ring records. It has however proved to be a new and very efficient method of handling the analysis of unstable periodicities, as will be explained at a later time. The procedures mentioned below therefore are specially adapted to the requirements of tree-ring analysis.

Tabulation. Cross-ruled paper with lines approximately 1 cm apart has been found very convenient for tabulation of ring measures and other data.

Curve Plotting. Conveniently-drawn coordinate paper for plotting curves is a K & E, N-8079, light green ruling on white 18 x 24 cm sheets, the smallest division 2mm, centimeter lines heavier. Narrow strips of this paper in which the width of 18 cm is cut into two or four equal parts are used for special purposes. Our "skeleton" plots are chiefly on the smaller of these two sizes.

Standardizing. In recent work by Schulman the measures are averaged without modification except for trees of specially fast or slow growth, when a rough equalization is secured by applying a gross factor such as x½ or x2; when trees of different ages are averaged it is often necessary, because of "age curve," to merge young and old trees separately and to delete the first decade or more of growth for one or more trees on averaging**.

*Continued from the July, 1943 issue.

**See also Douglass, Climatic cycles and tree growth, vol. 2, 40-50, 1928; Schulman, Bull. Amer. Meteorol. Soc., *23*, 152, 1942.

Smoothing. The lack of proper smoothing has too often resulted in estimated cycle lengths at whole numbers and poor judgment of fractions. So practically all tree-ring data are "hanned" before analysis, smoothed by running means of three *with double-weighted center term.* This smoothing may be done graphically using triangles on the plot.

H. CYCLEPLOTS

Paper and Curve-Tracing. The curves plotted and smoothed as described above are transferred to a heavy brown paper, 4 x 48 inches, by tracing through carbon paper. Then the cutting line is placed in the basal part of the curve so as to separate slightly the maximal areas one from another.

The Cutting Line.* In cyclic analysis the timing of the maxima is the feature that is tested; hence the delineation of these maxima becomes important. That in turn depends on the "cutting line" which is the base adopted above which the maxima will show. Cutting line practice lies between two extremes, the straight line, usually horizontal, representing a base for the maxima of the whole curve and a basal trend line that runs near the lower tips of the minima and automatically eliminates cyclics too long for the search in hand. The nearer straight the cutting line the longer will be the cyclics that advantageously appear. In this case, in order to see the shorter cyclics better, one has to extend narrow vertical tongues of paper across the maxima in places indicated by the data to isolate them slightly and make them visible in the cycloscope. At settings for longer cyclics these disappear, a change which is not important in this cyclic analysis, where timing of the maxima is the vital feature and amplitude is not made so fundamental a part of cyclic reality.

On the other hand when some trends or longer cyclic lengths are put in the cutting line safety may require the cyclic analysis of the cutting line itself. This very test has been made by the writer and interesting residuals found.

As an extreme, one can use the "graphic hann" line as the cutting line and plot the departure from it on a larger horizontal scale for cyclics less than 5 time units in length. But this permits only special tests to be made because one gets dangerously close to the lower limit of cycle length permitted by the data.

The difference between these two extremes becomes important in use of the ratio of compression in long sets of data when the group of next larger cyclic lengths is to be measured. Compression of a curve is its repetition on a ⅓ or 1/5 horizontal scale in order to get longer cyclics. The use of ⅓ should be preferred if possible. And finally, the character of the variations in the actual data in hand will give some preference in this cutting line matter. It is referred to in the next topic.

I. THE CYCLOSCOPE

Cyclic Analysis Method. A brief statement of the method is first given in order to make the descriptions more easily followed.

1. The maxima in the cycleplot are isolated as bright areas.

2. An optical device produces an image in which each maximum is extended vertically into a band of light whose intensity is proportional to the amplitude of that maximum and whose horizontal place fully represents its timing in the original curve.

3. These vertical maximal bands are cast upon a grating of narrow equally spaced transparent lines inclined at an angle of about 15° to the vertical and produce an interference pattern by transmission.

*See Douglass, *op, cit.*, vol. 3, 1936.

4. The interference pattern which comes through has the character that an alignment in the maximal images in any direction can result only from real periodicity in the maxima that form the line. So this alignment is called a "cyclic." Each cyclic thus made visible can be measured and examined for its time of beginning and ending, its regularity, its harmonics and the degree of accuracy of a setting on its alignment. All these are almost instantly visible in a pattern that presents all the maxima at the same time.

5. Precision measurement of cyclic length is made by a mirror setting that alters the scale of the image. As the scale changes the observed alignment "rotates;" therefore the horizontal position is used as a standard and is indicated by a stationary horizontal thread across the pattern. When the alignment is parallel to the thread the cyclic length is read off in the same field through a "periscope," described below, which shows a scale reading controlled by the position of the mirrors and which is inversely proportional to the size of the image cast on the grating. The operator is always conscious of the ease or difficulty of setting on a cyclic and the more time used in the setting, the less is the weight of the cyclic (often indicated by underlines). Thus all cyclics have an equal chance of being seen by the operator.

6. A comparator device renders very easy any comparisons desired between different sets of data.

Development of this instrument began in 1913 in the form of a periodograph which produced automatic periodograms showing cycle analyses of any data. This was inspired by Schuster's work. This first result was accomplished by a laboriously-made pattern, of the type of our present cyclogram, whose possible usefulness in the search for cycles was recognized at once. The automatic production of this pattern was accomplished in 1914. The instrument was rebuilt in 1918 to produce periodograms but was continuously used as a cycloscope. The form called the White cyclograph was built in 1922 and used extensively on sequoia ring records as a cycloscope, that is, in visual work. The present cycloscope constructed all in metal took form in the writer's drawings at the Carnegie Institution at Stanford University in 1936. The drawings were skillfully transferred to steel and brass by Mr. Stewart of and in the machine shops of the Physics Department of Stanford University to whose courtesy we owe a strong debt of thanks.

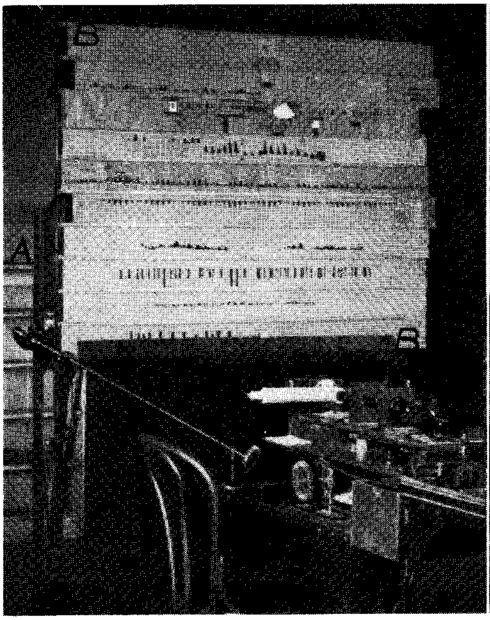
Illuminator and Comparator. The illuminator* is a box 46 inches long, 12 inches high, and 8 inches deep, supported on a stand some four feet above the floor. It contains a bank of ten 60-watt lights, frosted, spaced about 4 inches apart. Before them is the opening for the light which is diffused by a ground glass plate and single thickness of tissue paper.

The area thus available for projecting a beam through the cycleplot is 43 inches long by 5 inches high. Thus we can place one cycleplot along the center of this space or we can use two, one above the other and both illuminated, for minute comparisons between their cyclograms.

The cycleplots are placed in the "comparator" frame which can hold 10 at the same time, any one of which may be placed in front of the illuminator window. The frame, 46 inches wide and 41½ inches high, runs up and down in guides, is counterpoised, and moved by a handle conveniently placed for the operator. The spaces for the plots are separated by long S-shaped metal pieces, each having a slot opening upwards and one opening downwards. These slots take the long plots with minimum space lost in overlapping.

Thus the plot being examined is within reach of the operator who can check dating or verify identities in what he sees.

*The illuminator-comparator, illustrated in Fig. 4, was constructed by Mr. C. G. Keenan of Tucson.



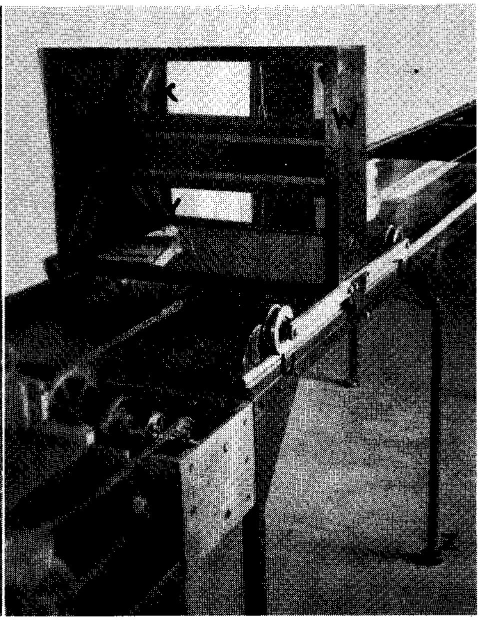


Fig. 4. Illuminator-comparator.
A—the illuminator box whose end shows at left center, back of the plots. B-B is the comparator frame with ten cycleplots; each plot slips into a slot above and below. C—the handle by which the operator moves the frame to bring the desired plot before the illuminated background.

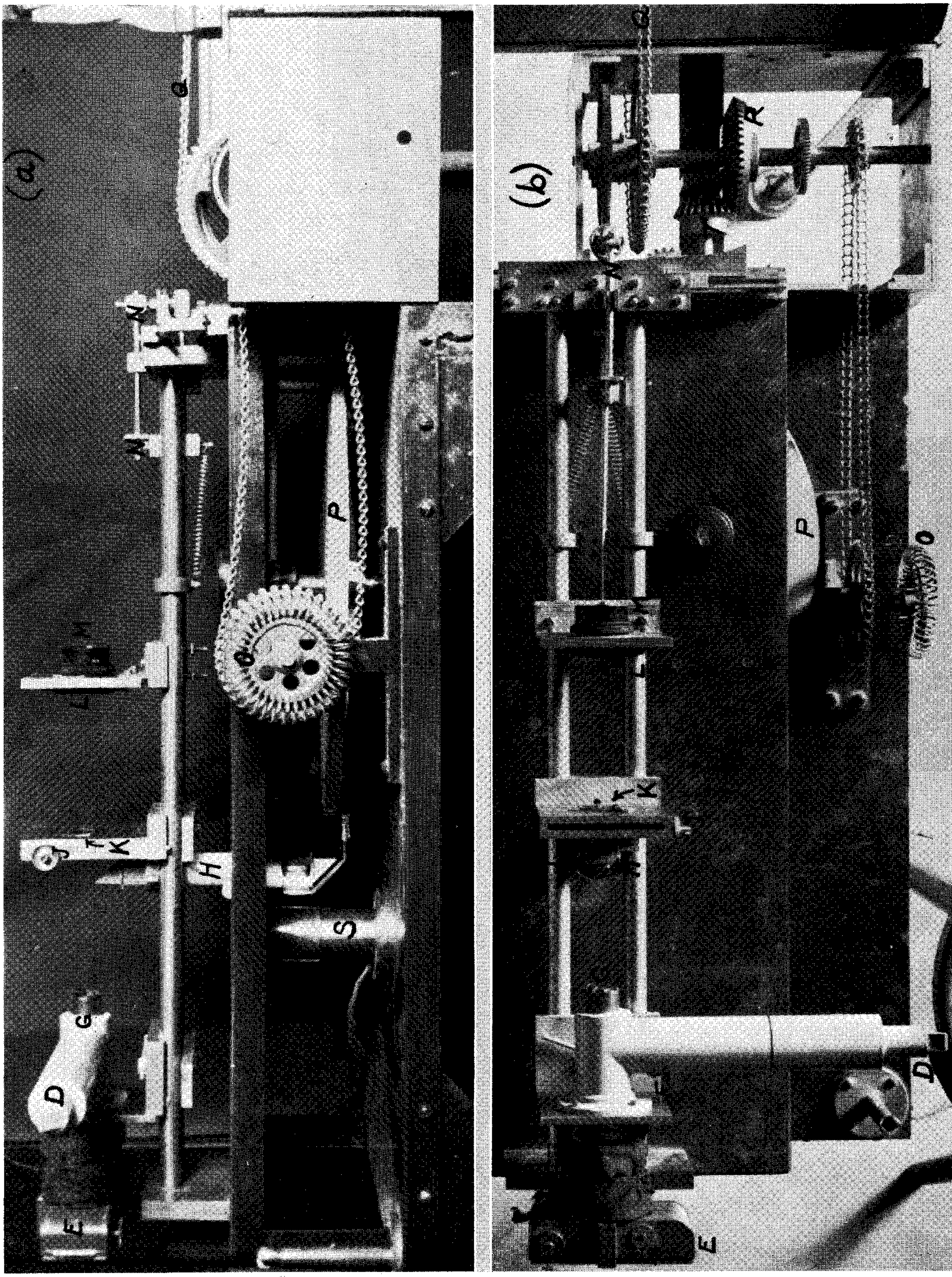
Fig. 5. Mirror box and carriage.
The carriage runs on three wheels; two of them are deep-grooved, U-U; the third, V, has a flat surface. The mirror box, W, opens toward the illuminator; the mirrors, X and Y, are inclined 45° to the horizontal and their centers are nearly 10 inches apart. An adjusting screw as at Z is placed at each leg supporting the track.

The distance of the illuminator stand from the analyzing table and mirrors controls the apparent reading of cycle lengths; standards at each unit of cycle length are kept close at hand for occasional checking of the scale.

Main Analyzing Device. The main analyzing device is on a double decked table. The lower part is 24″ x 30″; 5 inches above it is the upper deck 14″ x 30″, extending along the optical axis in a central position; 2⅛ inches above that are two ¾ inch steel rods which form an optical bench for the optical and photographic system.

The Lens. In Figs. 5 and 6 the light from the cycleplot comes from the left and passes above the analyzing parts to a pair of mirrors mounted on a carriage on a long track to be described later. Thence the light is returned to this analyzing table from the right. Near the right end of the optical bench is the main lens with an automatic focusing device. The latter consists of a stiff wire leading from the lens support to a wheel which bears upon a curved metal edge; this in turn is moved back and forth tranversely by the gear mechanism which operates the mirrors. The "curved metal edge" is so arranged that it corrects the distance from the lens to its focal plane on the grating for the varying apparent distance between the cycleplot and the lens as the mirrors are moved.

The main lens is a Zeiss Tessar of 6-inch focus, *f*4.5. Immediately behind that is a negative cylindrical lens of 12-inch focus with horizontal axis. Its effect is to bring to a focus the horizontal details in a general time scale at 6 inches on the grating and the vertical at 12 inches on the projection lens.


(a)
(b)

The Grating. The grating is etched on glass 2 x 5 cm on a scale of 50 lines to the inch. One-half of this 1/50 inch space is filled with opaque paint to get the desired effect. Two gratings are placed face to face and made slightly adjustable so that the relation of the transparent part to the spacing between line centers may be adjusted as desired. This grating is fixed in a slanting position so that the grating lines are inclined some 15° to the vertical and so to the maximal bands produced by the lenses as described.

The grating is held in place in the front one of two metal plates mounted together and stationary on the optical bench. Between them is a horizontal cross thread that is mounted in a thin rectangle which can be raised or lowered across the cyclogram in view.

Attached immediately back of the second metal plate is the condensing system of two 6-inch positive cylindrical lenses with vertical axes, placed curved sides together; they take the full spreading beam of light from the main lens after it has passed through the grating and reconverge it into small enough compass to enter the projection lens for visual or photographic purposes.

The Periscope and Scale. Immediately back of the condensing lenses is the periscope, some 8 inches long, mounted in a vertical position and so supplied with two right angle prisms and a projecting lens that a scale reading from the periphery of a large horizontal wheel below is projected to a plane below the condensers and so directed that its image appears just below the grating in the visual and photographic views.

The scale and a fixed pointer are brightly illuminated by a special lamp and are easy to read and to photograph. The scale wheel is 16 inches in diameter just above the right end of the lower level of the table (see Figs. 6a and 6b). On the same axis is a threaded wheel turned by a worm screw on a spindle connected by bevel gears to the main shaft of the mechanism which moves the mirrors, as will be described below.

Visual and Photographic Tail-Piece. Directly back of the grating and about 6 inches from it is a lens referred to above as a projection lens. It is a symmetrical lens of 3 inches focal length and about ¾ inch clear diameter. Vertical beams reach a focus at this point from the main lens and horizontal beams focused on the grating are reconverged by the condensers so that the whole picture comes through this lens. If permitted to go straight on, the picture of the grating comes to a focus at another 6 or 7 inches on the film of an Argus camera (with lens removed). This gives a scale very near that on the grating itself.

About 2 inches back of the projection lens a 1-inch right angle prism can be thrust into the beam causing the image to be directed toward the operator and formed within a tube of 2 inches diameter. At the focal plane in this tube condensers are inserted to bring the whole picture into the eyepiece, which contains a 4-inch lens and a small right-angle prism. Thus the operator looks directly downward. This last prism turns the picture up-

Fig. 6. Analyzing Bench; (a) from side; (b) from above.

D—the visual eyepiece, arranged for looking vertically downward. E is the camera. F—the pin that moves a prism into the beam in order to throw the image to the visual eyepiece, D, instead of into the camera. G—the projection lens that transfers the grating pattern to the camera. H—the periscope that brings the scale reading into the field of view. I—the condensing lenses that bring the beam into the projection lens, G. J—the thumb screw that adjusts the movable thread which gives the horizontal line across the grating pattern. K—the grating. L—the cylindrical lens. M—the main lens. N—the automatic focusing device. O—the hand wheel for moving the mirror box along the track. P—the scale wheel which turns as the mirrors are moved; the scale is marked along its wide outer edge. Q—the sprocket chain to the mirror box. R—the bevel gears controlling focus and scale. S—light to illuminate the scale. T—shaft and gears which control focus and scale.

right so that the eye sees it just as it will later appear in the photograph. Naturally nearly all the work with this instrument is done visually with the eye at this eyepiece.

Mirrors and Track. In this form of analysis a long range of cyclic lengths can be covered by varying the relative sizes of the image and grating. Thus there are two forms the instrument might take. The variable grating form is more compact and simpler to build and it has been tried in several sizes and designs. But it proves to be far inferior to the one using a variable image for in this form the settings on different cyclic lengths have the same weight or chance of being recognized and the harmonics are seen with the main cyclic and easily recognized. Thus the variable image design has finally come to be regarded as the only reliable one. The penalty, however, is that it takes much more room to vary the image size as it is most effectively done by changing the distance between the cycleplot and the lens; the range is proportionate to the change in distance. Therefore, a 20 to 40 foot track is required to return the light beam to the analyzing table. Multiple reflections have been tried and doubtless could be successfully accomplished with a series of mirrors which are optically near-perfect mirrors. Yet in using many surfaces there is danger of losing both light and definition.

The track for our cycloscope is 24 feet long to give a range in cyclic length from 5 units to 29. Even that ratio, near 1:6, is larger than perhaps is wise, for cyclics at such extremely different distances from the same plot are apt to receive different estimates of strength. This set-up permits a compression ratio of 1/5 in adapting data to longer cyclics. It is probable that a ⅓ ratio will prove to be a better procedure.

The cycloscope track rails are of ½ inch steel shafting and 21½ inches apart; different pieces screw together with a joint that does not disturb the even motion of the carriage. The latter has 3 wheels, two of them with deep V-shaped peripheries to run on one rail and preserve the alignment and the third wheel flat to run on the other rail.

Both rails are lined up as nearly horizontal as possible. To help in leveling, each leg of the long supporting table rests on an adjusting screw by which any irregularities of the floor can be taken up.

These details were introduced to prevent wavering of the image as the carriage moves out or in. Motion is imparted to this carriage by a light sprocket chain extending from the carriage in both directions. Outwardly it extends to a wheel at the extreme end and returns to a gear box which is placed between the long track and the analyzing table, there to join the other chain from the carriage.

The gear box carries the sprocket wheel holding the carriage chain. Its shaft has a separate short chain to a handle conveniently placed for controlling the mirror position. The shaft also has a bevel gear turning a second shaft extending toward and along the analyzing table in the space between the two levels. The second shaft carries two worm screws: one controls the 16 inch wheel carrying the scale and the other controls the automatic focus of the main lens.

The mirror carriage on the long track thus has a 3-point support on 3 wheels. It carries a metal box 23 x 17 x 6 inches with open face toward the illuminator and analyzing parts. Two flat mirrors about 21 x 8 inches in size pass across this box*. They are supported at an inclination of 90° to each other so that the upper one receives the light from the illuminator, passes it to the other mirror 10 inches below, which in turn passes the beam back to the analyzing devices. Thus in different positions of the carriage the light comes to the main lens from the same direction.

*These mirrors are now being replaced by two aluminized 6 x 22 inch mirrors.