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A METHOD FOR DETERMINING THE RANDOMNESS OF FIBERS IN A BONDED-WEB FABRIC

A THESIS

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By

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A METHOD FOR DETERMINING
THE RANDOMNESS OF FIBERS IN A
BONDED-WEB FABRIC

APPROVED:

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ABSTRACT

The strength of non-woven or bonded-web fabrics depends chiefly upon the arrangement of the fibers which form the fabric. If the fibers are randomly arranged, the fabric will have approximately equal strength in all directions. However, should the fibers be arranged in a parallel or non-random fashion, the fabric will have good strength in a "machine direction", but poor strength in an "across the machine" direction. In order to determine the degree of fiber randomness within a bonded-web fabric, it is necessary that a research tool be developed to determine those varying degrees of randomness. The only method previously used was the determination of the randomness by a visual inspection.

As a result of this investigation, an instrument was designed and assembled for measuring the various degrees of randomness within non-woven fabrics which functions on the principles of the measurement of light reflection. Three-inch diameter samples of different bonded-web fabrics were mounted on a turntable within a light-proofed machine interior. A constant voltage light was condensed through a lens system onto the sample, and the amount of light reflected from the sample was recorded at each 20° interval. Different samples, composed of random and non-random fiber

arrangements, were tested throughout a 360° revolution. The amount of light reflected, which was measured by means of a photronic cell, was recorded and plotted on polar coordinate graph paper.

Theoretically, if a sample were composed of fibers perfectly random in arrangement, the amount of light reflected from all angles would be equal. These light reflections, when plotted on the graph paper, would form a perfect circle. Conversely, if a sample were composed of fibers arranged in a parallel or non-random fashion, the amounts of light reflected would be of different intensity. When plotted on the graph paper, the non-random fiber arrangements would form an ellipse.

By applying formulae for determining the eccentricity of the ellipse, and by applying a formula devised by the author for determining the degree of randomness, a randomness number can be assigned to fabrics according to their degree of this quality.

From the data obtained during this investigation, it may be concluded that the degree of randomness of a non-woven or bonded-web fabric can be determined by measuring light reflected from a sample, and by plotting reflectance readings on polar coordinate graph paper. Measurements obtained from these graphs permit the application of mathematical formulae for the determination of randomness.

CHAPTER I

INTRODUCTION

Historical.--The efforts of the textile industry to develop a fabric without resorting to the conventional method of spinning, weaving, or knitting, has resulted in the production of a material variously described as unwoven cloth, unwoven sheeting, or non-woven fabric. Perhaps no term so aptly describes this fabric as does the name "bonded-web fabric" (1).

The development of a bonded-web fabric is not a recent one. A search of patent literature reveals a patent (USP 909,379) granted in 1909 to a Frenchwoman for a fabric (2) suitable for use as a substitute for morocco leather. This fabric was composed of waddings cut to a certain size and overlayed with other like waddings, with fibers crossed and bound together, and saturated with a rubber composition to hold the layers of wadding together. Another patent (USP 2,039,312), granted in 1936, describes a fabric made from a web of carded fibers, practically all of whose fibers were tied together by a binder infused locally into the body of the web (3).

The bonded fabrics of today are a far cry from the heavy, unattractive fabrics which were first produced. The bonded fabrics presently in production are in some cases very lightweight and attractive, possessing good draping qualities, and a soft, pleasing hand.

The bonded-web fabric is composed of two major parts—the web and the binder. The web, which is built up by the interlocking of fibers in the form of a mat, may be produced on cotton or woolen cards, garnetts, or on special adaptations of these machines employing principles of aerodynamics (4).

The three general types of bonded-web fabrics (5) which are being produced might be described as:

(1) Webs bonded by means of chemical action.

(2) Webs bonded by means of extraneous adhesives.

(3) Webs bonded by means of thermoplastic fibers.

Some chemicals used for the bonding of a web are natural or synthetic resins, phenol-, urea-, and melamine formaldehydes, polymerized vinyls, cellulose acetate or nitrate, bitumens, casein, insolubulized glue, and many others. Methods of application are as varied as are the binders used. The binder may be applied by spot bonding (a method similar to cloth printing), by immersion of the fabric into the binder and subsequent squeezing and drying, or by applying the binder in a powder form and heat setting the fabric (6).

Latices have come into widespread use when a waterproof bonded-web fabric is desired as an end product. This type of binder may be referred to as an extraneous adhesive.

Fibers possessing thermoplasticity have been blended in with the fibers composing the major part of the fabric. Heat is applied until the thermoplastic fiber has fused itself and the web together.

Many bonded fabrics, due to the method of manufacture from conventional textile machinery, are weak in a fillingwise or across the machine direction, since the fibers within the web are parallel to a great extent. The card, for example, has as its purpose the drafting and paralleling of the fibers, and it is easily understood that the strength of fabric made from this type of web would have a reasonably good strength in the warpwise or machine direction, but poor strength in the fillingwise or across the machine direction. For this reason, fabrics developed from card webs are not suitable for a particular end product requiring good crosswise strength. To combat this undesirable strength characteristic, a cross-laying method of web removal from the card has been developed. This process involves the laying of paralleled webs in the transverse direction in order to improve the transverse strength characteristics of the fabric. The procedure can be modified in such a manner that the transverse-layed webs are used either in conjunction with machine direction webs or by themselves (7).

The random scattering of fibers throughout a fabric so that the strength will be approximately equal in warp and filling directions can be accomplished by use of commercially available equipment, which employs two sections of machinery--a feeder section and a webber section. The feeder section is similar to the feeder section of a picker, consisting of a feeder hopper having a slat and pin conveyor system. The webber manipulates the fibers it receives from the feeder by means of a series of air streams. One air stream separates the large clumps of fibers, another separates the individual fibers, and the final air stream forces the randomly scattered fibers against a collecting screen or condenser from which the fibers are removed. This results in a random fiber arrangement within the fabric.

The isotropic arrangement of fibers within a bonded-web fabric has been a problem leading to much research during the past few years. Since fiber randomness is a desirable characteristic where fiber strength is desired, and non-random or parallel fiber arrangement is undesirable, it is important that a research tool be developed for determining the randomness or non-randomness of a fabric of non-woven material. As far as is known, no method, other than a visual observation, has been devised for measuring differences in fiber arrangements within a non-woven fabric.

Purpose of this investigation.--The purpose of this investigation was an attempt to develop a method and an instrument for measuring the varying degrees of fiber randomness within a bonded-web fabric by measuring the amount of light reflected from a sample of the fabric.

Theoretical considerations.--If it were practical to project a constant voltage light onto a single fiber and measure the amount of light which was reflected, a maximum reflectance would be observed when the fiber was perfectly perallel with the spot of light, at 0° and at 180°. The lowest reflection would be observed as the fiber was rotated through each quadrant, from 0° to 90°, from 90° to 180°, from 180° to 270°, and from 270° to 360°, depending upon the size of the projected spot of light. At exactly 90° and again at 270°, when the fiber was perpindicular to the spot of light, a reflection would be recorded which would not be as large as the reflection obtained when the fiber was parallel to the light source (8).

This would seem to hold true if a large number of parallel fibers were bonded together in a fabric and light directed onto the sample and the amount of reflected light measured. The reflected light would be in the same proportions as that which would be reflected from a single fiber, though the intensity of the reflection would not be as large or as extremely varied.

What would be the action of the reflected light if the fibers in the sample were randomly scattered rather than being parallel to each other in the sample? Theoretically, if the fibers were perfectly random in all directions, would not the amount of light reflected from the sample be the same regardless of the angle? For this to be true, the sample would have to be of relatively uniform thickness throughout. It would not be accurate to make this assumption if the sample had thick and thin places.

Other variables such as the use of different bonding agents, different types of fibers, or different deniers of fibers would not alter this theory since the relative or proportional amount of light reflected would be constant.

It was with this assumption that this investigation was begun.

CHAPTER II

INSTRUMENT DESIGN AND SPECIFICATIONS

General information.--Prior to designing an instrument for the purpose of determining and measuring differences in the fiber arrangement within a bonded-web fabric, the designers set up several properties which the instrument must possess. These properties were:

(1) The interior of the instrument would of necessity be absolutely light-proof so that only directed light would affect the samples.

(2) The voltage for the light source would have to be constant.

(3) The tests would have to be conducted at a known temperature and relative humidity, which could be carefully controlled.

Principles of the instrument operation.--The principle of operation of the instrument, as previously stated, was to measure the amount of light reflected from a bonded-web fabric. A constant voltage circuit was designed to lead to a single filament bulb so that a spot of light, approximately 600 square millimeters in diameter, could be directed onto a sample mounted on a turntable within the light-proof interior of the machine. No particular angle was chosen for the light to strike the sample, but the angle was approximately 45°. At exactly 180° from the direction of the light, a photronic cell was mounted in an aluminum tube to measure the amount of light reflected from the sample.

The light, mounted in a wooden holder, was condensed through a convex-concave condensing lens system, and directed onto a three-inch diameter sample of the bonded-web fabric. The cell was located approximately two inches from the sample. The cell was connected to a galvanometer, indicating light reflectance on its scale, which was graduated from 0 to 200.

The turntable, upon which the sample was mounted, was designed so that the sample could be revolved. Readings from the galvanometer were taken at each 20° interval by the use of a protractor mounted on the base of the turntable. The turntable was designed for easy removal from the instrument.

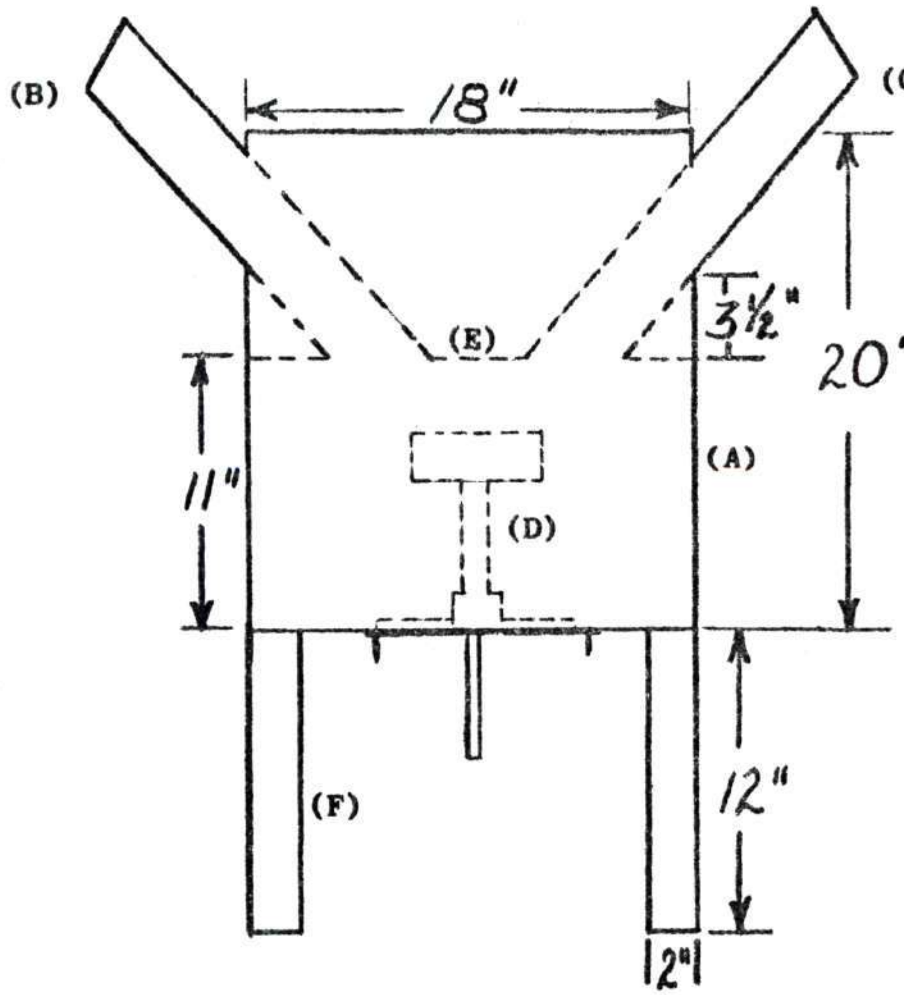
List of materials used in instrument construction.--The list of materials which were used to construct the machine is given below:

ITEM	MATERIAL	SIZE
Body of Machine	24 gauge sheet steel	20" x 56.6"
Interior (Bottom and False Bottom)	½" plywood	18" diameter
Lens and Cell Tubes	Aluminum tube	3" diameter x 18" length

ITEM	MATERIAL	SIZE
Lens (Convex-Concave)	Condensing Lens	2½" diameter
Lens, Cell, and Light Mounts	Oak wood	3" diameter
Light	Single Filament Sealed Beam Auto Headlight Bulb	32 candlepower
Photronic Cell	Weston Model 594	2½" diameter
Galvanometer	KS-6096	Model 319
Turntable	Wood	See Figure 3
Spindle	Aluminum	1" diameter and 8" length
Voltage Regulator	Thordurson Electric Mfg. Company, Automatic Voltage Regulator	Type T-47175

Instrument construction.--The attached drawings, figures 1, 2, 3, and 4, show the construction details of the instrument. The machining of the parts was performed at the machine shop of the A. French School of Textiles, Georgia Institute of Technology. The constant voltage circuit is shown in figure 5.

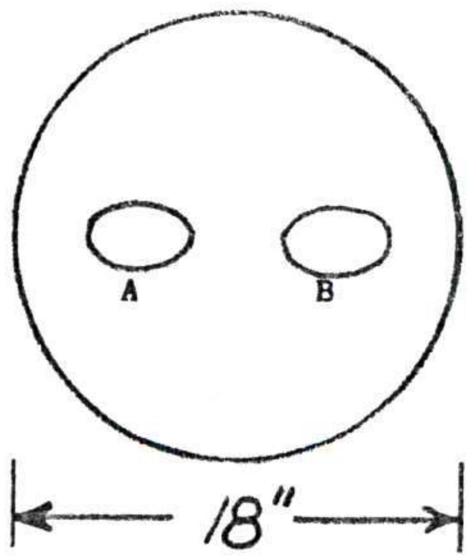
Turntable design.--The turntable is by far the most important part of the instrument. It is extremely important that the turntable be absolutely level and that it turn in a perfect circle. Should the top of the turntable not be level, the amount of light striking the sample would not be the same when the turntable was rotated. This would result in varying light intensities striking parts of the sample, and the



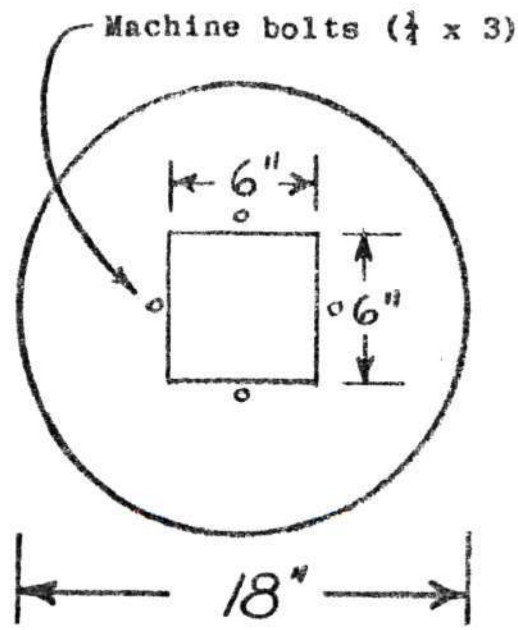
Scale - 1/8" = 1"

(A) Instrument Exterior
(B) Light Source, Lens System
(C) Photronic Cell Tube
(D) Turntable
(E) False Bottom
(F) Legs of Instrument

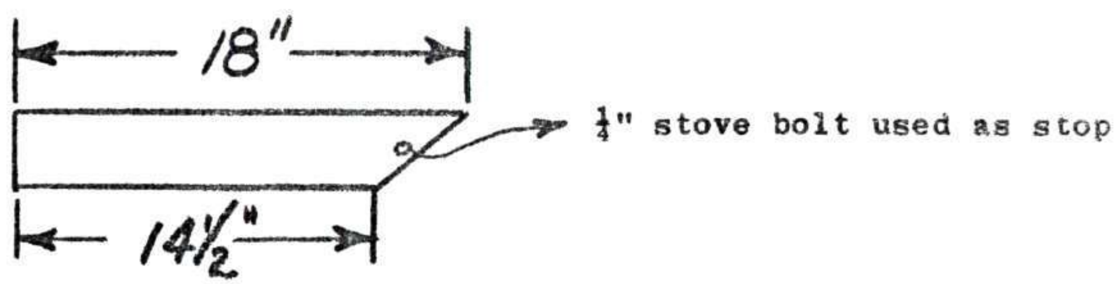
Figure 1. Side View of Instrument



Top view of false bottom. (No dimensions are given for holes A and B since size will depend upon angle of tubes)



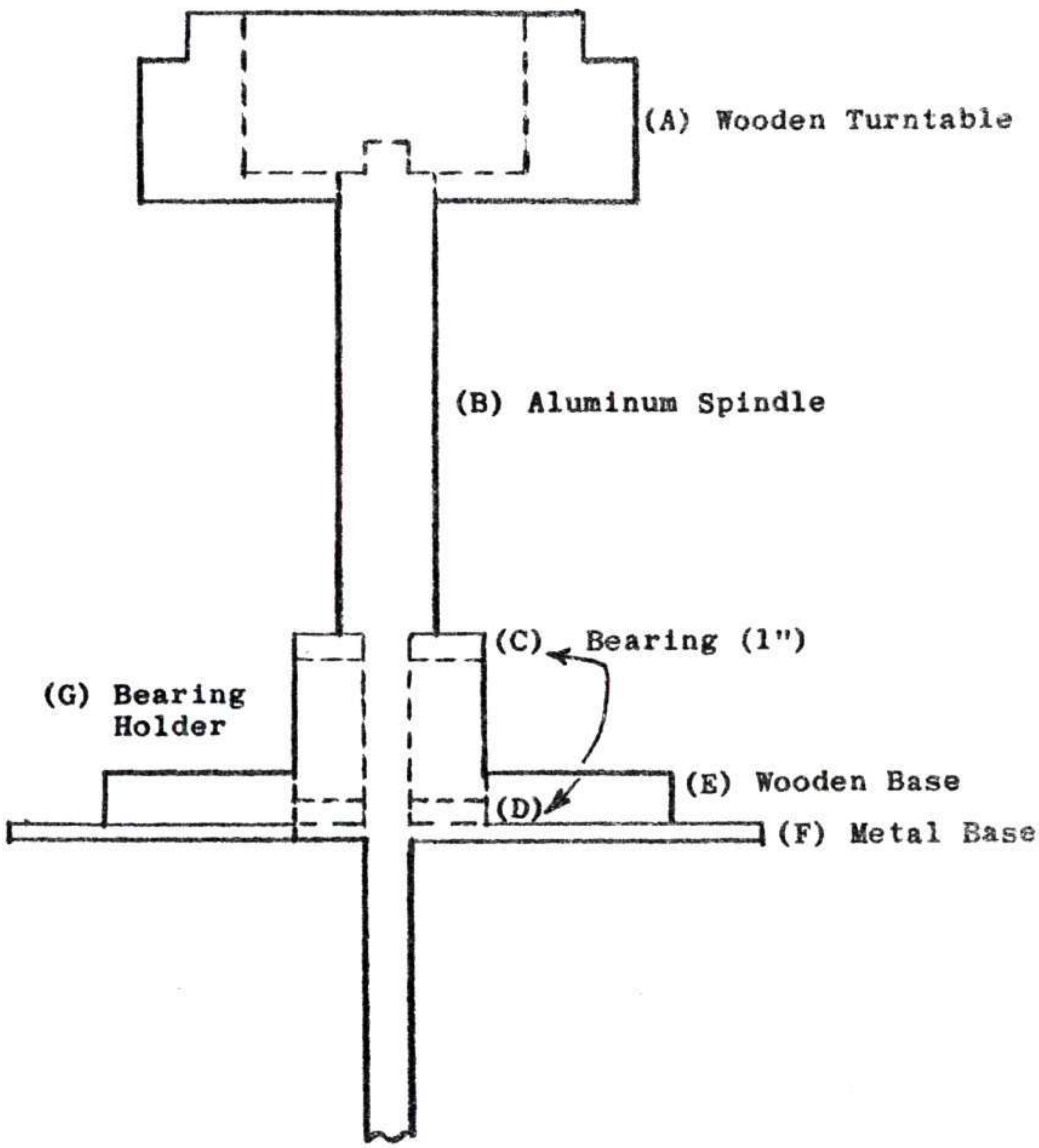
Bottom of instrument. Top view.



Lens and photronic cell tubes

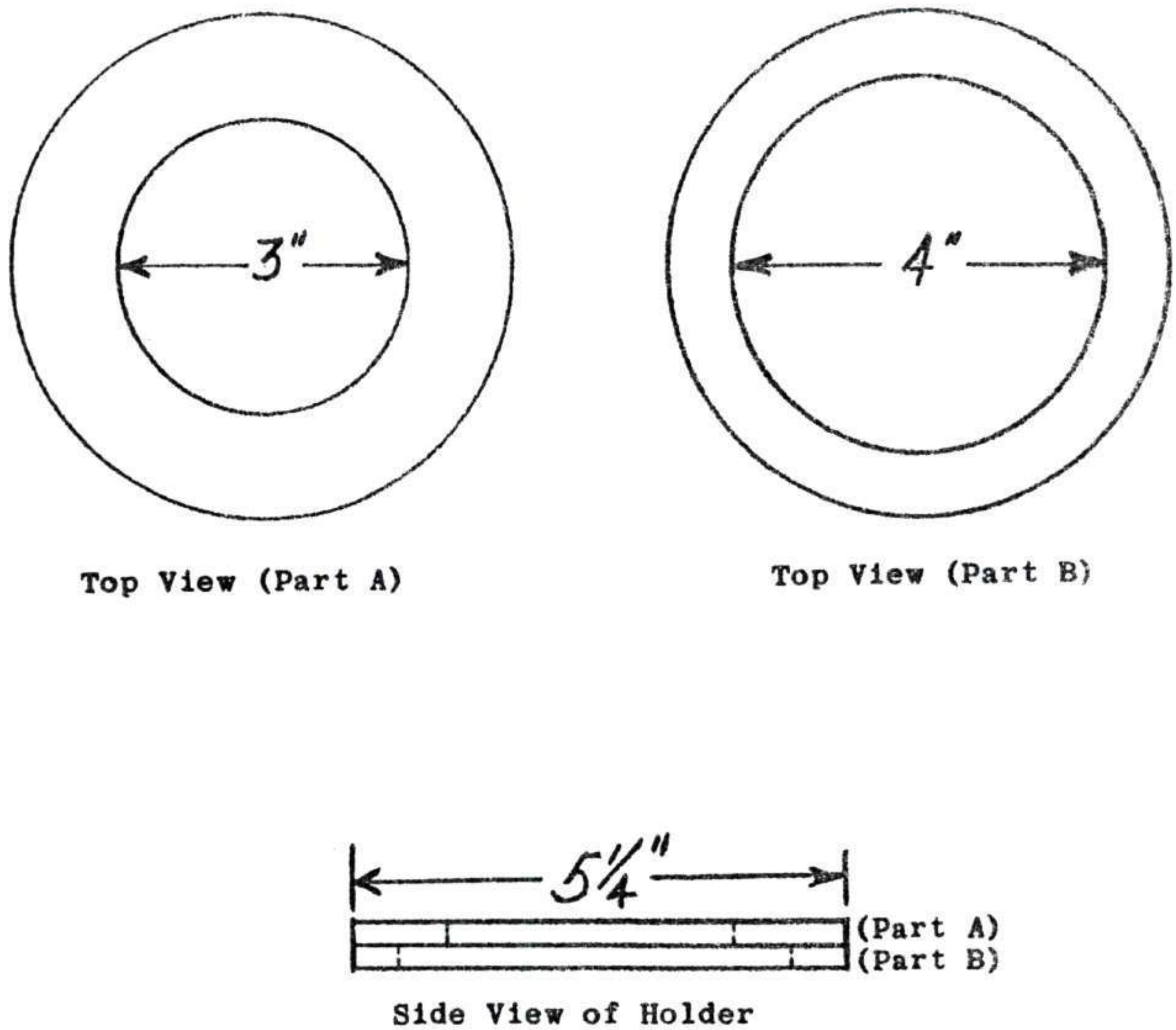
Scale - 1/8" = 1"

Figure 2. Dimensions of Instrument Interior Components



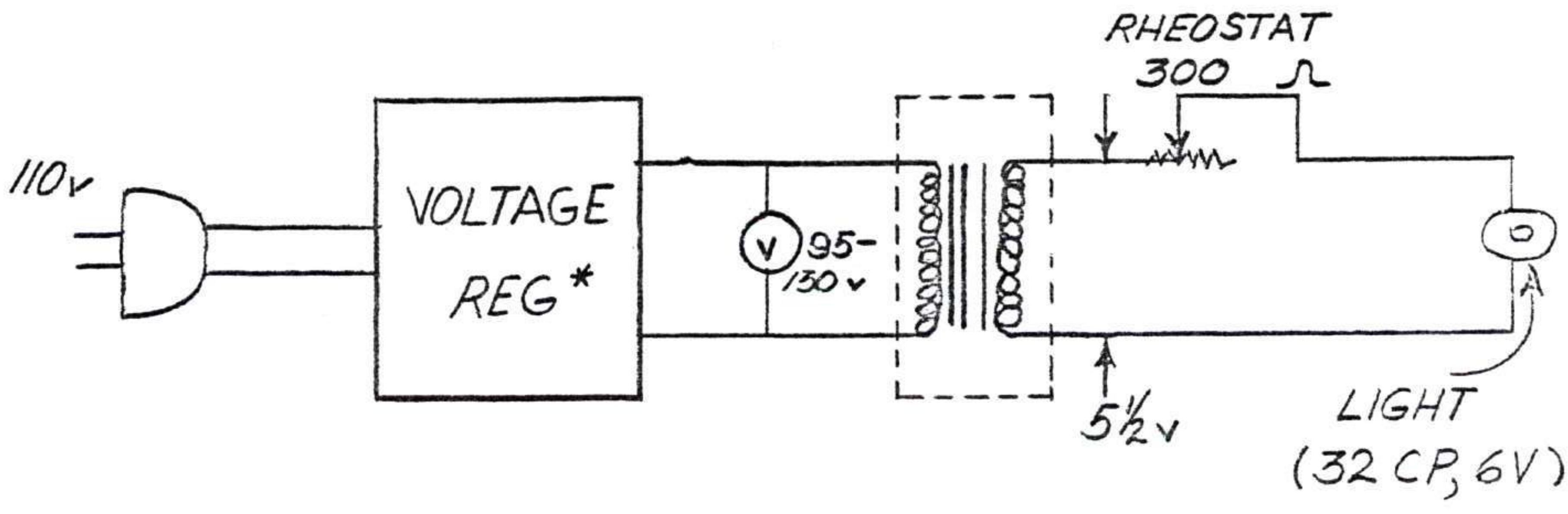
Scale - ½" = 1"

Figure 3. Turntable Design



Scale - ½" = 1"

Figure 4. Sample Holder Design



*Automatic Voltage Regulator,
Thordurson Electrical Company,
Type T-47175, 95-130 V.

Figure 5. Constant Voltage Circuit Diagram

light reflectance measurements would be erroneous. The turntable must be constructed so that when it is turned, it will turn absolutely circular. The slightest eccentricity will result in different amounts of light striking the sample as it is revolved on the turntable.

The spindle for the turntable was first constructed of wood. However, due to the wearing through use, the spindle began to turn eccentrically and had to be discarded. The spindle was then made of aluminum and mounted in roller bearings. There was no tolerance allowed and a drive fit was made between the spindle and the roller bearings. This eliminated the eccentricity and the turntable turned true.

At the base of the turntable, and on the exterior, two protractors were mounted so that a 360° scale could be used in taking readings from the samples. A small hole was drilled into the spindle so that an indicator could be mounted on it for reading the scale. Since the scale was mounted on the bottom of the turntable, it was necessary to place a mirror beneath the machine to read the scale. No problems resulted from rotating the turntable since the spindle was mounted in roller bearings.

Lightproofing the instrument interior.--Masking tape was placed around the base of the instrument to prevent the entrance of extraneous light. This masking tape was painted with a non-reflecting black paint. The interior of the instrument and the aluminum tubes were painted with the flat black paint, and the turntable and its components were also painted. The false bottom, when screwed to the exterior of the machine, permitted minute amounts of light to enter the machine interior. This was eliminated by placing black rubber cement between the false bottom and the sheet steel exterior. The rubber cement was then painted with the flat black paint.

CHAPTER III

PROCEDURE AND EXPERIMENTATION

Sample preparation.--Different types of bonded-web fabrics, both random and non-random, were requested from manufacturers for use in the experimental phase of this investigation. The non-random or parallel fiber sample was difficult to obtain, and only one sample was obtained in quantity enough to compute an accurate average of its light reflectance.

The samples and the identifying numbers used in the experimental phase of this thesis were:

SAMPLE NUMBER	TYPE OF FIBER	STAPLE LENGTH	DENIER
1	Viscose rayon	2"	3
2	Viscose rayon	1½"	1½
3	Nylon, Type 6	1½"	6
4	Rayfiber, Viscose	Mixed	1½ - 5
B	Cotton	15/16"	-

The materials were obtained in such quantity that ten samples of each fabric could be tested. The samples were taken from the fabric in such a manner that the entire width of the fabric was included in the surface area of the ten samples. Each sample tested was three-inch diameter.

In addition to the above samples, the following non-random single samples were tested:

SAMPLE NUMBER	TYPE OF FIBER
L	Cotton
X	Viscose rayon
Y	Viscose rayon
Z	Cotton

Samples L, X, Y, and Z were of such small size that only one three-inch diameter sample could be removed for testing.

Method of keeping line voltage constant.--From the beginning of this investigation, it was known that the line voltage and the amount of light directed onto each sample would have to be the same. Even the slightest voltage change or fluctuation would result in varying amounts of light striking different samples, and, therefore, comparison of the sample readings would be impossible. After the design and construction of the constant voltage source, it was decided to use a standard material for ascertaining the correctness of the line voltage from sample to sample. A piece of bond paper was the first standard tried, but it quickly became apparent that the standard would become dirty through use and therefore unsuitable. Secondly a piece of white glazed ceramic tile was suggested. Unfortunately, the light reflectance from this object was too great for the galvanometer scale, and the tile was discarded. The final object tried was a piece of white porcelain of the type used in cooking utensils and it proved to be satisfactory. This object was cut into a three-inch diameter sample, and it was so marked that it could be inserted into the machine in exactly the same position each time. This insured that the spot of directed light was covering the same surface area of the standard each time.

Prior to the insertion of each sample into the machine for testing, the porcelain standard was inserted. By means of a knob located on the rheostat of the electrical circuit, the amount of light directed onto the standard could be controlled and would be the same for all samples. For the purposes of this investigation, the light was adjusted so that a reflectance of 70 microamperes was indicated on the scale of the galvanometer when the standard was used.

Sample readings.--Each sample to be tested was marked in such a manner that it could be placed on the turntable in exactly the same position each time. The sample was placed on the turntable, and the turntable inserted into the machine. The turntable was rotated, and a reading of the light reflectance of the sample was taken at each 20° interval, making a total of 18 readings for each sample. The readings from the scale of the galvanometer were recorded in tabular form for each of the ten specimens tested, with the exception of samples L, X, Y, and Z, where only one sample was tested.

Tabulation and calculation of results.--Since the samples of the bonded-web fabrics were not marked in the same place on each of the ten specimens, the light did not strike each sample specimen in the same place. For this reason, the readings obtained from the samples were rearranged so that the reflectance of greatest magnitude was first so that it facilitated plotting and calculating results. The highest reading was located from the tabulated results, established as the 0° reading, and the remainder of the readings were listed below it, in correct order. For example, if the reading at 160° were the highest, it was established as the reading at 0°; the reading at 180° became the reading at 20°; and the reading at 200° became the reading at 40°. It should be stressed that this was done so that a common starting place be used for all samples. The readings taken on the ten specimens for each of the fabrics were then averaged.

After the rearrangement of the sample readings, a system of ratios was established for plotting the average readings of the samples on polar coordinate graph paper. The highest average reading for the ten samples, which was the 0° reading, was divided into each of the other readings.

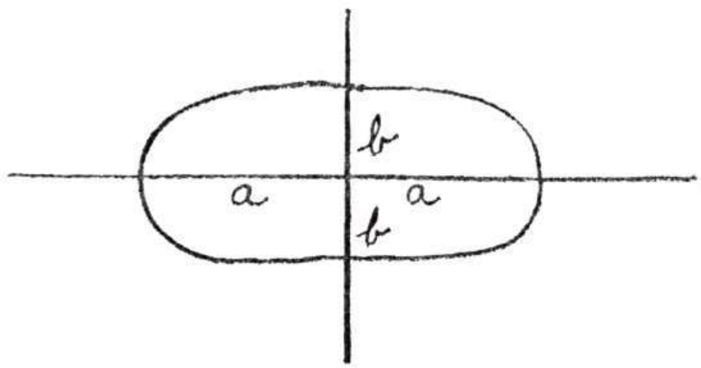
Hence, the first average, which was the largest, when divided by itself, would equal unity. All other averages would be less than unity.

The system of rearranging the readings may be seen in tables 1 and 2. Calculated ratios for all of the samples may be found in tables 2 through 7.

The theory of calculating and plotting the reflectance on polar coordinate graph paper was that if the sample being studied were completely random, then the light reflectance from all angles would be the same, and the scale readings indicated on the galvanometer would be the same throughout the 360^{o} revolution of the sample. If all readings were the same for the ten samples of a fabric, then all ratios would be equal to unity, and when plotted on polar coordinate graphs the plots connected together would form a perfect circle. The greater the degree of parallelization, or non-randomness, the more elliptical would be the shape of the sample when it was plotted.

Since the ratios varied only a small amount from each other, the center point of the polar coordinate paper was established as .80, and a scale was established which could be used for all samples. Comparisons between samples could then be made.

The formula for computing the eccentricity of an ellipse, according to Borger (9), is:



Major axis: a + a or 2a

Minor axis: b + b or 2b

$$\text{Eccentricity} = \sqrt{\frac{a^2 - b^2}{a}} \quad \text{or} \quad \sqrt{\frac{a^2 - b^2}{a^2}}$$

As previously stated, if the sample under investigation were completely random, the readings from all angles of revolution would be the same, and the ratios would be equal to unity. If all ratios were equal to 1, when plotted on the polar coordinate paper, the plots from the 18 readings would form a perfect circle. When the major and minor axes were determined from the graph of the ratios, a and b would be equal and the eccentricity would be equal to 0.

A formula for determining the "randomness number" was then computed to be:

Randomness = 1 - eccentricity of the ellipse

It is readily understood that if perfect randomness existed in the fabric under study, the eccentricity would be equal to 0, and, when the randomness formula is applied, the randomness would be equal to 1. Therefore, it may be stated that perfect randomness would be equal to 1, and all other degrees of randomness would be less than 1.

Graphs and calculations.--A graph of the actual readings obtained for each individual fabric (average of ten samples) was made on the polar coordinate paper. These graphs, figures 6 through 14, show that the degree of eccentricity between a random and a non-random sample could be easily distinguished by a visual inspection of the graphs. The averages of the ten samples of each fabric were then converted to ratios and plotted on polar coordinate paper.

Since the major axis in most cases was along the $0 - 180^{\circ}$ line, and the minor axis along the $90 - 270^{\circ}$ line, it was easy to determine the values of a and b from a graph of the ratios. Values for a were computed from the graph in this manner: $\frac{a + a}{2}$, and the values for b computed in a like manner.

The formula for computing the eccentricity of an ellipse was then applied to each sample, and its eccentricity calculated.

The formula for the computation of randomness was then applied and the calculated randomness recorded for each sample.

CHAPTER IV

DISCUSSION OF RESULTS

Data collected during the research phase of this investigation indicate that the assumptions that a bonded-web fabric composed of fibers in a random arrangement would give equal reflectance of light from all angles, and that a fabric in which the fibers were non-random would give varying light reflectance were correct.

Figures 6 through 14 are polar coordinate graphs of the actual reflectance (in microamperes) obtained from samples of bonded-web fabrics in which the fibers were randomly arranged. These plots of samples 1, 2, 3, and 4 formed almost perfect circles.

Sample 1, figure 6, displayed the greatest eccentricity but the deviation of the graph from a perfect circle was small. The deviation amounted to approximately 2 microamperes. This slight distortion may be observed at 0^{o} and again between 90 - 180^{o}.

Samples 2, 3, and 4 revealed very little distortion. Sample 3, figure 8, was the sample with the least distortion. A slight increase in reflectance might be observed at 0^{o}.

Deviations from perfect circles may have been caused by a number of variables. Among these variables could have been that the turntable upon which the sample was tested might have been slightly unlevel; thick and thin places might have been present in the fabric; a human error in reading the small scale of the galvanometer could have been made; minute particles of soil might have been imbedded in or imparted to the fabric during testing, causing the light reflectance to vary; or it might be that the fibers were not randomly arranged in one small section of a fabric.

The non-random or parallel fiber samples, figures 10 to 14, revealed a great amount of eccentricity and deviated sharply from the circular shape. These plots all formed ellipses. This elliptical shape was expected, as discussed in Chapter I, and in the case of sample B, the elliptical shape formed by the plots was readily apparent. This sample, figure 10, had the greatest deviations occurring at 0^{o} and again at 180^{o}. The minor axis, along the 90 - 270^{o} line (east and west) was of equal length on both sides of the center mark. Between the angles of 320 - 40 degrees and from 140 - 220 degrees, the plots deviated and formed the elliptical shape. The arms of the major axis were then longer than were those of the minor axis. This deviation occurred when the fibers of the fabric were parallel to the directed spot of light. The reflectance plots of sample B indicated that the statement made in Chapter I concerning the theoretical shape that the plots should assume was correct. The more parallel the fibers within the fabric, the more pronounced should be the elliptical shape formed by the plots.

Samples L, X, Y, and Z, all non-random samples, were of such size that only one sample could be tested, and this fact makes it difficult to discuss the results obtained. However, the results of the polar coordinate graphs, as seen in figures 11 to 14, tend to uphold the statement made in the preceding paragraph about sample B.

The most pronounced elliptical shape was that of sample L, figure 11. The major axis of this sample is along the 90 - 270° line and the minor axis along the 0 - 180° line.

Sample X, figure 12, shows a somewhat elliptical shape, though not so pronounced as that for samples L and Y.

Sample Y, figure 13, showed similar results as for sample L. Sample Y was bonded with a latex binder, and the results obtained from the test indicated that the instrument will function accurately for this type of binder.

Sample Z deviated from the expected elliptical shape but does not, however, form a circular shape which would be formed by the perfectly random sample.

The randomness of the various samples is shown in Table 8. As was expected, the samples in which the fibers were random showed higher randomness numbers than did the non-random samples. The random samples, 1, 2, 3, and 4, had randomness numbers of from .64 to .77. No units are given since the numbers are abstract.

The non-random samples B, L, X, Y, and Z had randomness numbers of from .50 to .60.

It was interesting to note the variations among the random samples. None of the results were so close as to prevent distinction between the randomness of the samples. This tends to show that the instrument is accurate enough to determine the most random sample from a group of random samples.

CHAPTER V

CONCLUSIONS

The object of this investigation was to develop a research tool and a method for determining the varying degrees of fiber randomness within a bonded-web fabric.

The results obtained from the experimental phase of this thesis indicate that the measurement of reflected light is a suitable method for determining the degree of randomness in bonded-web fabrics. A difference existed between the random and non-random samples in both graphs and randomness number calculations.

This would seem to indicate that the instrument designed for this investigation functioned correctly. While the results obtained might not be as extremely varied as desired, they were of such variation as to readily distinguish the most randomly arranged sample from groups of random and non-random samples and, as far as is known, this instrument is the first to be designed employing light reflectance measurements for determining the differences in the randomness of bonded-web fabricε

It is possible to use the instrument and the evaluation methods to assign a "randomness number" to a bonded-web fabric. With further development, it would seem possible that manufacturers could use such an instrument to determine the degree of randomness within fabrics, and to assign an identifying randomness number to particular fabrics.

CHAPTER VI

RECOMMENDATIONS

During the research and experimental portions of this investigation, it quickly became apparent that the angle at which the light struck the fabric was of extreme importance. Instead of using a 45° angle, which was approximately the angle used, what would be the effect of increasing or decreasing the angle at which the light strikes the sample? It is suggested that a study of various light angles would be beneficial.

Another point of interest was the angle from which the reflected light was measured. More specifically, where should the photronic cell be located? It may be of interest to experiment with the scattered light reflectance measurements. In this investigation, the light was measured at 180° away from the light source. What would be the effect of measuring the light at some angle other than 180°?

Another method suggested for measuring the randomness of fibers is to direct the light from beneath the sample and measure the amount of light which penetrates the sample. Thickness of the fabric might be too important in this case and the results may be erroneous.

In conclusion, it is recommended that an instrument be designed and constructed completely from metal so that the parts could be more accurately machined.

B I B L I O G R A P H Y

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A P P E N D I X

Table 1. Original Reflectance Readings From Sample 1
(In Microamperes)

Angle of Readings	Specimens									
	A	B	C	D	E	F	G	H	J	K
0	36	33	35	32	34	33	36	32	32	37
20	34	33	35	32	34	33	36	34	31	35
40	34	33	35	33	36	33	36	35	32	36
60	34	34	35	33	36	33	36	36	33	36
80	35	34	36	35	37	35	37	36	34	37
100	36	36	36	35	38	36	40	36	35	39
120	36	35	37	34	38	38	39	36	36	39
140	37	34	36	34	36	40	38	35	35	38
160	37	34	35	34	35	40	36	32	33	36
180	37	34	35	33	36	40	36	34	34	37
200	35	35	35	33	37	39	39	36	33	37
220	35	34	34	33	37	38	38	37	33	37
240	37	34	36	34	37	38	39	38	35	37
260	36	35	37	35	38	38	39	38	36	38
280	35	36	36	36	37	37	38	36	35	38
300	36	34	35	35	36	37	36	34	34	37
320	37	34	34	33	35	35	35	32	33	36
340	36	33	33	32	34	34	35	32	32	35

Table 2. Rearranged Light Reflectance Values For Sample 1 (In Microamperes)

Angle of Reading	Specimens A	B	C	D	E	F	G	H	J	K	Average	Ratio*
0	37	36	37	36	38	40	40	38	36	39	37.7	1.000
20	37	35	36	35	38	40	39	38	35	39	37.2	.987
40	37	34	35	33	36	40	38	36	33	38	36.0	.955
60	35	34	35	32	35	39	36	34	34	36	35.0	.928
80	35	34	35	32	36	38	36	32	33	37	34.8	.923
100	37	35	34	32	37	38	39	32	33	37	35.4	.938
120	36	34	36	33	37	38	38	32	35	37	35.6	.943
140	35	34	37	33	37	37	39	34	36	37	35.9	.952
160	36	35	36	35	38	37	39	35	35	38	36.4	.965
180	37	36	35	35	37	35	38	36	34	38	36.1	.957
200	36	34	34	34	36	34	36	36	33	37	35.0	.928
220	36	34	33	34	35	33	35	36	32	36	34.4	.913
240	34	33	35	34	34	33	35	36	32	35	34.1	.904
260	34	33	35	33	34	33	36	35	31	37	34.1	.904
280	34	33	35	33	34	33	36	32	32	35	33.7	.893
300	35	35	35	33	36	35	36	34	33	36	34.7	.920
320	36	34	36	34	36	36	36	36	34	36	35.4	.937
340	36	34	36	35	37	38	37	37	35	37	36.2	.960

*Ratio equals: $\frac{\text{Individual Readings}}{\text{Largest Reading}}$

Table 3. Rearranged Light Reflectance Values For Sample 2 (In Microamperes)

Angle of Reading	Specimens A	B	C	D	E	F	G	H	J	K	Average	Ratio*
0	53	53	54	52	54	54	54	54	52	53	53.2	1.000
20	53	51	53	51	52	53	54	52	51	52	52.2	.981
40	52	52	52	50	51	50	51	50	49	50	50.7	.954
60	53	53	53	51	50	48	50	48	47	48	50.1	.943
80	53	51	52	51	50	47	48	47	46	47	49.2	.925
100	51	51	51	52	50	46	47	46	46	46	48.6	.915
120	50	51	49	51	51	46	48	48	47	46	48.7	.916
140	49	52	47	49	54	46	48	49	47	47	48.8	.917
160	49	50	48	48	53	49	49	49	49	49	49.3	.927
180	50	49	49	49	52	50	51	51	49	50	50.0	.940
200	49	49	48	48	49	52	52	52	51	51	50.1	.943
220	48	49	49	47	48	51	52	52	50	49	49.5	.930
240	50	51	50	48	47	49	51	50	48	47	49.1	.923
260	50	49	50	50	47	47	50	49	48	48	48.8	.917
280	51	49	50	51	47	48	49	49	47	48	48.9	.920
300	52	50	49	51	48	50	51	51	49	50	51.0	.943
320	52	50	50	51	50	51	52	53	50	51	51.0	.958
340	52	52	51	51	52	52	52	53	51	51	51.7	.973

*Ratio equals: $\frac{\text{Individual Readings}}{\text{Largest Reading}}$

Table 4. Rearranged Light Reflectance Values For Sample 3 (In Microamperes)

Angle of Reading	A	B	C	D	Specimens E	F	G	H	J	K	Average	Ratio*
0	50	48	49	48	47	46	49	50	48	48	48.3	1.000
20	49	47	49	47	47	46	48	50	47	47	47.7	.988
40	48	45	49	45	47	46	48	50	47	46	47.1	.976
60	46	44	49	45	47	45	48	49	46	46	46.5	.963
80	46	46	48	45	47	43	48	49	46	44	46.2	.957
100	46	46	47	46	46	43	48	47	47	46	46.2	.957
120	48	48	47	45	45	42	49	47	47	48	46.6	.965
140	48	48	46	44	44	45	49	48	48	46	46.6	.965
160	47	48	46	43	47	44	48	46	47	45	45.8	.948
180	47	45	47	45	43	45	48	47	45	45	45.7	.947
200	47	46	45	45	44	45	48	47	43	45	45.5	.941
220	47	45	45	45	44	44	47	46	45	43	45.1	.934
240	45	46	45	45	46	44	47	45	45	42	45.0	.932
260	45	45	47	45	46	43	49	47	44	42	45.3	.937
280	45	45	48	46	46	43	48	47	44	45	45.7	.947
300	46	45	46	46	44	43	47	47	45	45	45.4	.940
320	47	46	46	46	44	45	47	48	45	47	46.1	.955
340	49	46	48	45	46	45	48	47	47	47	46.8	.970

*Ratio equals: $\frac{\text{Individual Readings}}{\text{Largest Reading}}$

Table 5. Rearranged Light Reflectance Values For Sample 4 (In Microamperes)

Angle of Reading					Specimens						Average	Ratio*
	A	B	C	D	E	F	G	H	J	K		
0	47	47	44	47	46	43	41	41	42	42	44.0	1.000
20	46	46	44	46	46	43	41	39	41	42	43.4	.975
40	45	44	44	44	44	42	41	36	42	42	42.4	.963
60	45	43	42	43	42	42	40	38	42	42	41.9	.953
80	45	42	42	43	42	40	40	39	41	40	41.4	.941
100	45	43	41	43	42	42	37	39	40	41	41.3	.939
120	44	42	40	45	42	42	39	39	39	41	41.3	939
140	43	42	44	44	42	40	40	39	38	41	41.3	.939
160	43	43	44	43	42	40	40	38	37	41	41.1	.933
180	45	43	43	43	43	42	41	37	36	42	41.5	.943
200	44	45	43	43	45	42	41	37	35	41	41.6	.947
220	45	46	42	44	45	40	38	38	37	40	41.5	.943
240	45	44	43	43	43	40	37	37	39	38	40.9	.930
260	46	44	41	41	43	39	39	37	41	38	40.9	.930
280	46	44	42	43	43	39	38	38	40	39	41.2	.937
300	45	44	40	43	45	39	38	39	40	38	41.1	.933
320	44	45	42	45	45	39	38	38	40	39	41.5	.943
340	44	44	43	46	45	42	39	39	39	40	42.1	.957

*Ratio equals: $\frac{\text{Individual Readings}}{\text{Largest Reading}}$

Table 6. Rearranged Light Reflectance Values For Sample B
(In Microamperes)

Angle of Reading	Specimens A	B	C	D	E	F	G	H	J	K	Average	Ratio*
0	43	44	46	40	42	43	44	45	47	47	44.1	1.000
20	42	40	41	40	42	41	44	44	45	44	42.3	.958
40	40	40	39	39	39	39	42	42	41	40	40.1	.910
60	38	39	40	40	39	37	41	42	42	40	39.8	.903
80	39	38	40	40	39	37	39	41	43	39	39.5	.895
100	41	38	39	40	38	39	40	40	44	39	39.8	.903
120	41	40	39	38	38	40	41	40	45	40	40.2	.913
140	42	44	40	35	39	43	42	44	45	43	41.7	.946
160	43	47	41	32	41	44	44	44	47	46	42.9	.973
180	43	46	42	36	43	43	47	47	47	45	43.9	.995
200	40	43	41	38	42	41	47	45	44	42	42.3	.958
220	38	40	40	38	40	40	44	43	43	41	40.7	.923
240	39	38	38	39	37	38	41	41	40	39	39.0	.885
260	39	37	37	39	36	39	38	41	41	39	38.6	.873
280	41	38	38	39	37	38	38	40	42	39	39.0	.885
300	41	39	41	37	38	40	38	43	43	41	40.1	.910
320	42	41	42	39	39	41	40	43	43	43	41.3	.935
340	41	42	45	38	39	42	42	44	46	45	42.4	.960

*Ratio equals: $\frac{\text{Individual Readings}}{\text{Largest Reading}}$

Table 7. Rearranged Light Reflectance Values For Samples L, X, Y, and Z (In Microamperes)

Angle of Reading	L	Ratio*	X	Ratio*	Y	Ratio*	Z	Ratio*
0	31	1.000	38	1.000	29	1.000	47	1.000
20	31	1.000	37	.974	28	.965	47	1.000
40	31	1.000	36	.947	27	.931	45	.957
60	27	.871	36	.947	26	.896	42	.894
80	25	.806	35	.921	27	.931	42	.894
100	25	.806	34	.895	27	.931	40	.851
120	24	.774	33	.868	26	.896	40	.851
140	23	.742	34	.895	27	.931	42	.894
160	27	.871	35	.921	28	.965	43	.915
180	27	.871	36	.947	27	.931	44	.936
200	28	.903	37	.974	25	.862	42	.894
220	28	.903	36	.947	25	.862	41	.872
240	27	.871	35	.921	25	.862	42	.894
260	26	.839	34	.895	25	.862	42	.894
280	25	.806	35	.921	25	.862	45	.957
300	27	.871	36	.947	26	.896	46	.979
320	27	.871	37	.974	26	.896	45	.957
340	28	.903	37	.974	28	.965	45	.957

*Ratio equals: $\frac{\text{Individual Readings}}{\text{Largest Reading}}$

Table 8. Randomness Number Calculations For Samples

SAMPLE	ECCENTRICITY OF ELLIPSE	RANDOMNESS NUMBER
1	.352	.648
2	.337	.663
3	.230	.770
4	.273	.727
B	.457	.543
L	.495	.505
X	.398	.602
Y	.420	.580
Z	.397	.603

SPECIMEN CALCULATION (For Sample B)

$$a = \frac{1 + .995}{2} = .9975 \qquad b = \frac{.876 + .900}{2} = .888$$

$$\text{Eccentricity} = \frac{(.9975)^2 - (.888)^2}{(.9975)^2} = .457$$

Randomness = 1 - eccentricity = 1 - .457 = .543

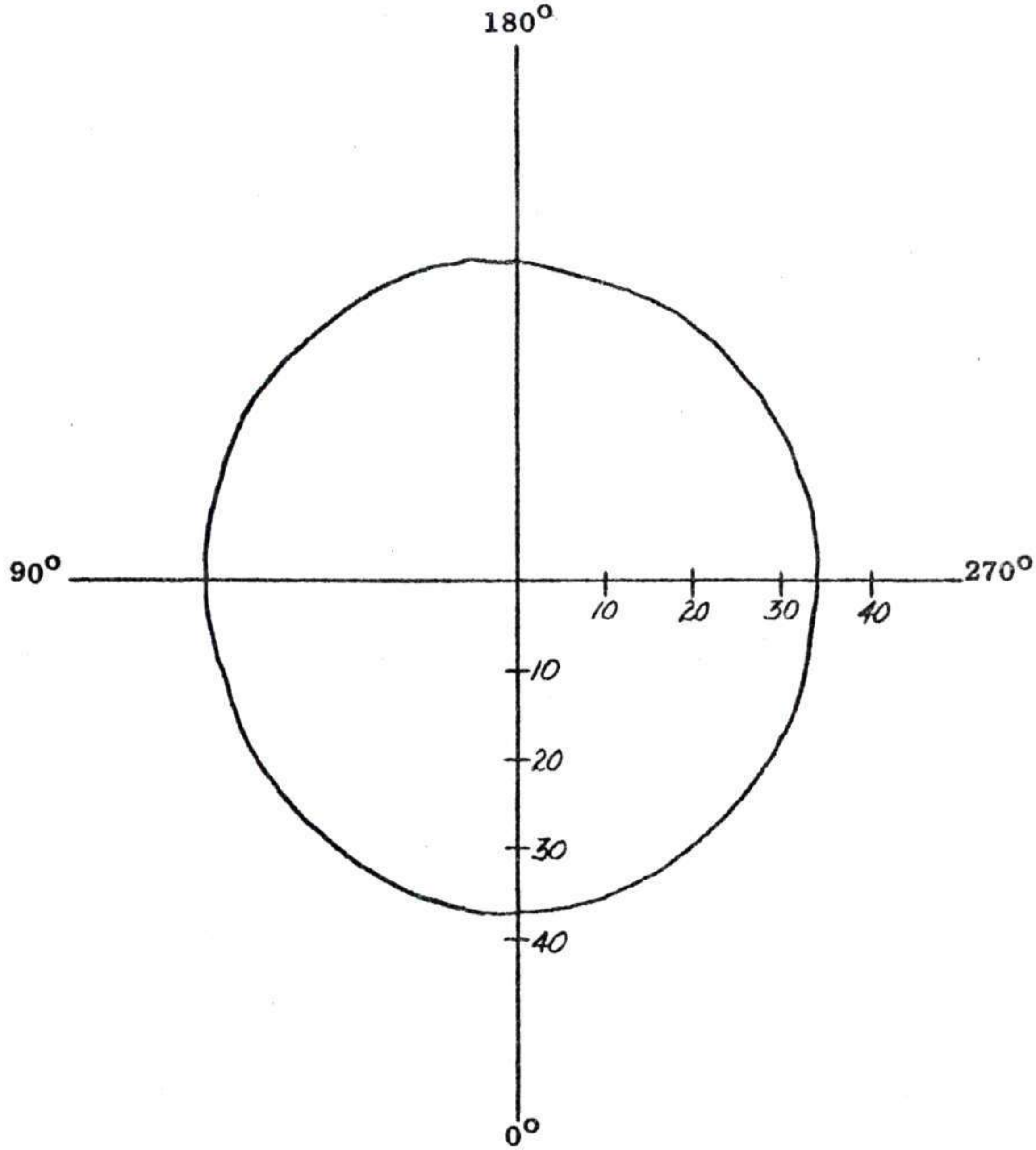

Figure 6. Graph of Light Reflectance (In Microamperes) of Sample 1. (Ten Sample Average)

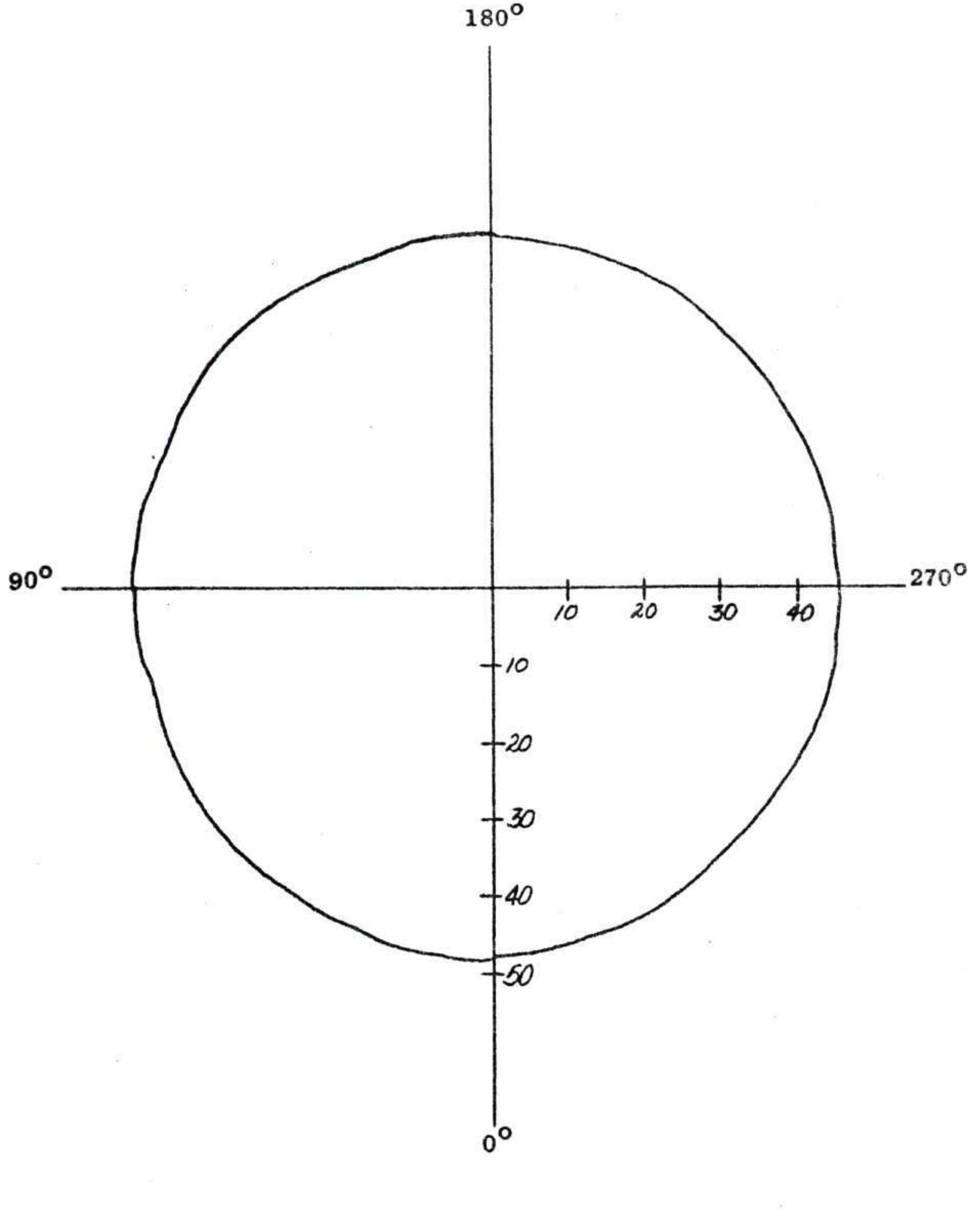

Figure 7. Graph of Light Reflectance (In Microamperes) of Sample 2. (Ten Sample Average)

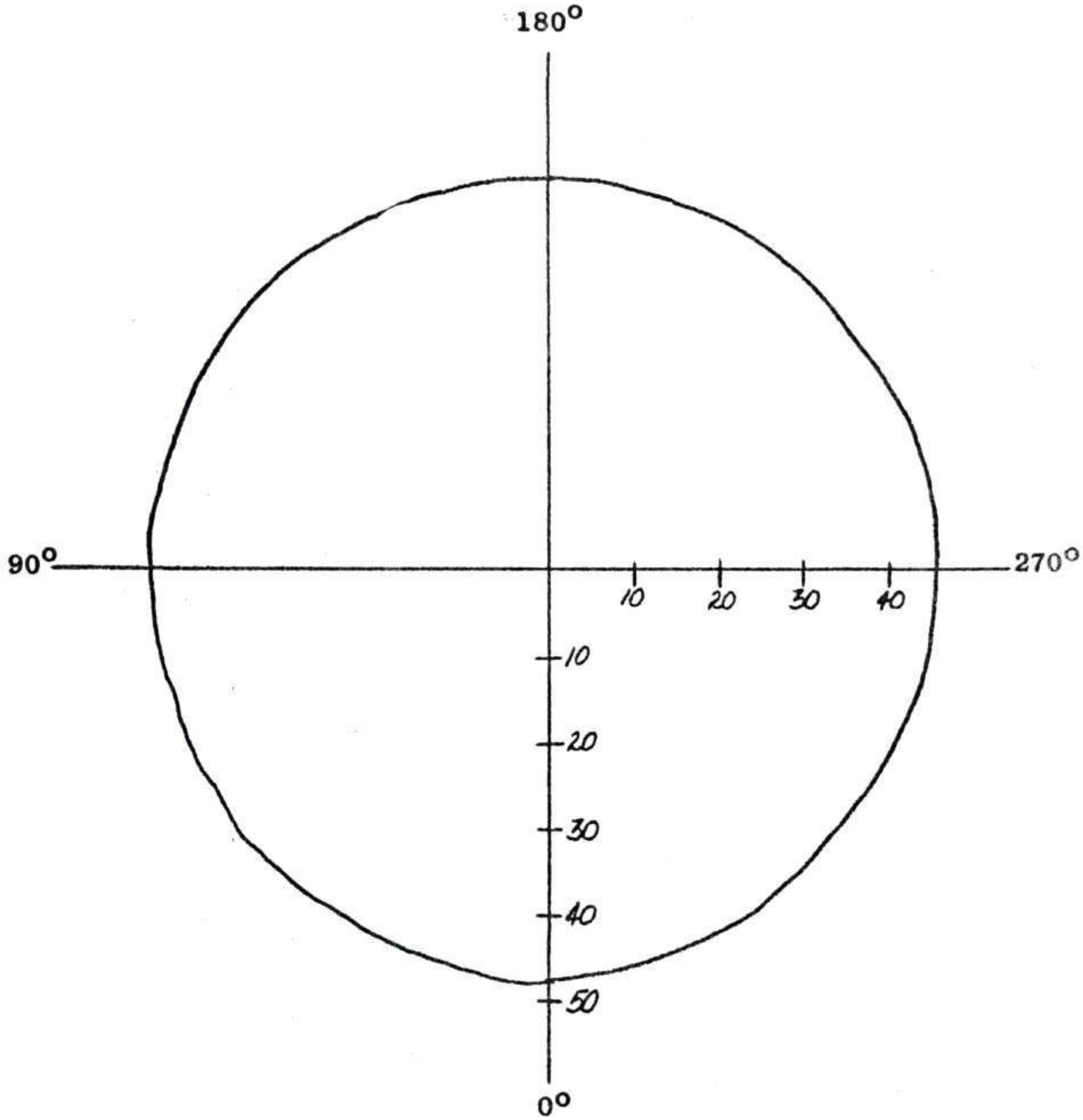

Figure 8. Graph of Light Reflectance (In Microamperes) of Sample 3. (Ten Sample Average)

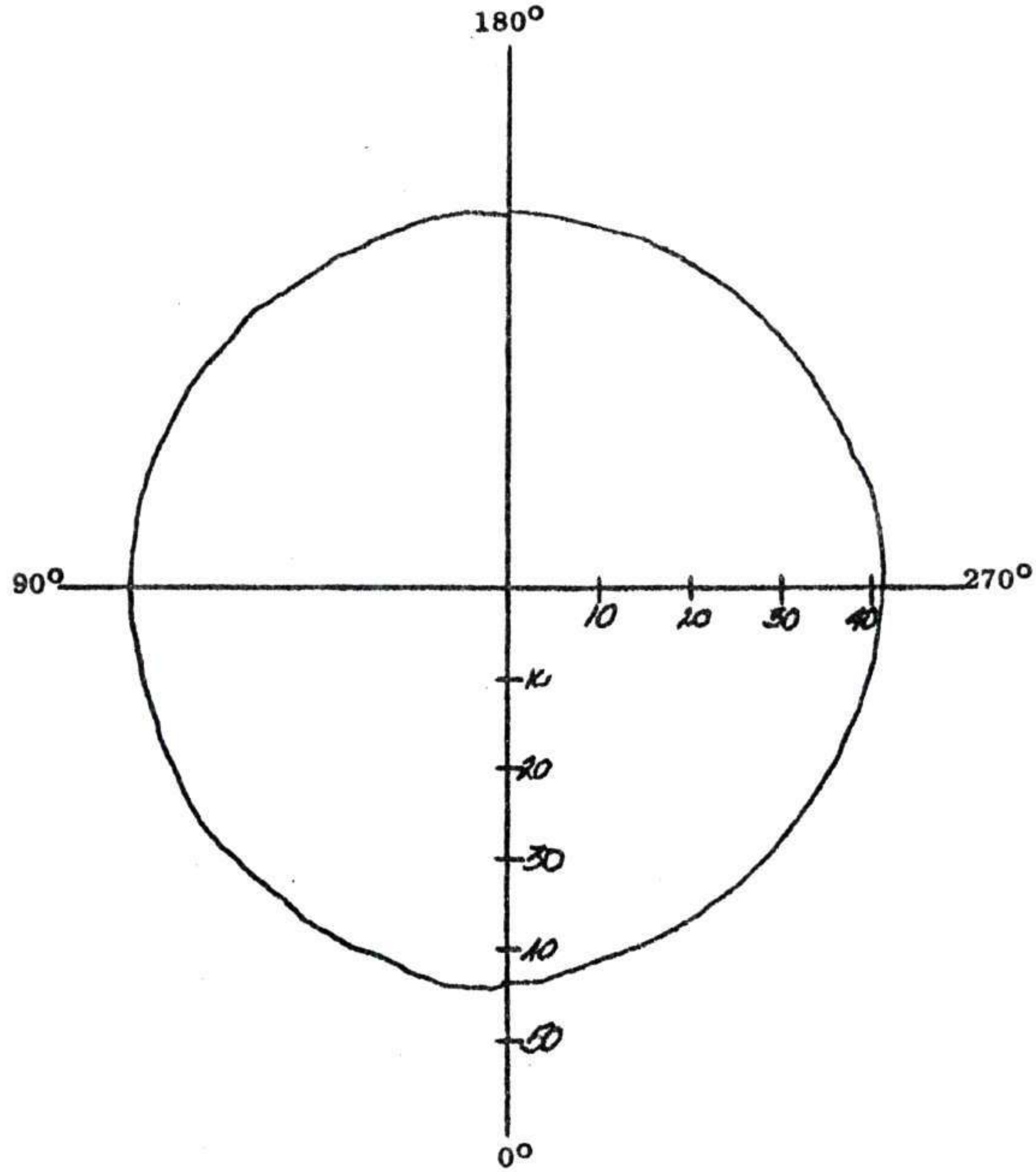

Figure 9. Graph of Light Reflectance (In Microamperes) of Sample 4. (Ten Sample Average)

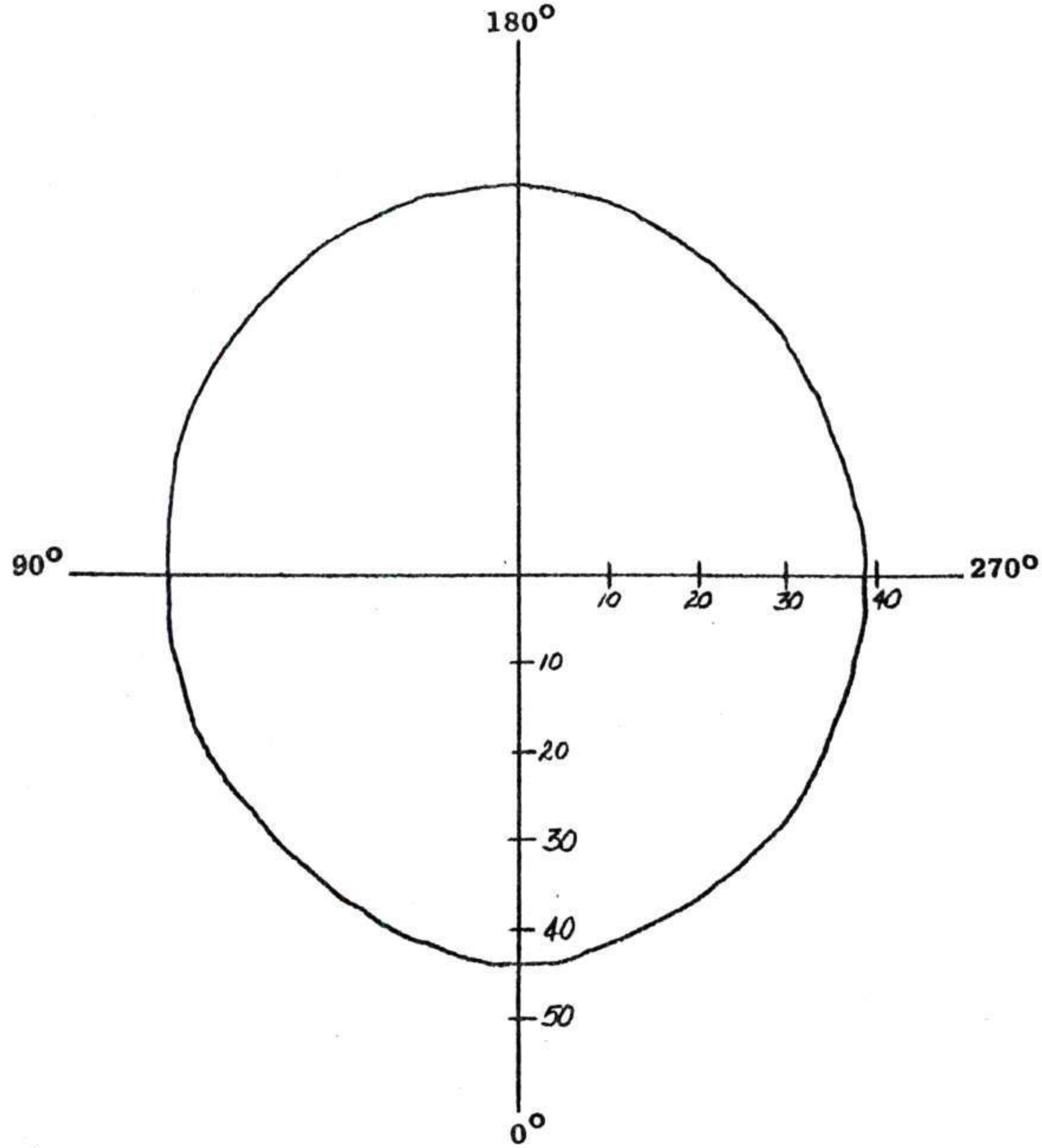

Figure 10. Graph of Light Reflectance (In Microamperes) of Sample B. (Ten Sample Average)

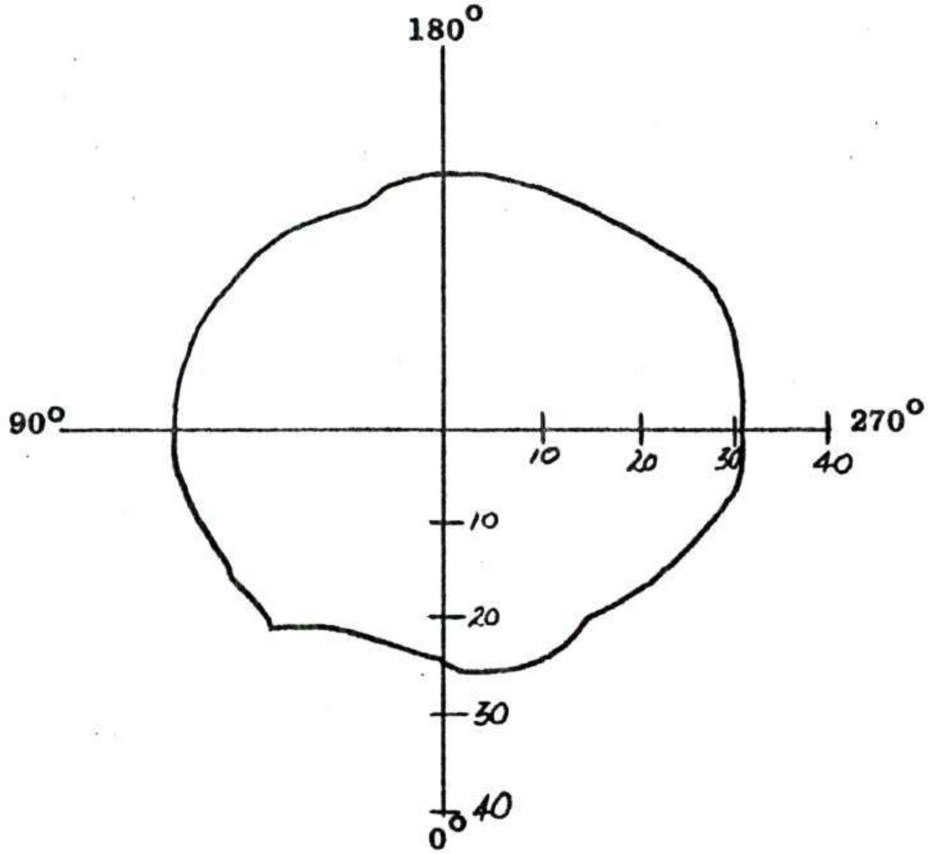

Figure 11. Graph of Light Reflectance (In Microamperes) of Sample L. (One Sample)

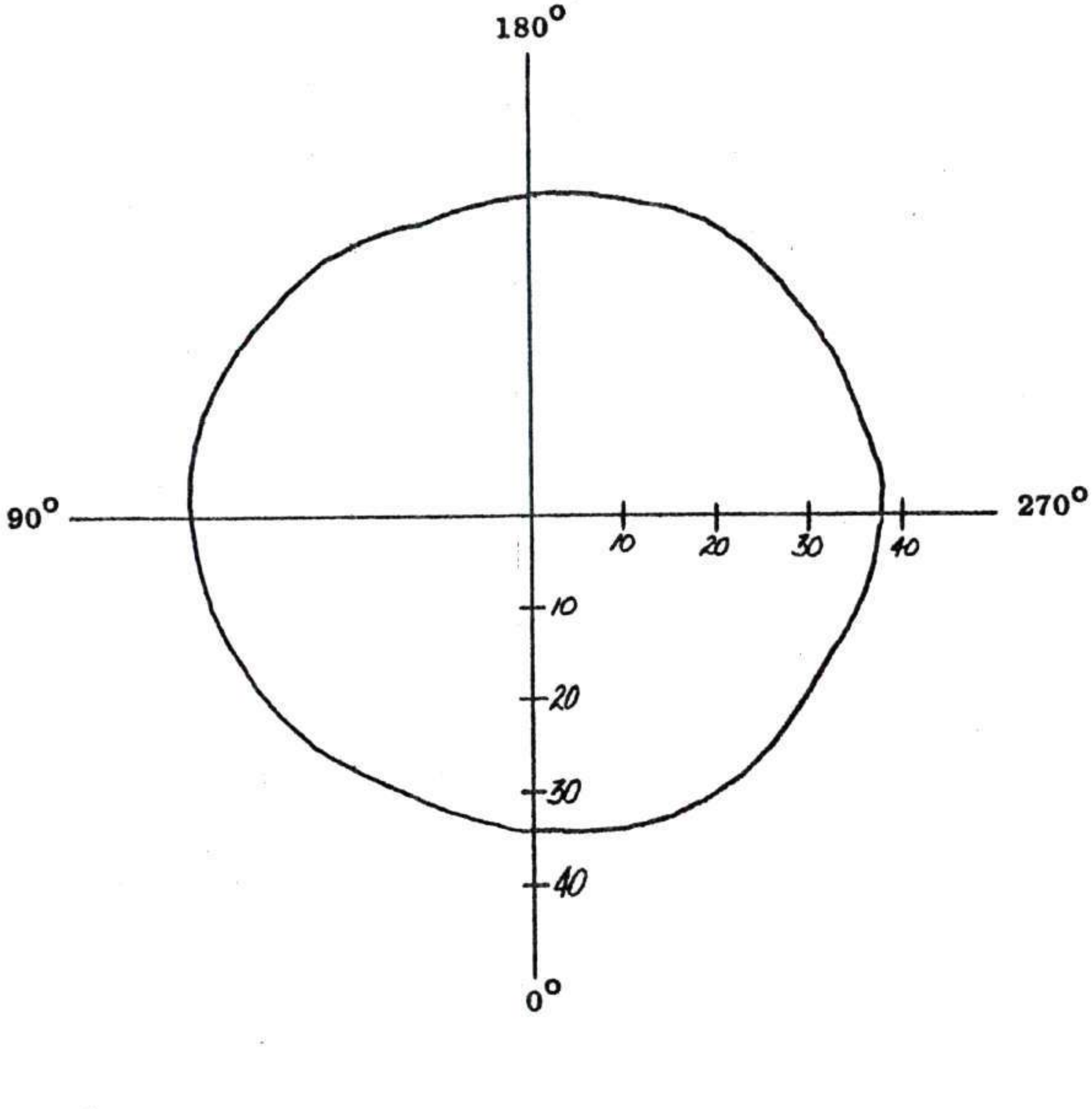

Figure 12. Graph of Light Reflectance (In Microamperes) of Sample X. (One Sample)

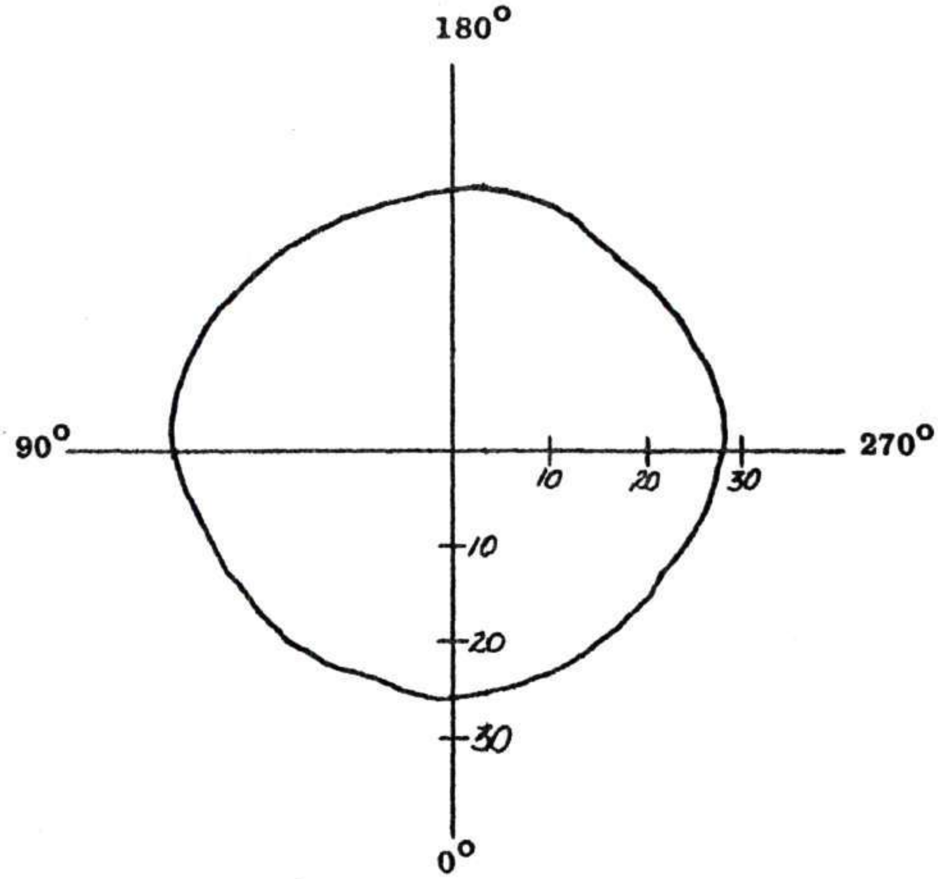

Figure 13. Graph of Light Reflectance (In Microamperes) of Sample Y. (One Sample)

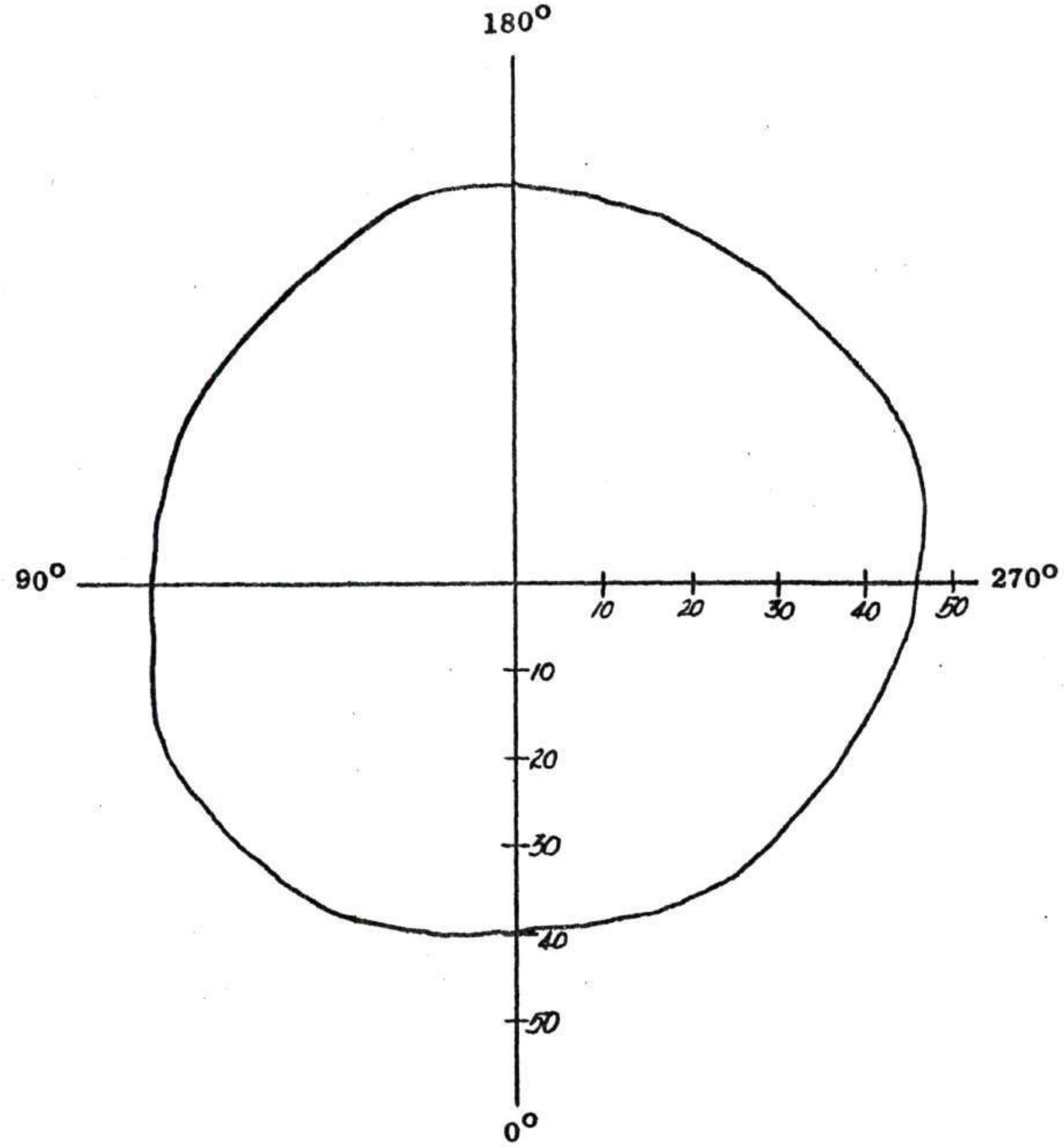

Figure 14. Graph of Light Reflectance (In Microamperes) of Sample Z. (One Sample)

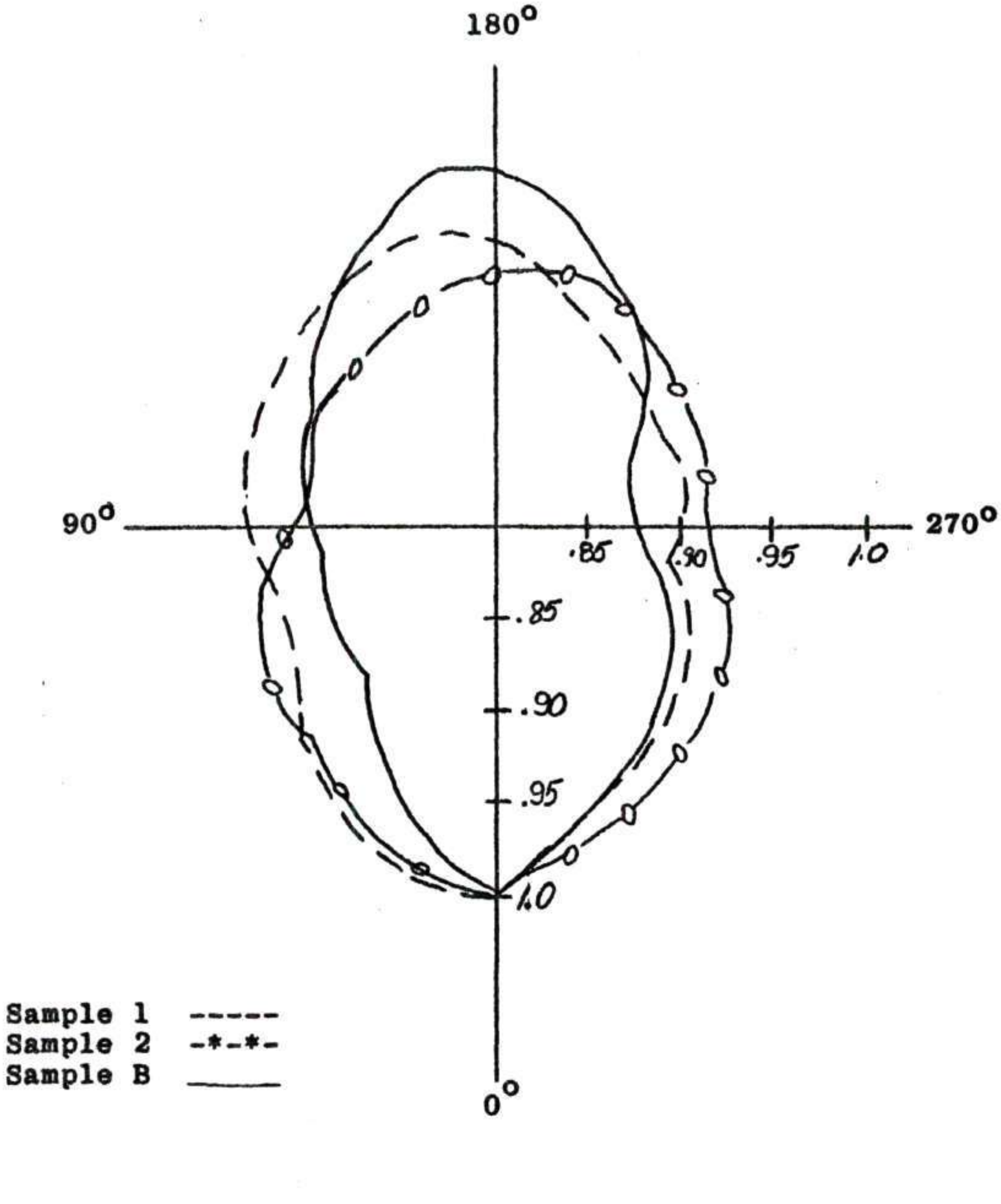

Figure 15. Graph of Ratios (Light Reflectance) of Samples B, 1, and 2.

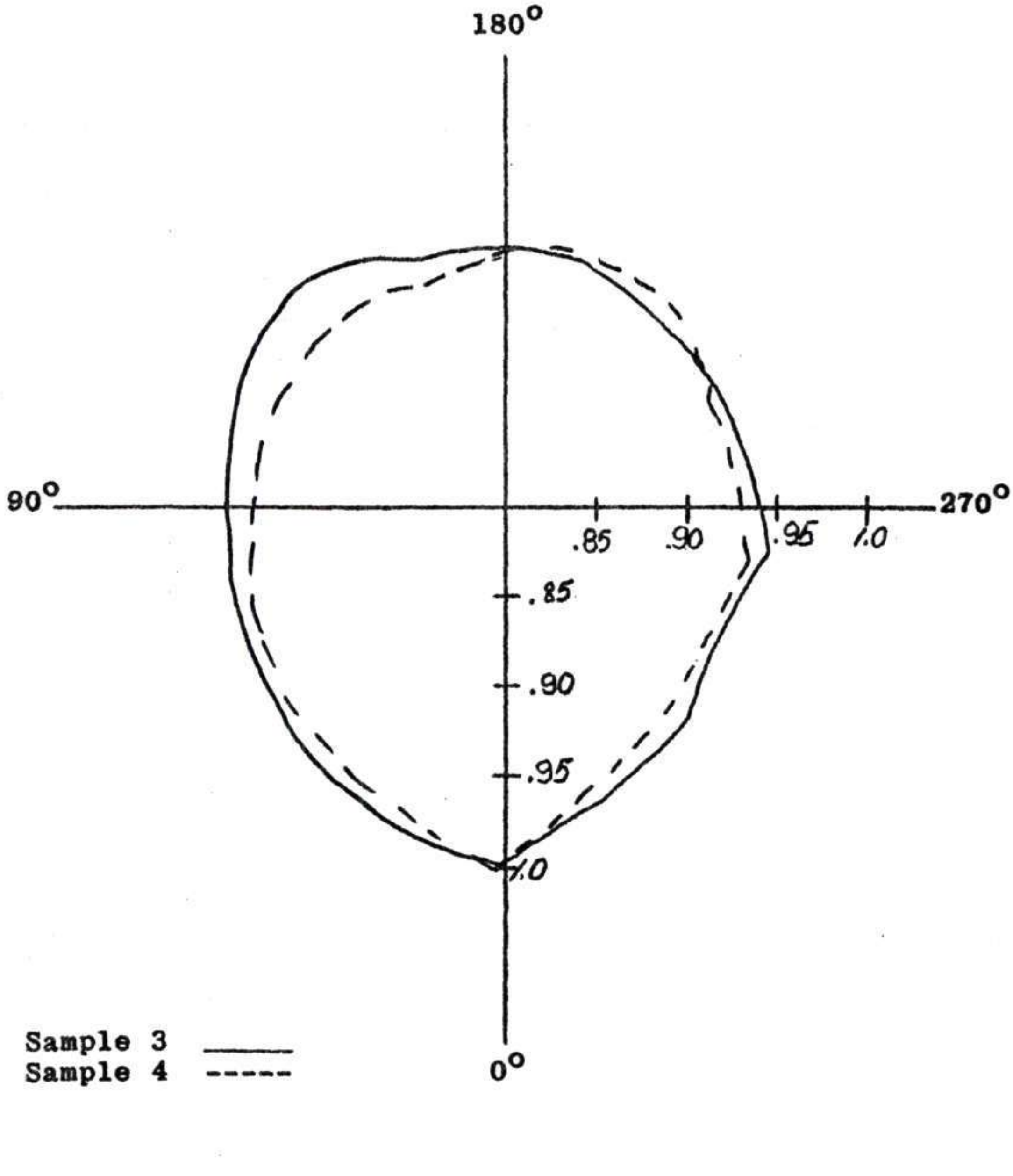

Figure 16. Graph of Ratios (Light Reflectance) of Samples 3 and 4.

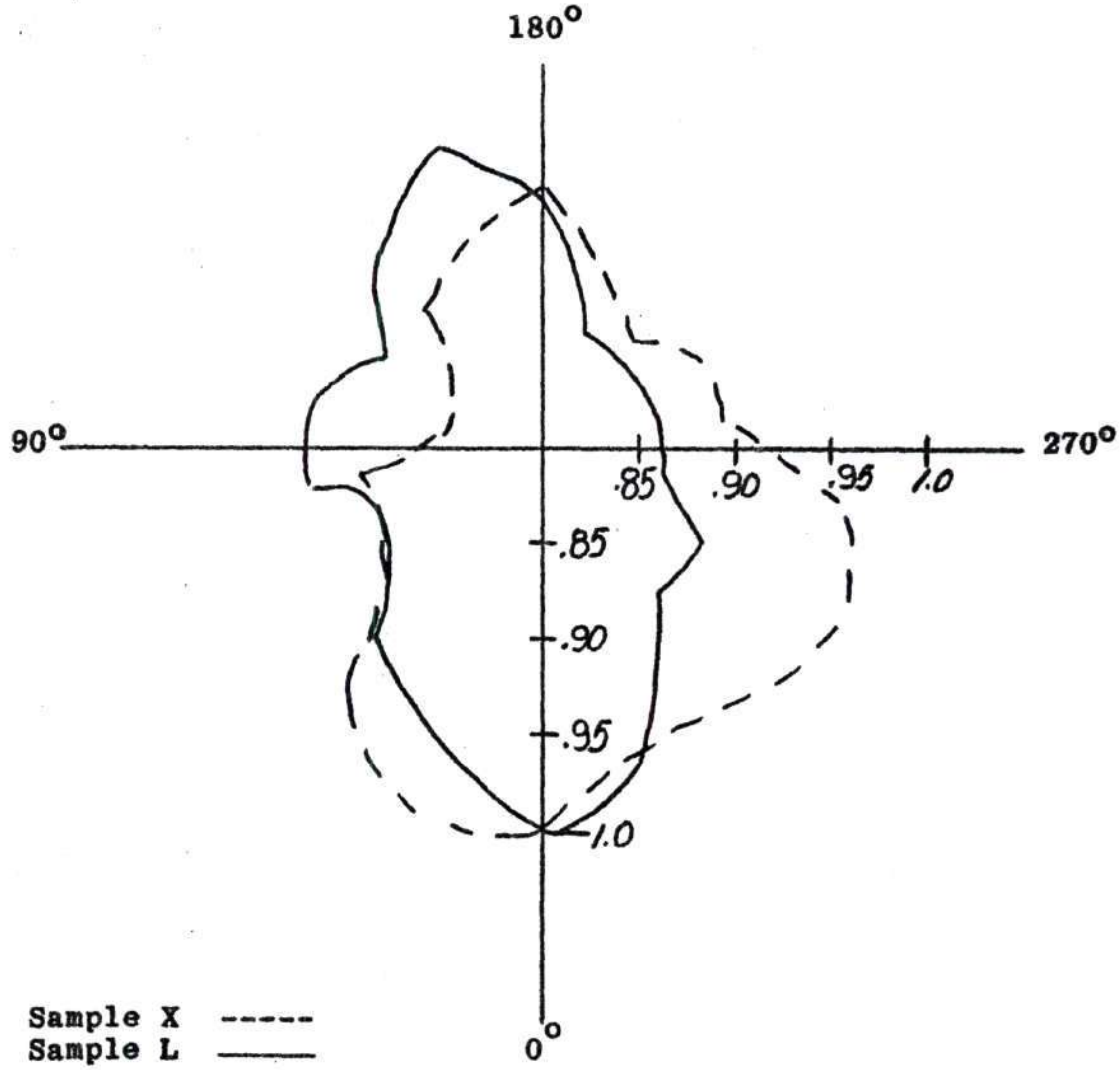

Figure 17. Graph of Ratios (Light Reflectance) of Samples L and X.

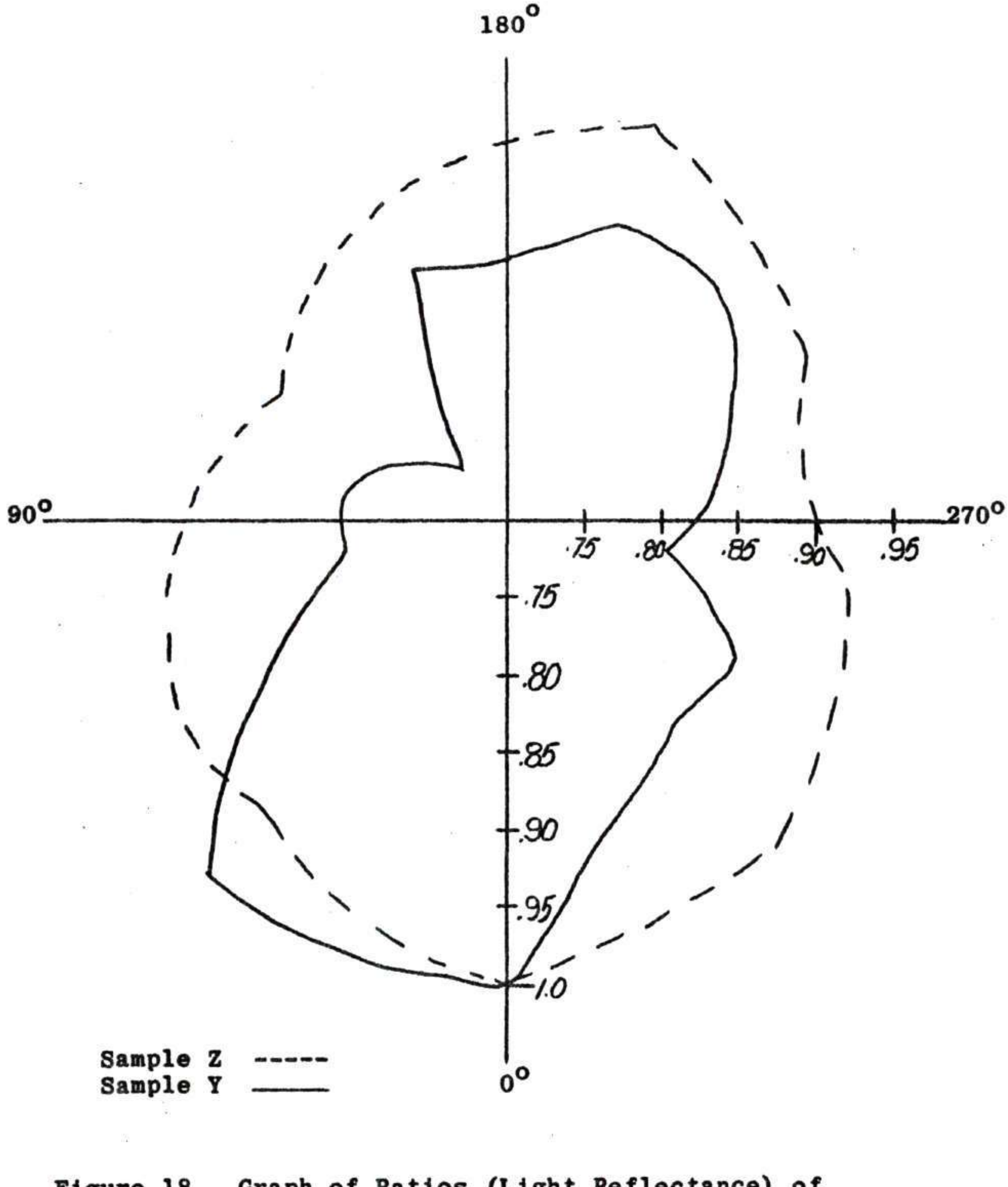

Figure 18. Graph of Ratios (Light Reflectance) of Samples Y and Z.