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The Evaluation of Paper by Means of the Densichron Instrument

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THE EVALUATION OF PAPER BY MEANS OF THE DENSICHRON INSTRUMENT

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Evaluation of the Universal Magnephot Densichron as a reflectometer, opacimeter and color analyzing device.

TABLE OF CONTENTS

Abstract

An Evaluation of the Universal Magnephot Densichron as a Reflectometer, Opacimeter and Color Analyzing Device

This paper is a report on the evaluation of the Universal Magnephot Densichron, an electronic photocell instrument developed for the photographic industry, for use in the paper industry. This instrument has been found to have several errors which makes its use impractical for research work in the laboratory, but can be used in paper mills for control purposes. If used for this type of work certain precautions have to be taken as outlined. The major portion of this paper deals with the possibility of this instrument being used as a device for the study and control of color in the paper industry using the Tristimulus Method of Colorimetry. It has been found that this instrument does not give as good a result as other instruments that are being used today for this type of work. Though the Densichron can not be used in the study and analysis of color, it could be used for mill control work with papers white, near white and light pastels provided standardization of the instrument is watched and checked at certain intervals. With refinements by the manufacturer this instrument can find a place in the paper industry for Brightness testing, reflectance testing and opacity testing as well as color analyzing testing and study.

Introduction

In the paper industry today, there is a great need for an inexpensive, yet sufficiently accurate and precise reflection meter for mill control of brightness. In the past, results could be obtained but only by means that circumvented well-established means and procedures. These circumventions incorporated the use of improper filters, for corrections, non standard geometrics of illumination and of viewing specimens.

Another need in the paper industry is a like instrument that can be incorporated to check the opacity of paper during the manufacturing process for control purposes. A study of opacity in paper testing reveals that the contrast ratio method, TAPPI opacity #T425-m-44 has long been advocated for the measurement of the opacity of paper. (1) Research in this field has shown that the use of light transmission for the purpose of measuring opacity is objectionable, for transmittance measurements have little fundamental meaning. (2) However, there is one slight advantage on the use of light transmission; it is limited but of importance when utilized properly. If one correlates the readings of transmission to the readings of contrast ratio for a particular grade of paper in production and makes frequent checks against a standard opacimeter for corrections or adjustment of transmission limits, a quick and simple means of mill control of opacity of the paper can be established using light transmission values as an indicator. In view of these facts, the paper industry is constantly in search of an instrument that will fit the above needs. Thus with the foregoing thoughts in mind, the author interested himself in the investigation as to the possibilities and limitations of the Densichron as a possible piece of apparatus for research and for mill control work in the Paper Industry. This investigation was instigated by the following manufacturer's claim.

"The Densichron", in the words of the manufacturer, "is a simple devise to operate and its excellent design as a basic unit makes it a universal instrument in the hands of the photographer, engraver, coloranalyst or other specialists" (3). The question is asked, can this piece of equipment be utilized by the paper research chemist for research or by quality control in the paper mill? A review of existing literature points to the possibility of this instrument being used in both of these fields with certain limitations or corrections.

General Factors Influencing Reflection and Opacity Meters

The general factors that can cause varience in readings taken by the Densichron and other Reflectance and/or opacity meters can be summed up in the following catagories:

Determinate Errors (4) are those errors that can be controled by the operator or observer.

1. Errors due to poor construction and/or calibration of the instrument.
2. Personal errors due to the observer's method and exactness.
3. Errors of method, such as quality of sample, sampling, and prevailing experimental conditions.

Indeterminate Errors (4) are those errors that are accidental, such as deviations, not being controlable. The best representative value is taken as the arithmetical mean of the different values.

E = accidental error of the arithmetical mean
$\Sigma|d|$ = sum off all deviations regardless of sign
n = total number of observations

Formula: $$E = \pm \frac{\Sigma |d|}{n n^{\frac{1}{2}}}$$

<u>Spectral Errors</u> (4) are those errors that are constant, reoccuring for every sample of the same brightness. Causes are listed below.

1. Operating voltage compared to rate voltage changes with length of service of the lamp.
2. Filter should have the same transmittance effect on wave length; transmission should vary keeping the magnitude of the wave length band passed by each filter as narrow as possible, if this is not true spectral error will result.
3. If wave lengths greater than 700mu effect the phototube spectral errors will result. A correction filter will over come and correct this error.
4. Any variation in wave length of the light being used that is detected by the sensitive phototube will result in spectral error.

<u>Constant error</u> (4) is corrected for by constructing a correction curve which will give the amount to be added or subtracted from the scale readings to give accurate relative values for apparent reflection or opacity. This error can stem from incorrect wave length detection of the phototube. The effective wave length for reflection in brightness tests has been determined to be approximately 475mu, which is located approximately in the center of the wave length spread for blue light. A cell so designed is little effected by infra-red light and keeps constant error to a minimum.

<u>Geometrical errors</u> (4) predominate to brightness and opacity meters are listed below:

1. Failure of the instrument to check accurate results due to inaccurate scales, instrument calibration and changes in the standard used.

2. Failure of the instrument to reproduce readings taken a short time before. This is due to failures in circuits, providing the instrument has had full time to warm-up,
3. Meter responses to movement of light past cracks and openings in the instrument itself due to light leakage.
4. Dirt on the optical parts usually causes erratic operation.
5. Changes in temperature in locality of instrument.

The Densichron

The Densichron is a new photo-electric instrument, designed primarily for densitometry, having such high sensitivity that it can be readily adapted to the measurement of reflectance. It is versatile and does not need a highly skilled technician for operation. Though being a very accurate light sensitive device, it embodies no cumbersome nor elaborate operating procedures. Once having been warmed up for use and zero set, it does not need to be constantly reset for zero position. Its sensitivity is much greater than that of the ordinary photo electric instrument. It ranks next to that of the Photomultiplier Tube, (the most sensitive of all photo electric tubes excepting the photo electric Geiger-Muller Tube) (5). The Densichron has a maximum sensitivity equal to approximately 0.1 microlumen when the meter scale is used. Light values in the order of $5x10^{-3}$ microlumens can be detected by connecting the amplifier output into an osscilloscope (3).

Measurements made with one Densichron of the flux emitted by a 0.12 W Lamp, filament temperature about 1950K, gave threshold sensitivity values of $4.5x10^{-9}$ lumen for the blue sensitive probe and $3.3x10^{-9}$ lumen for the red-sensitive unit. The lowest flux values measurable on the meter scale (meter reading 4.5) were $1.04x10^{-7}$ lumen for the blue-sensitive probe and

0.51×10^{-7} lumen for the red-sensitive cell unit. The sensitivity is approximately the same for each unit. The only variation is due to phototube sensitivity (3).

The Densichron embodies a new principle in light-measuring devices in conjunction with an A.C. amplifier. The chief problem associated with photo emissive cells as radiation detectors centers about the amplification of the D.C. space currents which flow between the electrodes of the cell. The manufacturer calls this new device the Magnephot System (patent number 2424933). The principle of this system centers upon a new approach to the problem of amplifying very small photo-electric currents. The first step in this new approach utilizes well known laws of physics governing the action of electrons in magnetic fields. Basically the Magnephot System can be described as follows: a given amount of light strikes part of the cathode of the tube releasing a proportionate number of electrons. This stream of electrons flows at a steady rate to the anode, providing the light source is constant. In order to amplify this flow of electrons, in an A.C. type of amplifier, it is necessary that this current flow be converted into alternating or pulsating currents. The manufacturer accomplishes this conversion by placing the phototube in a magnetic field applied transversely across the path of the photo electrons. This field is produced by a 60 cycle, 120 volt alternating current. As the magnetic field strength reaches a maximum, the electron flow within the phototube is diminished proportionately until the point of maximum magnetic field strength is reached at which time the electron flow from cathode to anode is brought to a very bare minimum or cut off. When the field strength declines the electron flow is again permitted. The flow of electrons is thus inversley proportional to the alternating magnetic field. This alternating current output from the phototube permits the use of an A.C. amplifier of extremely high gain.

Since the converted A.C. potentials have twice the frequency of the current in the magnetic deflecting circuit, they can be easily isolated from the stray voltages emitted from the excitation coils. Leakage currents found in other types of phototubes are not effected by the magnetic field and therefore are not subjected to modulation. This method affords complete separation of the actual photo currents from all leakage currents in the input circuit without the use of A.C. light sources or light chopping mechanism (6). This permits a high amplification of photo current variation where the accuracy is only limited by thermal agitation with the circuits incorporated. The use of the A.C. amplifier avoids instabilities usually found in D.C. amplifiers, for example, changes in tube characteristics, such as cathode emission, and even changes in ambient temperature. Another disadvantage corrected by the use of A.C. amplifiers is that of high voltages with the ensuing high voltage power packs necessary. This allows the use of the Densichron throughout the mill for it is easily carried around from place to place.

Physical Description of the Densichron

The Universal Magnephot Densichron apparatus consists of the following units:

No. 2150 Densichron
No. 2150D Transmission Unit
No. 2150A Reflection Unit
No. 2150B,C,or V Probe Housing Unit

Piece No. 1842 Small Spot Refection Light Source
Piece No. 1847 Gray Scale Holder
Piece No. 1782 Cone

Accessories are also furnished for the calibration of the Densichron, they are:

Piece No. 1859 Eighth Standard Gray Scales Chips with Calibration Chart
Piece No. Photographic Step-tablet

Other accessories furnished by the manufacturer that are necessary for laboratory and mill work include:

No. 2150K Small Spot Reflection Tube
No. 2150M Voltage Regulator Transformer
No. 2150G Voltage Regulator Transformer for unstable power lines

Piece No. 1813 Linear Scale Meter

Other accessories may be obtained from the manufacturer to fit special needs. These include a Scale Expander for enlargening scale readings, an Auxiliary Meter which has a larger scale than that furnished with the standard equipment, and color standards with basic colorimetric specifications in terms of ICI standard observer and coordinate system.

Specifications and full details regarding the use of recorders with the Densichron can be obtained by consulting the Engineering Department of the W. M. Welch Manufacturing Company manufacturers of the Densichron.

The Densichron Unit contains a five stage tuning and amplification circuit. This circuit has been tuned at the factory and is not to be adjusted except by factory trained men. However, old tubes may be replaced by the operator. If the Densichron fails to operate correctly after new tubes have been inserted it is recommended by the manufacturer that the unit be returned to the factory for adjustment. Instructions for the replacement of the tubes can be found in the literature furnished by the manufacturer.

The Densichron also houses a D'Arsonval type (0-1) milliameter laid off in logarithmic increments. This meter is used in densitometric evaluations because the photo current is translated directly into density values within the instrument itself. Its values are read as the log of the reciprocal of the current $D = \log_{10} 1/i$ A jack located in the back of the Densichron is provided as a source of signals for the operation of the linear scale meter in transmission evaluation and in reflection study. This auxilairy meter is also of the D'Arsonval movement type of meter. It is calibrated in the top portion in percent transmission. Optical density is plotted against percent transmission on the lower portion of the scale. The Controls for the amplification and the volume are located on the front of the Densichron and are marked "RANGE" and "VOLUME" respectively. The range switch divides the total amplification into four steps, o, 1, 2 and 3, which are the logarithms of 1, 10, 100, and 1000. The Volume control has a gain factor of approximately 10. This control is used for meter settings required in most operations. In the back of the Densichron is located the adjustment resistor for setting the meter to minimum deflection when putting the Densichron into operation.

The Densichron Transmission Unit, together with the No. 2150 Densichron, is a complete transmission Densitometer. The measurement of transmission densities with this unit reads ASA diffuse transmission density according to the ASA standard Z38.2.5-1946 on the Densichron meter scale (3). This unit houses a constant voltage transformer, a focusing mechanism for focusing the lamp on various aperture sizes, a lamp rheostat, and three filters that can be changed from the outside of the housing. It also has, at the rear of the housing, an outlet for 6.3 volts with which to operate the No.2150A reflection head for the Densichron. An extension arm with a clamp bracket which is used for holding the Probe Housing Unit No. 2150B, C, or V, is attached to the transmission unit.

The Probe Housing Unit is made of aluminum, anodized: blue to indicate a blue S-4 phototube, red for the S-1 red sensitive phototube and black denotes the ultra-violet sensitive phototube.

The No. 2150A Reflection Unit consists of an aluminum casting containing a light source, Filter wheel, and a coupling tube. This unit is not provided with a power source. Power may be obtained from the No. 2150D transmission unit or a No. 2150M voltage regulator. The filters supplied with this unit are the Wratten A, B, 16, and 38A. These filters can be easily removed and replaced. This unit used in conjunction with unit No.2150 Densichron, unit No. 2150D transmission unit (for power), unit No. 2150B, C, or V Probe housing unit, Piece No. 1782 Cone, and Piece No. 1842 Small Spot Reflection Light Source is used for the studing of reflection density.

The Densichron is relatively inexpensive, yet very sensitive and precise as well as stable in its response. For these reasons the Densichron was picked by investigators as being suitable for study under the APPA program (5). This Program is part of the Instrumentation Studies series conducted by the APPA and published in the Magazine Tappi from time to time. These reports are published by the Institute of Paper Chemistry to its members and are classified as Instrumentation Reports.

The Densichron as a Reflection Meter in the Evaluation of Paper.

The Densichron instrument was primarily constructed for use in the Photographic Industry as a unit to be used in the study of photographic densitometry. In this field its application has been found to be of merit. However, recent studies made by the Paper Institute have found that its application as an instrument for the evaluation of paper in research work is very limited and that in the field of mill control the results will only be relative. Refinement of the instrument may lead to its use in this field in the future.

A study of this instrument by the Paper Institute has shown that this instrument has a linearity error in its response. Though this error is of no importance to the purpose for which the instrument was devised, it is large enough to make its use in the paper industry impractical. With special refinements, correction apparatus and correlation tables the Densichron can be used for the relative measurement of reflectance. The manufacturer of this piece of equipment is working to improve the response and do away with this linearity error.

The Paper Institute has found that the instrumental response of the effective wave length, using a Wratten 49 filter, is not the proper value for brightness determination. However, this can be corrected through the porpure use of a suitable corrective filter. With this correction and with the incorporation of corrections for nonlinearity, proper values for brightness can be obtained. This procedure is not recommended for mill application as it is impractical. With these corrective measures utilized the Densichron correctly indicates the variability of brightness of paper, with a standard deviation essentially the same as that calculated from data on standard brightness (5).

Preferred Methods for Checking Linearity and Other Deviations (5)

Checking the linearity of the Densichron incorporates the use of the General Electric Reflection Meter that is in calibration with the master meter at the Paper Institute. General Instructions follow:

1. This method is based on the use of the variable sector photometer of the GERM*.
2. The Densichron Probe is fixed in the position of the "active" PJ-22 phototube of the GERM.
3. A 9/32 inch black paper aperture is fitted on the probe of the Densichron.
4. The exit aperture of the GERM is covered with a flashed glass, flashed side placed next to the bottom side of exit aperture. This gives a better difusion.

* GERM, General Electric Reflection Meter

5. The sample aperture of the GERM is covered with a block of freshly prepared $MgCO_3$.
6. A steady illumination is furnished by operating a lamp with a suitable voltage regulator.
7. The photometer dial of the GERM is set at 100. The Densichron is set at 100 divisions on the linear meter (full scale).
8. By changing the dial of the GERM the meter of the Densichron should read the same if linear.
9. The light intensity was varied by means of screens and apertures in the incident light beam of the GERM to obtain ten different response settings.
10. Ten readings are taken from each range of the Densichron and for each dial setting, 2, 4, 6, 8, and 10.

The readings obtained by the above methods were found to be badly non-linear (relative to the level of accuracy required in colorimetric work and in brightness determination), for the Densichron. These errors varied from 10 percent at the center of the range to 20 percent at the 1 lower levels of the GERM dial setting range.

Checking the deviation of linearity due to aperture sizes is tested by the following methods (5):

1. The standard screen transmission was calculated and tested at 42.5%.
2. An Institute of Paper Chemistry Transparency meter was used for a steady nearly parallel beam of light.
3. The beam was directed into an integrating cube through a circular port.
4. The probe of the Densichron was placed on the port of the cube at right angles to the beam of light and at right angles to a Western Blocking Layer Photocell (type 3, color code yellow, red).

5. The Western Photocell was calibrated as being linear and the results of the tests were compared using the readings of the Densichron in comparison to the standard readings of the Weston Photocell.

This test showed that there was a definite deviation due to changes in the size of the aperture and also to deviations due to response settings of the instrument. The results of this test were reproducible. Another Densichron was incorporated in this test and the results were similar but numerically different in behavior.

Other Deviations were encountered while the Densichron was under study among these were those accentuated by fluctuations in the line frequency by faculty assembly by the manufacturer, and deviations caused by the use of the phototube S-4 in the Densichron.

Deviations due to line frequency fluctuations are corrected by changing certain components in the electronic circuits of the Densichron, if it is found that response-frequency curve maximum for the Densichron under consideration is not within the 60 to 60.1 cycles per second wave length band. The Densichron should be operated on lines of accurately controlled frequency, with particular regard to the absence of sudden changes in frequency (1). Deviations that are brought into being by assembly are hard to find and are very seldom encountered. Check over the apparatus carefully for any apparent mistakes in assembly. If it is reasoned that something is wrong it is best to consult the manufacturer before one tries to remedy the cause. Deviations caused by the use of the Phototube S-4 have to be corrected for by use of a correction filter which can only be made after the amount of spectral response difference there exists between it and the Phototube PJ-22 used in the General Electric Reflection Meter. This is accomplished by using the same arrangement as was used in checking the linearity of the Densichron. The effective wave length was determined by the regular APPA method (7), and TAPPI Standards T 452m-48 and T 217m-48. The Densichron was used as a null detector thus eliminating errors of nonlinearity. Null methods are characterized by the fact that the two photocurrents due to the light from the sample and the standard are equal. Null Balance methods provide compensation for any fluctuations of intensity of the light source (8). The Institute has found that though line voltage changes to the lamp will change the wave length these changes may or may not effect the wave length in such a manner as to correct or compensate for the linearity error of the Densichron. The Best method is to make a liquid filter using an aqueous solution of Auramine and Cobalt Sulphate. This Filter is adjusted by trial and error.

The manufacturer has found that some causes of linearity deviation could be helped through certain changes in the electronic circuit. Replacing Capacitor C_{12}, and replacement of the 6SN7 tubes will sometimes help. Also it has been found that changing the leads to the magnet will sometimes aid correction of deviation. This changes the phase of the magnetic field and any induced electrical currents by 180 degrees.

The Densichron as an Opacity Meter in the Evaluation of Paper

Recent work with Densichron in the field of opacity evaluation of paper points to the use of the Densichron as a transmission indicator and not as an opacity meter. A recent study was made by the APPA for their Instrumentation Program evaluating the Densichron for opacity study indicates that this instrument can be used with certain limitations by the paper industry for mill control work but not for research projects.

For accurate opacity measurements the instrument employed has to have a spectral response to the blue portion of the spectrum approximately the same as that in the Bausch and Lomb opacimeter. Unfortunately the spectral response of the Densichron studied was relatively too great in the blue portion of the spectrum to be most effective in the measurement of opacity. Correction of the effective wave length would help but in itself this change would not solve all the problems one faces in using this instrument in this field of work.

Studies made using the Densichron as a piece of apparatus for mill control of opacity centers around its being used as an indicator of transmission of light. A comparison of the results of opacity readings, determined with a standardized Bausch and Lomb opacimeter utilizing the contrast ratio method prescribed by TAPPI, with those reading of transmission taken of the same samples by the Densichron it was found that a correlation did exist. This correlation, however, only holds true for tests made on one specific type of paper. In plotting the results of many tests it was found that correlations were not the same thus showing there could be no general correlation that would cover all types of paper. Furthermore, there was no assurance that a general correlation taken today would be accurate after a passage of a number of days, even though the paper did not change in any way.

In accordance with TAPPI Standard T 425m-44 the investigators, which studied the Densichron as an instrument for evaluation of opacity, found that this instrument is not, in its present state of development, ready for use in the industry. For this reason consumers and manufacturers of papers are urged not to incorporate in commercial specifications opacity limits in terms of transmission 1/T (1).

Conclusions on the Densichron as an Instrument for the Evaluation of Paper

As a Reflectance Meter the Densichron may be used to measure papermaker's brightness if the following precautions are taken:

1. The specific calibration method is employed and used for corrections in readings obtained.
2. If suitable filters are used to correct the spectral error, these filters should correct the effective wave length to 457mu.
3. Have fixed optimum aperture size.
4. Set the instrumental response controls at fixed, optimum vales.
5. Make sure that the line frequency is steady at 60 cycles per second and that line voltage is fairly constant.
6. Make comparative checks from time to time of readings taken from the Densichron with those taken by the GERM using the same sample under the same conditions.

It is hoped that the manufacturer will make the necessary improvements needed for correcting the linearity error and the spectral error found in the Densichron at the present time. Its low cost, great sensitivity and versatility of application are of prime importance for application in the paper industry (5).

As an Opacity Meter the Densichron may be used to measure opacity of paper by interpretation of the measurement of transmission 1/T.

1. If it is used with frequently checked correlations with the Bausch and Lomb opacimeter.
2. If the Densichron is corrected for an effective wave length near the vicinity of 560mu.
3. Providing the same precautions are taken in regards to the frequency, controls and voltage as mentioned before when

the values of the Densichron as a reflection meter were discussed.

Summary

The Densichron may be the answer to the paper industry for an inexpensive instrument for use in the mill for mill control, and to the research paper chemist for research studies if the manufacturer can correct the faults now prevalent to the Densichron. However, regardless of these present disadvantages the Densichron can be used to a limited extent for mill control. Its advantages, as to speed in obtaining readings and its lack of lenses and other optical parts causing the price to rise, the Densichron has certain advantages over other gear used in the industry.

The End

Addendum

The literature survey has shown the possibilities of the Densichron as an instrument for testing the opacity of paper and for the measurement of reflectance and brightness of paper. With these evaluations of the Densichron already made the author decided to turn his attention to another field in evaluating the Densichron. This field of endeavor was in Colorimetry.

Could the Densichron be used, in its present state, for analyzing the color of paper? It has been mentioned before (Page 2) that this instrument could be used by the coloranalyst. It has also been stated in this paper (Pages 8 and 9) that the Densichron also contains a filter system with Wrathen filters A, B, 16 and 38A. With all these facts considered, it was decided that the research problem be directed towards color analyzing making use of the Photoelectric Tristimulus Colorimetry method incorporating three filters. This new research problem, it was felt by the author, offered a better challenge and was more practical than just trying to substantiate work already performed by others.

Photoelectric Tristimulus Colorimetry is a method of color analyzing using three source-filter-photocell combinations of such spectral character that they duplicate the standard I C I observer for colorimetry (9). This is in reality the use of an artificial eye for color measurement. Its distinguishing feature is the approximate spectral equivalence of the current source-filter-photocell combinations of the apparatus and the tristimulus specifications of the spectrum which characterize the color vision of the average normal observer (9).

Many instruments are on the market today that can be used for "Tristimulus Colorimetry" or for "Photoelectric Colorimetry". Among these are notably the G.E. Reflection Meter, the Photo-Volt, and the Hunter Universal Reflection Meter.

Recent research in the field of photoelectric tristimulus colorimetry carried on by R. S. Hunter, J. A. Van den Akker, A. C. Hardy and others along with studies made by the Institute of Paper Chemistry has shown that the above mentioned instruments give good results in color analyzing using the tristimulus method. However, it should be kept in mind that the measurements of each instrument may differ to some degree. These variations may be minimized by use of correction tables, filters and by incorporating different light sources. The results of such corrective measures should be computed into trichromatic coefficients using known standards as the test samples.

These values thus computed should be correlated with the trichromatic coefficients obtained from the Spectrophotometric readings of the same standard samples. If such correlations do not vary more than .032*, the corrective apparatus can be incorporated for all practical purposes. Porcelain enameled standards are usually obtainable from the manufacturer for tristimulus work, however, if such standards do not exist provisions such as setting up new standards or using known standards of similar apparatus will have to be made.

Every Photoelectric tristimulus method is subject to error because of the spectral inaccuracy inherent in the source-filter-photocell combinations

* computed from (xy) diagram, figure 2, U.S.Department of Commerce, Bureau of Standards, Circular C-429, "Photoelectric Tristimulus Colorimetry".

(9). For this reason when using any photoelectric tristimulus method for color matching it is best to set up standards as close as possible spectrally, to the samples being measured. A procedure for this operation can be found in Circular C-429 put out by the U.S. Department of Commerce, National Bureau of Standards entitled "Photoelectric Tristimulus Colorimetry With Three Filters".

The author's problem does not concern color matching of samples to known standards. It deals with the evaluation of the Densichron in comparison with two other photoelectric devices which are known to be spectrally responsive to color analysis by the method being discussed. Therefore, the author has made numerous measurements on many color samples on the following equipment in order to compare the computed results.

The conclusions derived from these measurements will be stated later in this paper.

Photoelectric instruments used:

Hunter Multi-purpose Reflectometer

Photovolt Reflection Meter

Universal Magnephot Densichron

G. E. Recording Spectrophotometer

The first two instruments were chosen because of their accessibility in our laboratory as the checking or standard instruments with which to check the operation of the Densichron. The G. E. Spectrophotometer was incorporated into the project as being the absolute standard for all three instrument measurements.

With these two standards and the absolute standard as reference points the author intends to find out if the Densichron can be used as it is today as a tristimulus colorimetric device. This is based upon the following statement by Dr. P. J. Bouma: "The same law applies to color measurements as to brightness measurements, i.e., a method is correct when its results correspond with values arising from the standardized equipment." (10).

PART TWO

Laboratry, expirementation

Laboratory Work

Although there are hundreds of articles written upon the field of tristimulus colorimetry, the author has read several comprehensive literary reviews covering the subject. Due to the change of interest and the challenge of a new approach at such a late date, the author read reviews of work performed by others and consulted a few original papers for his background material. With the knowledge gained from reviewing material available the author set up the following program.

Step I. Familiarization with the operation of the Densichron, Hunter Multipurpose Reflectometer and the Photovolt Reflection Meter.

II. Take tristimulus readings with each instrument thus setting up a procedure to be followed when taking actual test measurements.

III. Obtaining color samples with which to make the test measurement.

IV. Selecting and determining the number of test samples to use and the number of measurements to be taken for correct interpretation of the results.

V. Obtaining Spectrophotometric graphs and computations of same into tristimulus x & y values for each color sample.

VI. Computations of the A, G, & B values obtained from the photoelectric instruments into tristimulus values of x & y.

VII. Graphical analysis of the x & y values.

VIII. Summary.

IX. Conclusions

In order to be able to take the necessary measurements in as short a time as possible, so that conditions would be the same for all tests, the author had to be familiar with each of the three instruments used in this problem. Several days were spent in testing samples on each of the three instruments, the Hunter, the Photo-volt, and Densichron. These test samples were obtained in the paper laboratory of Western Michigan College. From these test runs knowledge was gained as to the best procedure to use, the size of sample to be used, the number of tests to take per sample and the types and color of the samples to use for reliable and valid results. Previous work done by other researchers has shown that results of measurements taken on dark colors were subject to many errors not found in the lighter hues. Previous research by others has also shown that results are also dependent upon the type of finish present on the sample (11). The work carried on in this project has substantiated these previous findings.

With this in mind the author selected for this project twelve colors (samples of which are included in this paper) ranging from whites through pastel shades into medium hues of blue, yellow and red.

These colors were selected from many samples submitted by the Hawthorne Paper Company located in Kalamazoo.

Sample 1

Sample 2

Sample 3

Sample 4

Sample 5

Sample 6

Sample 7

Sample 8

Sample 9

Sample 10

Sample 11

Sample 12

It was then decided by the author to take ten measurements of each sample selected and obtain the mean for a representative figure for the sample. These ten samples of each color were taken from ten different sample sheets chosen from stock available. These ten samples were cut into 4 x 4 inch sheets and were then made into a pad thus making backing material unnecessary. The sample was then tested in the exact center with the felt side being the test side.

With the type of sampling and the types and color paper chosen the author proceded to take the measurements necessary for the evaluation of the Universal Magnephot Densichron. Ten readings were taken on each sample using a green, then blue and then an amber filter with each of the three photoelectric source-filter-photocell devices available in the laboratory. This meant that 1080 measurements were used for computations leading to conclusions to be discussed later.

As a further check point the author, through the courtesy of the Hammermill Bond Paper Company and Hercules Powder Company, obtained spectrophotometric graphs and computations of these graphs into x & y tristimulus functions of all the colors being used for this project.

There are several methods of computing the measurements taken with the amber, green and blue filters. (These readings will be hereafter referred to as A, G, and B). The author elected to use the method which converts the A, G, and B values into the coordinated x, y & Y of the I C I standard system for his computing and evaluating work. This method is fast and gives reliable results with minimum error (9). The formulas used for computations are listed below.

$$X \doteq 0.80A + 0.18B$$

$$Y \doteq 1.00G$$

$$Z \doteq 1.18B$$

These equations have been checked and established by Richard S. Hunter to be suitably accurate for many purposes (9). The Y value gives directly the approximate value for the luminous apparent reflectance. This value, as can be seen above, is given directly from the green filter measurement.

To indicate chromaticity in the I C I system, the trilinear cordinates of a color are computed as follows:

$$x \equiv X/\ (X + Y + Z)$$

$$y \equiv Y/\ (X + Y + Z)$$

The x and y coordinates can then be plotted on an I C I (x,y) -diagram, see figure (1). Table 1, shows the mean values of all the measurements taken while Table 2 shows the computed values (the x & y coordinates) of all three instrumental readings. Figure 2, shows the plotting of all the x and y coordinates. The point $x = 0.3101$ and $y = 0.3168$ represents a freshly prepared magnesium-oxide surface. From the relationship of the (x-y) points for each test instrument on each color being tested the results of the author's problem rested. If the Densichron's trilinear coordinates placed within tolerable limits to the points of the trilinear coordinates for the checking and standard instruments the worth of the Densichron could be established.

TABLE 1. The mean values for the twelve samples as measured using the Amber, Green, and Blue filters on the Hunter Multipurpose Refection Meter, the Photovolt Reflection Meter and the Universal Magnephot Densichron.

Sample	Green	Amber	Blue	
1.	89.28	90.66	82.47	
2.	83.46	85.28	76.30	
3.	81.42	87.11	57.97	
4.	72.34	71.38	60.99	
5.	84.51	89.96	41.01	
6.	55.97	71.16	13.27	Hunter
7.	29.72	22.81	50.85	
8.	30.50	46.17	20.21	
9.	52.77	46.58	44.87	
10.	58.56	52.07	67.07	
11.	60.87	72.81	32.16	
12.	66.14	77.51	62.17	
1.	86.95	87.25	80.35	
2.	81.25	84.00	75.20	
3.	79.00	83.55	57.80	
4.	72.30	71.60	60.25	
5.	81.15	86.70	41.55	
6.	57.65	72.20	13.70	Photovolt
7.	33.55	23.95	51.75	
8.	32.05	50.20	20.55	
9.	56.35	48.15	46.85	
10.	61.80	54.90	67.85	
11.	60.80	73.00	32.60	
12.	66.90	77.65	61.40	
1.	90.80	89.75	84.85	
2.	84.15	84.95	80.35	
3.	76.80	85.60	60.20	
4.	73.55	74.60	64.50	
5.	82.14	88.60	45.50	
6.	45.30	64.15	16.15	Densichron
7.	37.25	27.70	52.95	
8.	16.65	34.95	21.10	
9.	61.85	54.50	48.25	
10.	68.00	57.20	70.05	
11.	49.55	67.40	34.05	
12.	56.95	67.85	63.40	

TABLE 2. The computed (x,y) coordinates derived from the mean values for the twelve samples as measured, using the filter systems of the Hunter Multipurpose Reflectometer, the Photovolt Reflection Meter and the Universal Magnephot Densichron.

Sample	x	y
1.	.319	.326
2.	.321	.327
3.	.349	.354
4.	.321	.340
5.	.373	.398
6.	.454	.427
7.	.234	.254
8.	.427	.321
9.	.300	.349
10.	.281	.306
11.	.367	.417
12.	.342	.311

Hunter

Sample	x	y
1.	.317	.326
2.	.322	.324
3.	.343	.351
4.	.325	.336
5.	.370	.379
6.	.414	.440
7.	.231	.272
8.	.438	.320
9.	.296	.349
10.	.284	.312
11.	.393	.372
12.	.344	.314

Photovolt

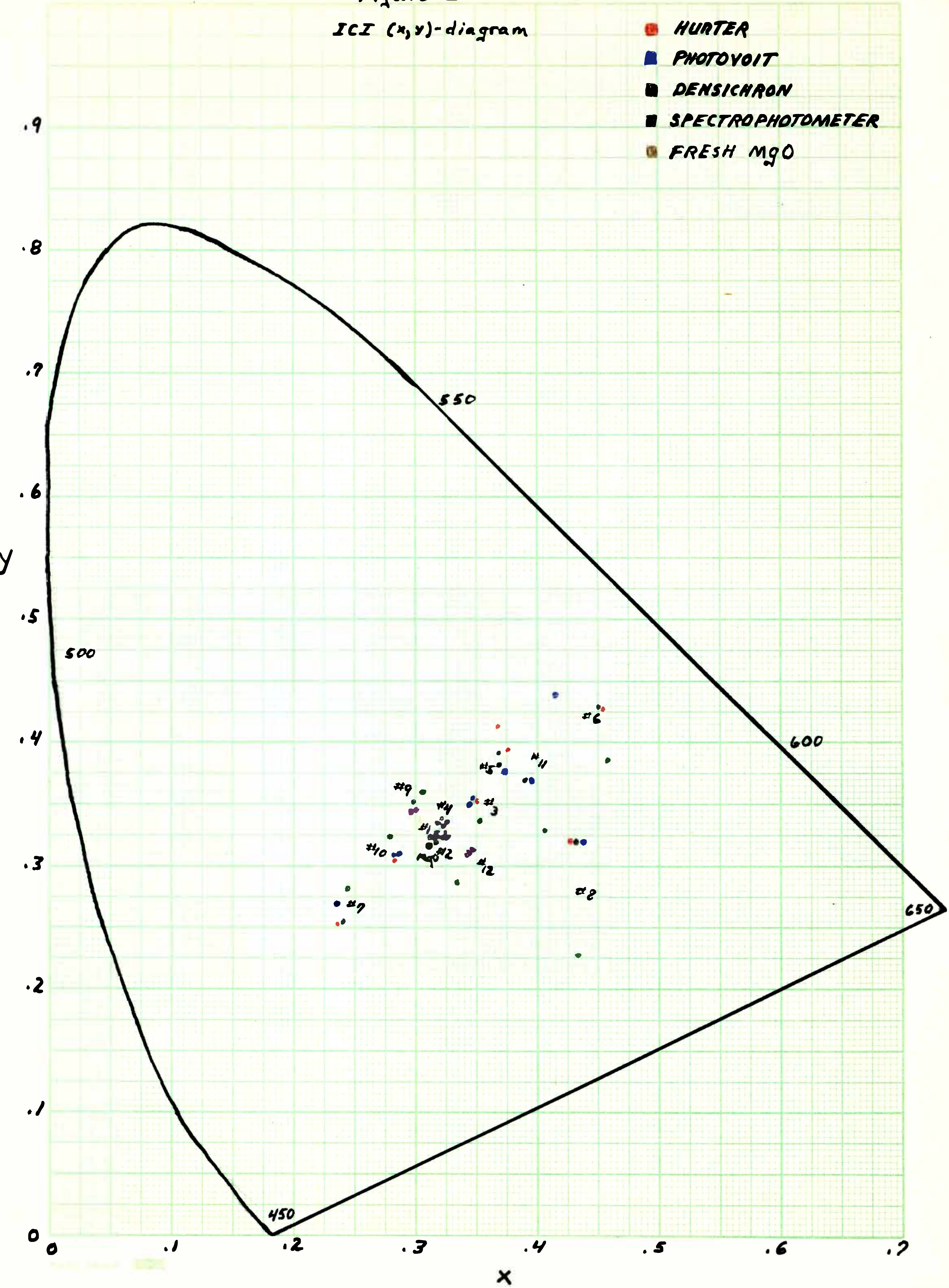
Sample	x	y
1.	.313	.327
2.	.315	.322
3.	.352	.338
4.	.323	.333
5.	.368	.382
6.	.457	.382
7.	.241	.284
8.	.433	.227
9.	.305	.361
10.	.279	.325
11.	.403	.331
12.	.333	.288

Densichron

Sample	x	y
1.	.3160	.3236
2.	.3185	.3258
3.	.3445	.3530
4.	.3190	.3398
5.	.3661	.3968
6.	.4473	.4283
7.	.2365	.2546
8.	.4290	.3213
9.	.2956	.3498
10.	.2814	.3066
11.	.3909	.3726
12.	.3418	.3115

Spectrophotometer

Figure 1


ICI (x,y)-diagram
HUNTER
PHOTOVOIT
DENSICHRON
SPECTROPHOTOMETER
FRESH MgO
.9
.8
.7
.6
y
.5
.4
.3
.2
.1
0
0
.1
.2
.3
.4
.5
.6
.7
x
550
500
600
650
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#2
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#10
#11
#12
MgO

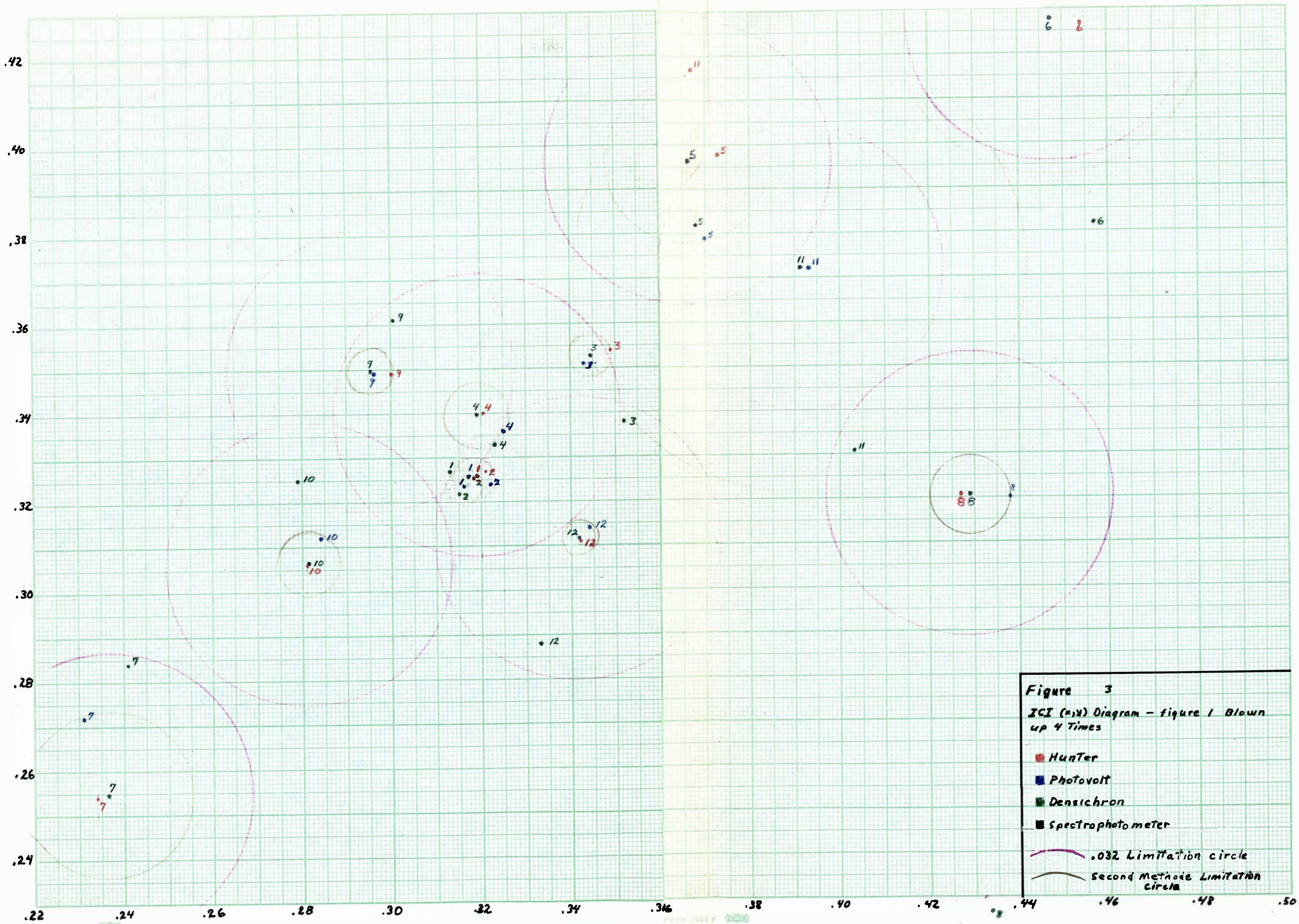

Figure 3

ICI (x,y) Diagram – figure 1 Blown up 4 Times

Graphical Analysis

Since no references could be obtained in the conduction of the new literary review concerning the correct procedure for analyzing the I C I (x, y)-diagram, the following procedures were devised by the author. Measurements were taken on an established I C I (x, y)-diagram (9) which showed the tolerable limits allowed in comparing the Hunter Reflectometer with the G.E. Spectrophotometer in color matching. See footnote page 7 . This value of limitation was approximated to be .032 units.

On ICI (x, y) -diagrams prepared from the computations made on all the measurements taken in the laboratory the author plotted in the (x,y) coordinates obtained by the G.E. Spectrophotometer. With the spectrophotometric (x,y) coordinates as the hub, circles having a radius of .032 units were made for each sample.

If the other (x,y) coordinate points for each sample, as derived from the measurements taken by the other instruments under test, fell within this circle those measurements could be taken as being valid and reliable and the instrument can be used for Tristimulus Colorimetry. If the computed points for any instrument fail to come within the circle less than 80 percent of the time that instrument would not be usable for Tristimulus Colorimetry. This type of graphical analysis was made on the measurements taken with the instruments under test.

Another method of analysis was devised by the author to further substantiate his conclusions. The basis for this type of analysis rests upon the knowledge that both the Photovolt Reflection Meter and the Multipurpose Reflectometer can be used for Tristimulus Colorimetry.

Again, with the (x,y) coordinates for the G.E. Spectrophotometer as the center point, circles were drawn in such a way as to include both of the (x,y) coordinates for the Photovolt and the Hunter Reflectometer. If the Densichron's (x,y) coordinate point falls within the circle for the same sample it would be deemed within limits. Graphs of these two methods of analysis are found in this paper, Figures 3 and 4 respectively.

From these graphs conclusions were drawn and shall be found at the end of this paper.

Summary

The Densichron can be used in the paper industry to a limited extent. Its best use would be in the field of mill control work for the taking of reflection measurements and for brightness testing if certain precautions are taken as outlined earlier in this paper.

This instrument is not readily adaptable to taking opacity measurements at the present time, however methods and procedures can be devised for mill control purposes.

In the field of Tristimulus Colorimetry the Densichron falls short of expectations. As will be seen in the conclusions the Densichron gives usable results in white and near white colormatching. It is possible that it could also be used for pastels and deeper shades if color standards are used that are near to the color being tested. More research has to be done along this line. However, the fact still exists that the Densichron has certain faults that have to be removed in order for it to take its place as an instrument for the testing of paper in any of the fields covered by this paper. It is true that these errors may be circumvented but this in itself makes the Densichron of lower value than other similar instruments being used today in the industry.

Conclusions

Definite conclusions as to the worth of the Densichron in the fields of Reflectance and Opacity may be found elsewhere in this paper, therefore the present section will be devoted to conclusions drawn from laboratory work.

From a study of the analyzing graphs incorporated as part of this report the following conclusions may be stated:

1. The Densichron may be used for Tristimulus Colorimetry if the samples being tested are white or near white in hue and chroma.
2. The Densichron may be used for Tristimulus Colorimetry for mill control purposes if the precautions stated earlier (under conclusions as a Reflection meter) are adhered to.
3. Tristimulus values A, G and B can be taken very quickly

without disturbing the sample due to the engineering of the filter wheel in the Reflection Head. This is a very good advantage over the Photovolt Reflection meter.

4. The computed readings of the Densichron follow the same trend as do other instrumental measurements. That is, clusters found in white or near white region of the ICI (x,y)-diagram spread out as the sample colors become darker in hue. This was taken into account when these conclusions were taken from the graphs.

5. No conclusions were reached as to the reproducibility of one Densichron's measurements with those of another but it is believed that the same fault would be present here as it is when using the Densichron as a Reflection meter, i.e., the results would not be the same.

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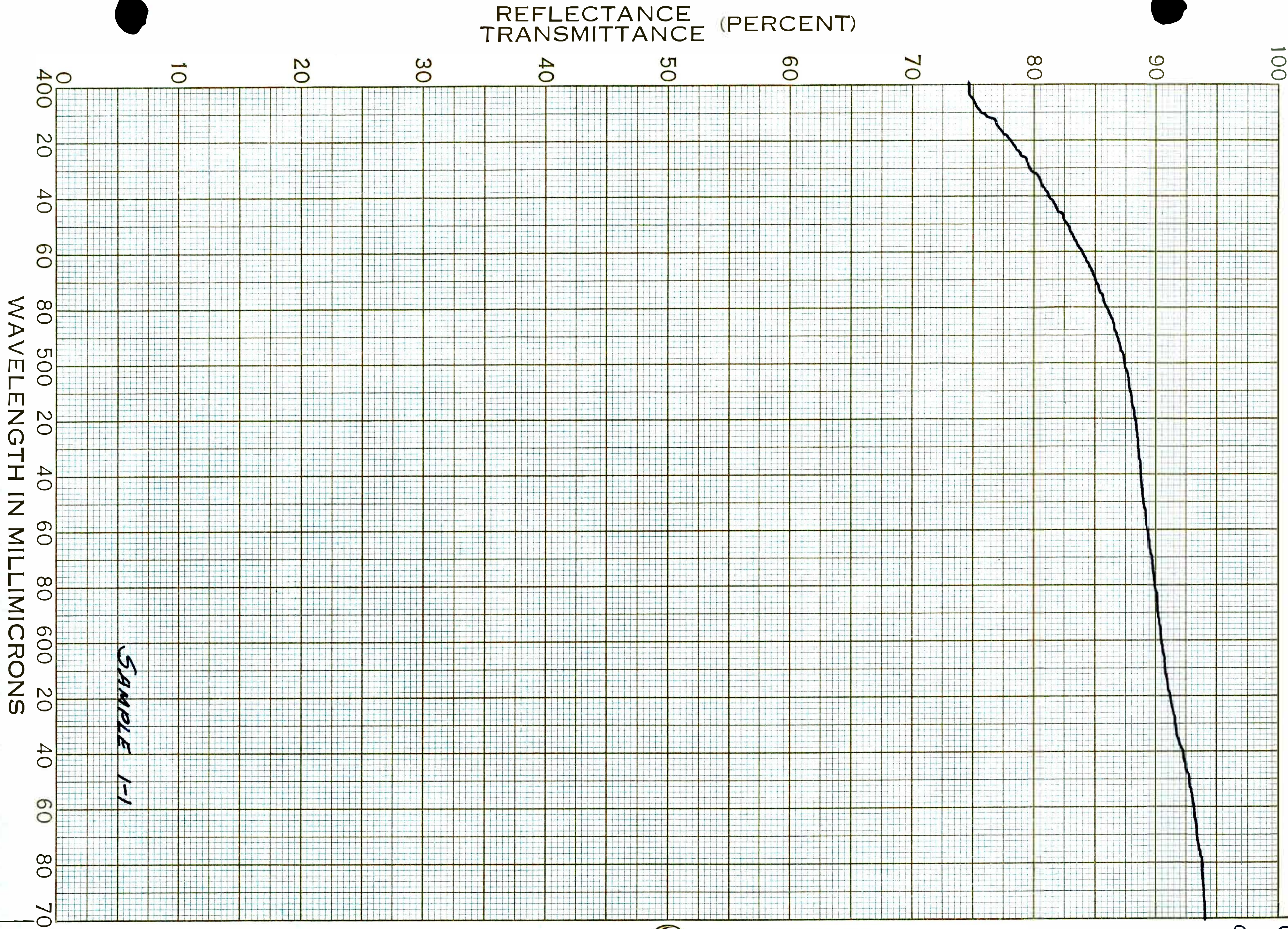

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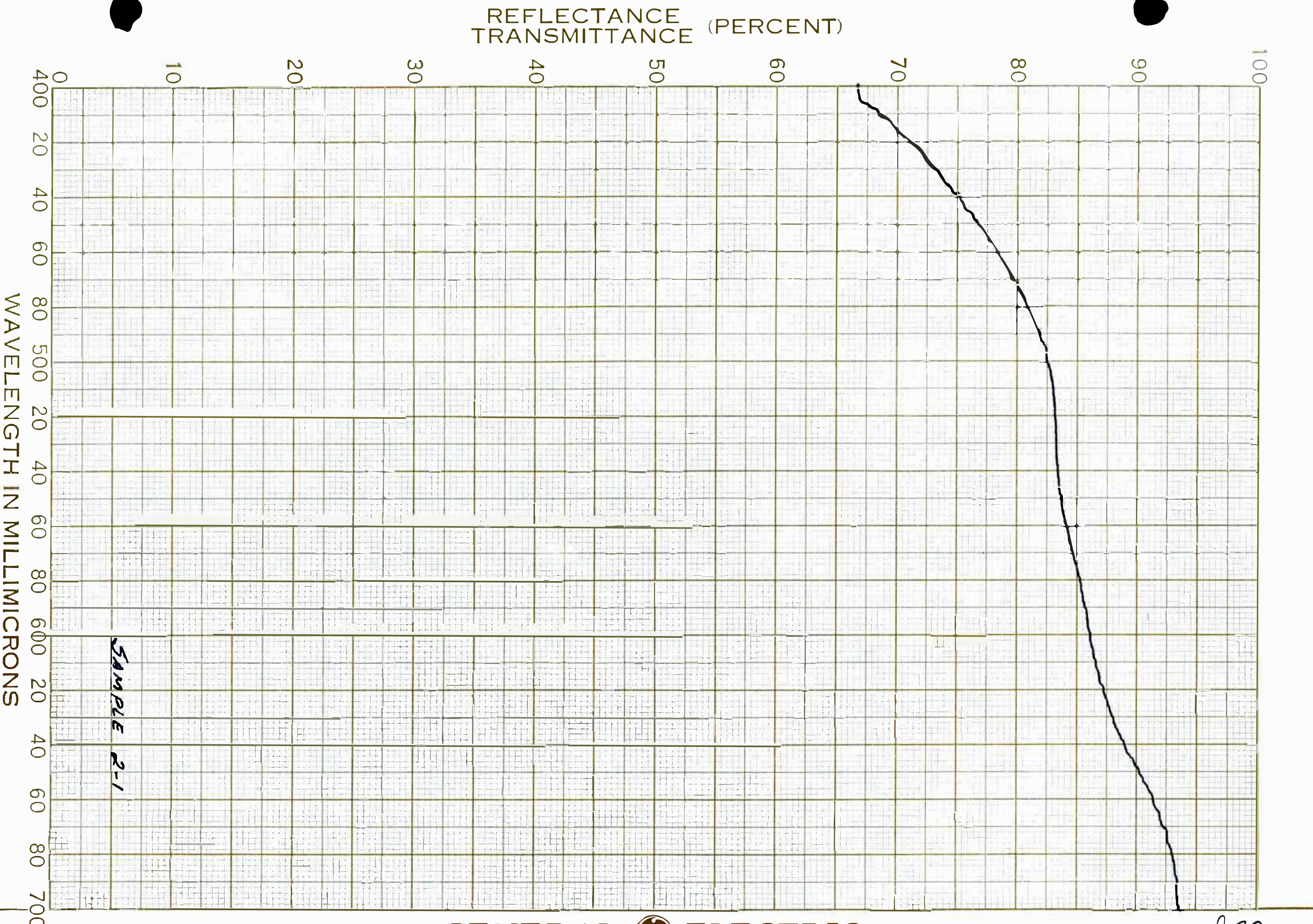
TEST NO. .... BY

DATE 4/21/52

N.P.62581



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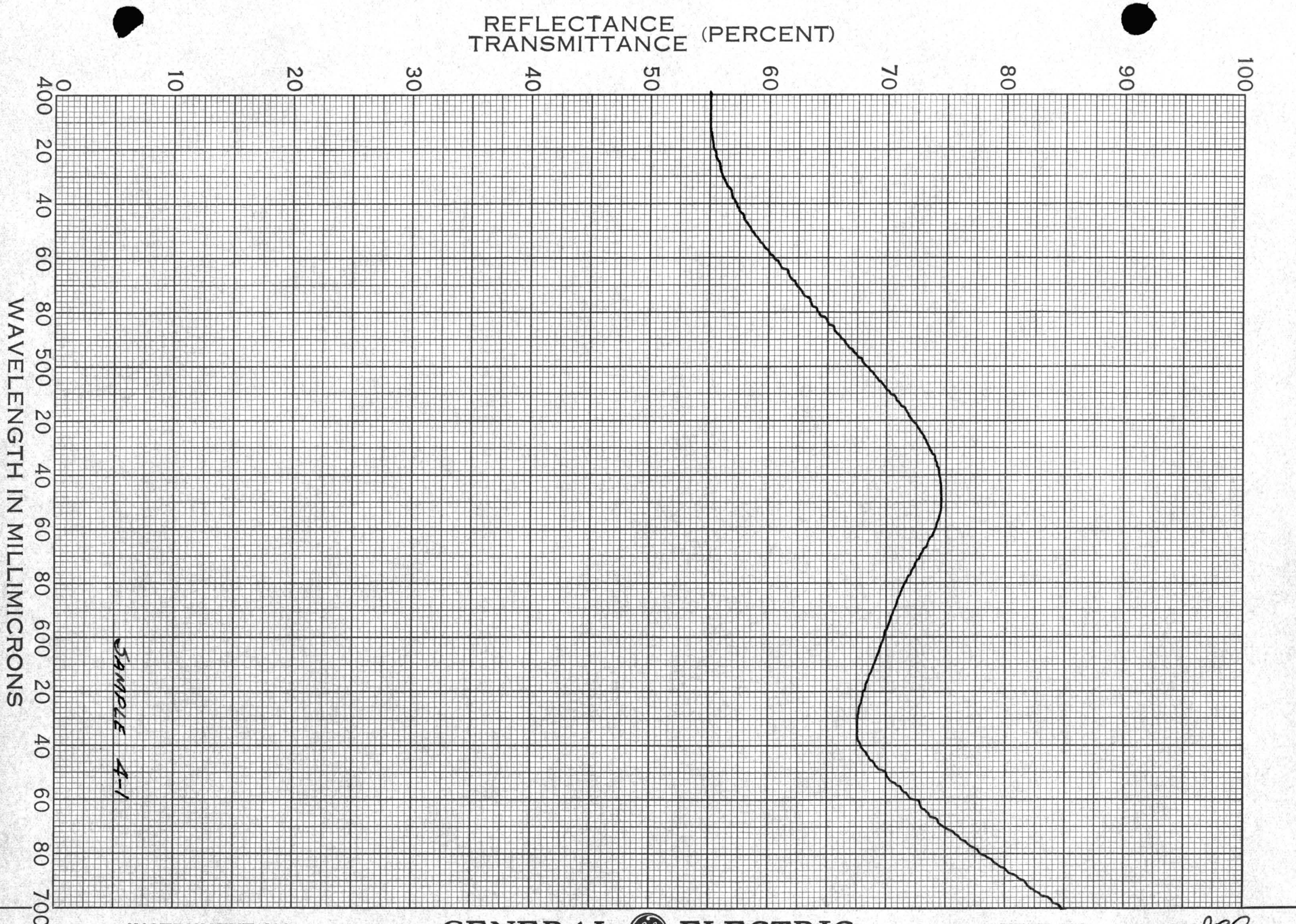

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DATE 4/21/52

N.P.62581

INSTRUMENT NO.

GENERAL ELECTRIC
RECORDING SPECTROPHOTOMETER

TEST NO. BY

DATE 4/21/52

N.P. 62581

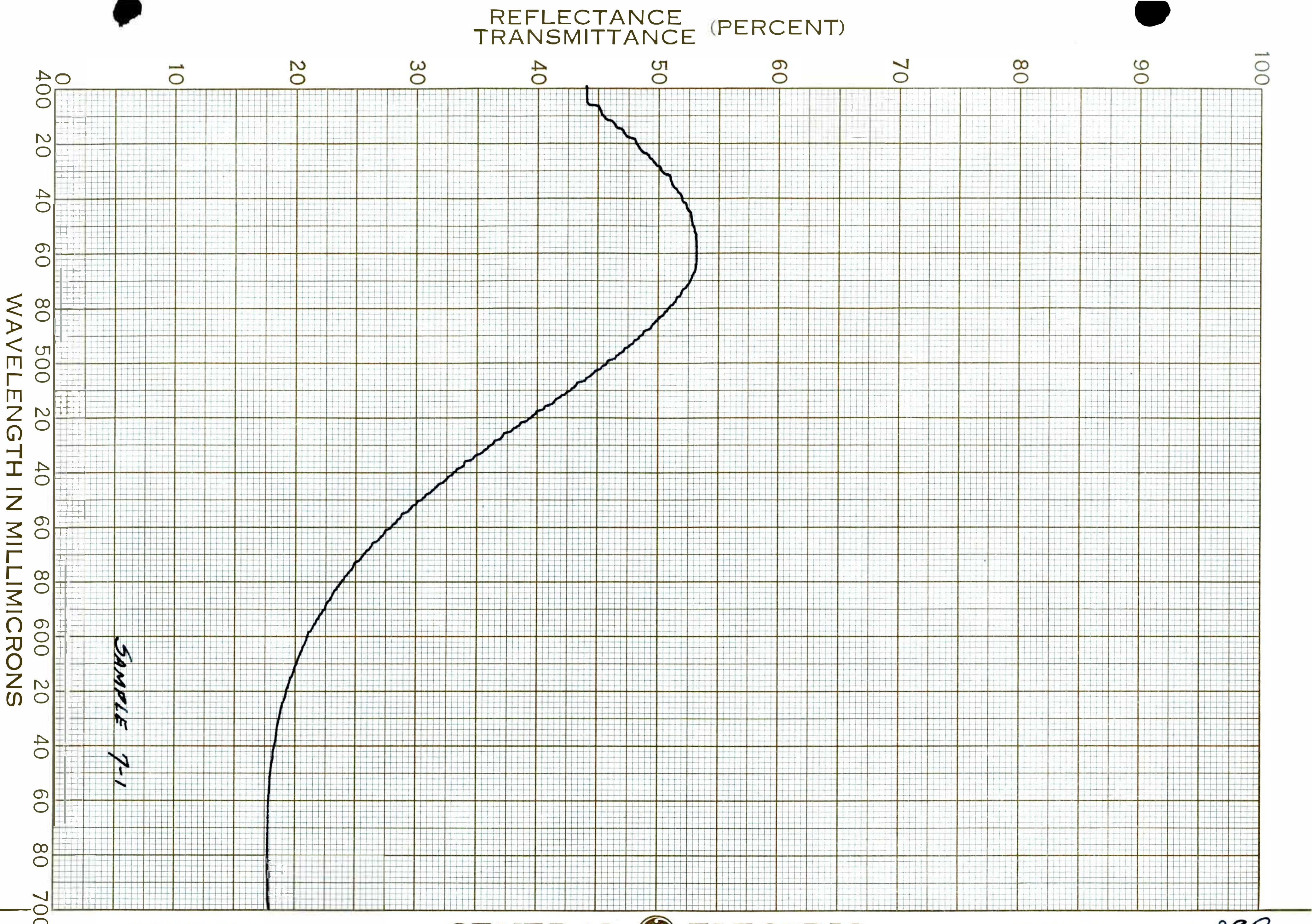
REFLECTANCE
TRANSMITTANCE (PERCENT)

INSTRUMENT NO.

GENERAL ELECTRIC
RECORDING SPECTROPHOTOMETER

TEST NO. BY JRP
DATE 4/21/52

N.P.62581



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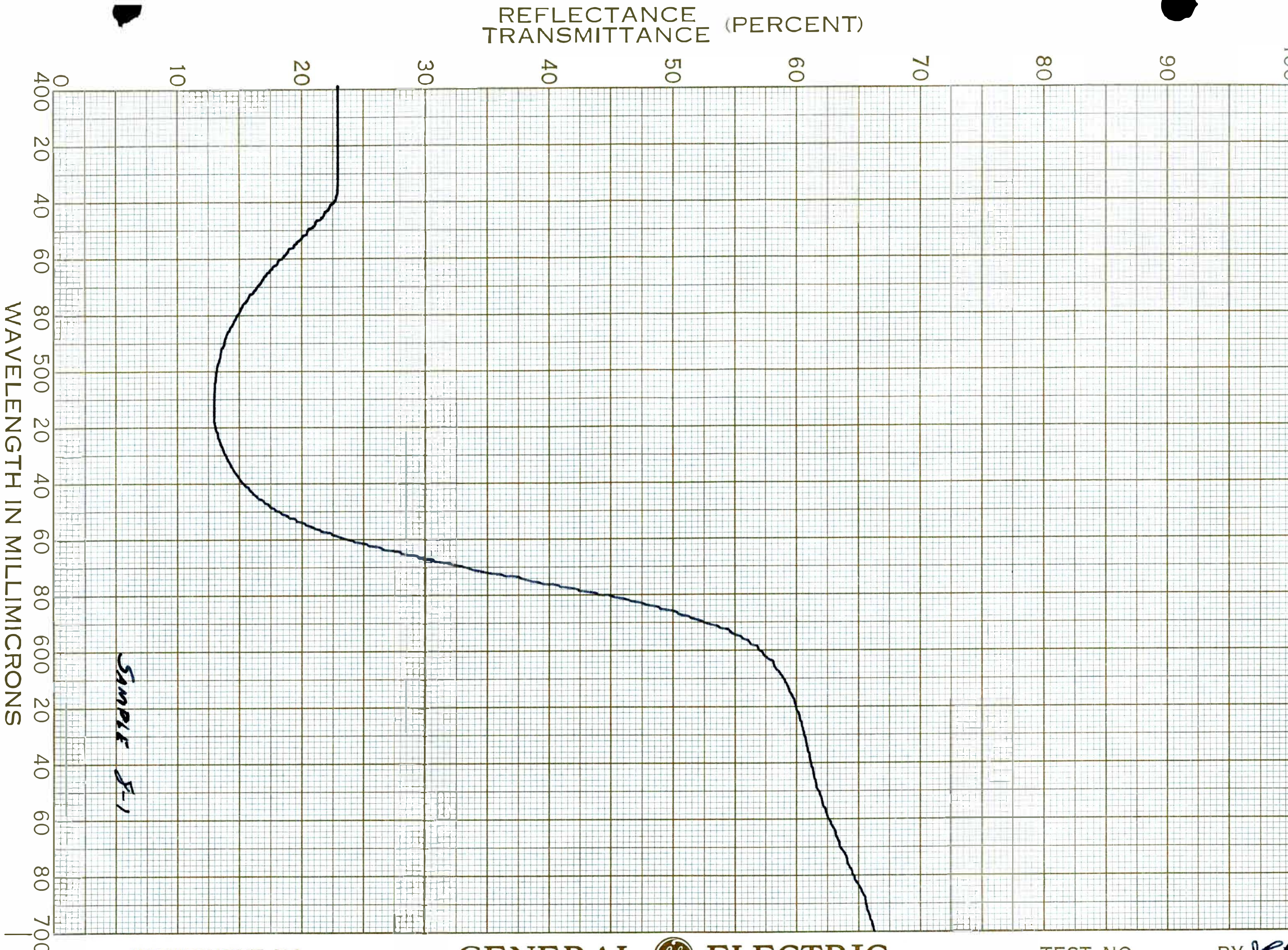
DATE 4/21/52



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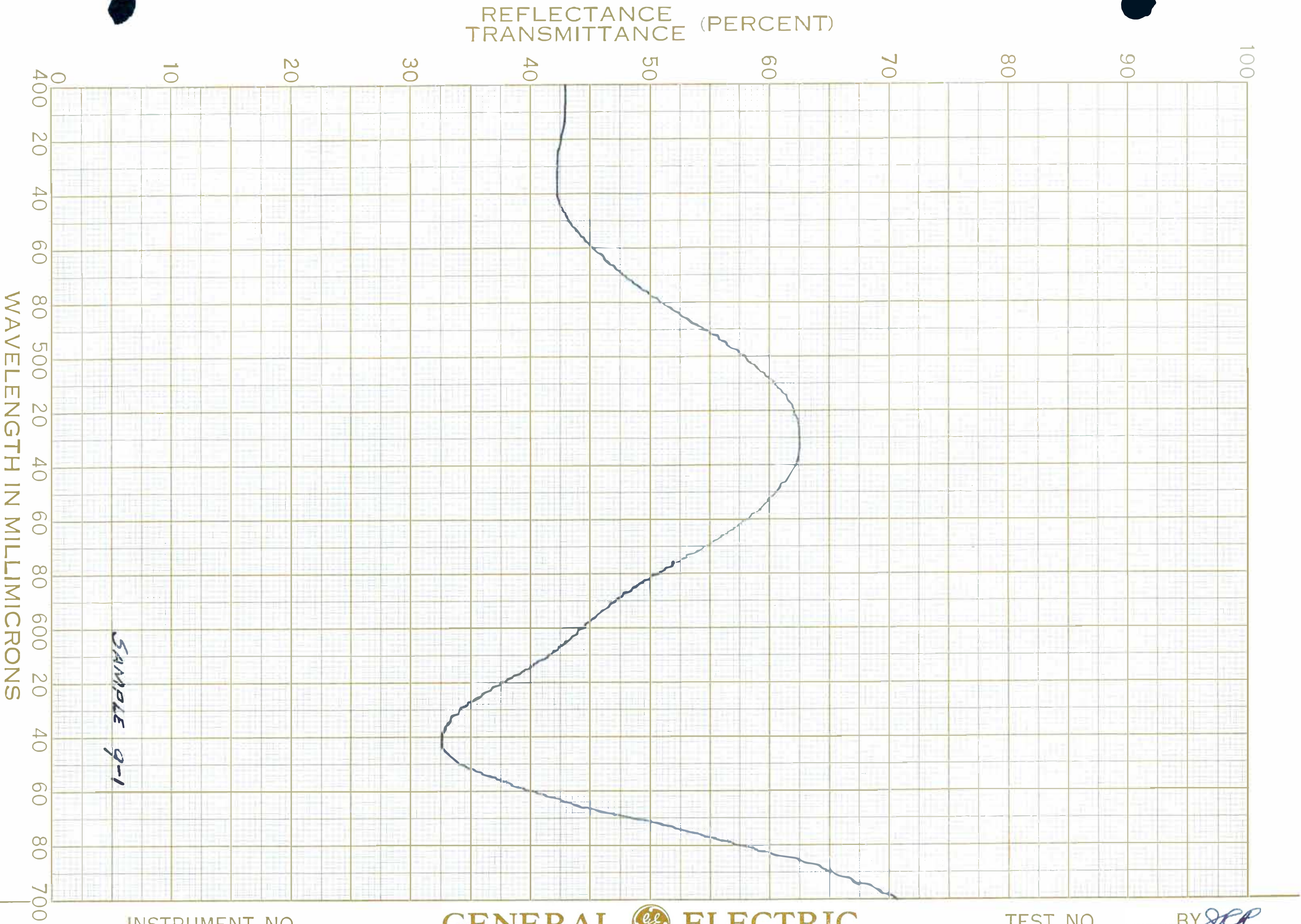

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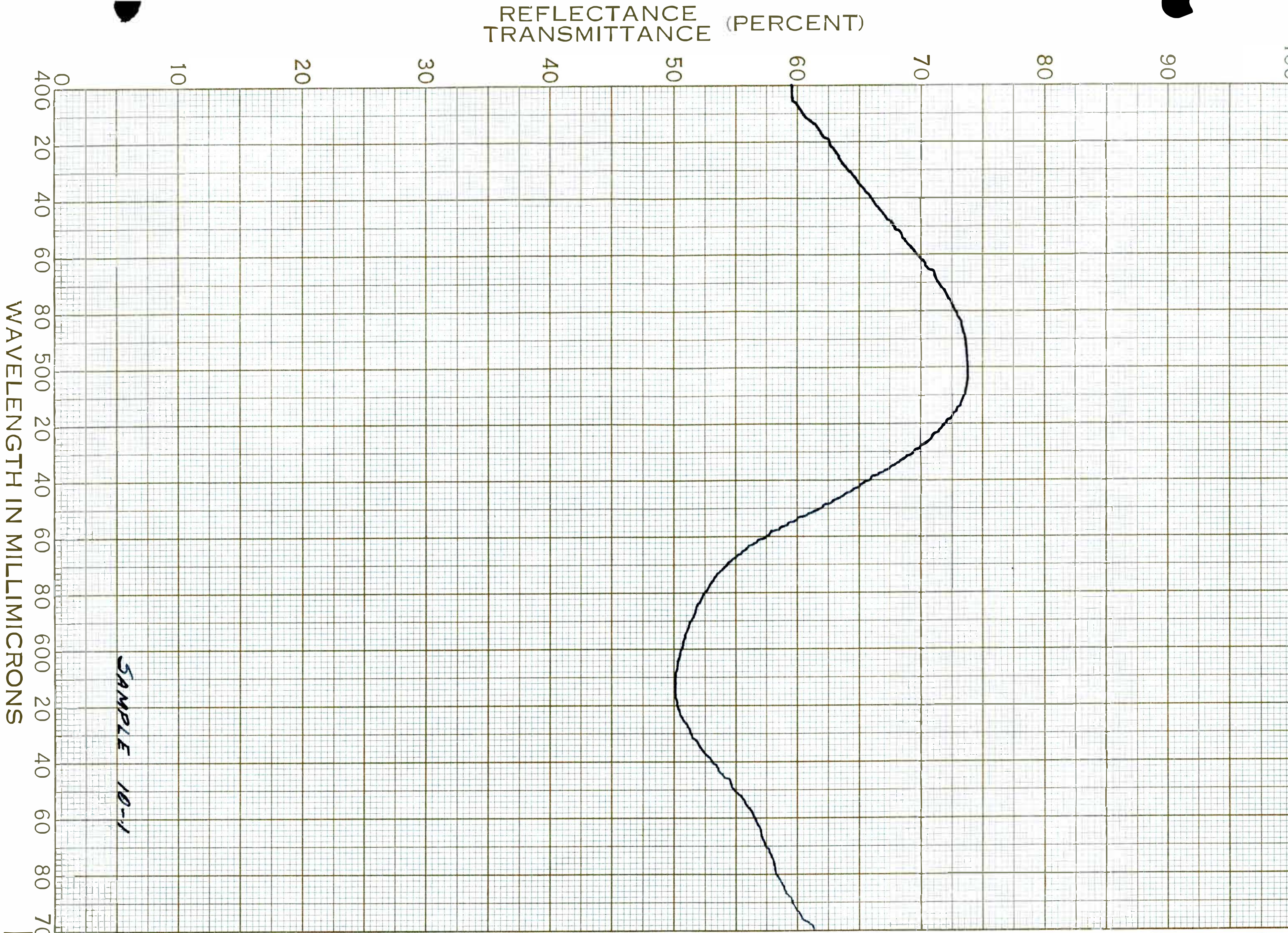

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DATE 4/21/52

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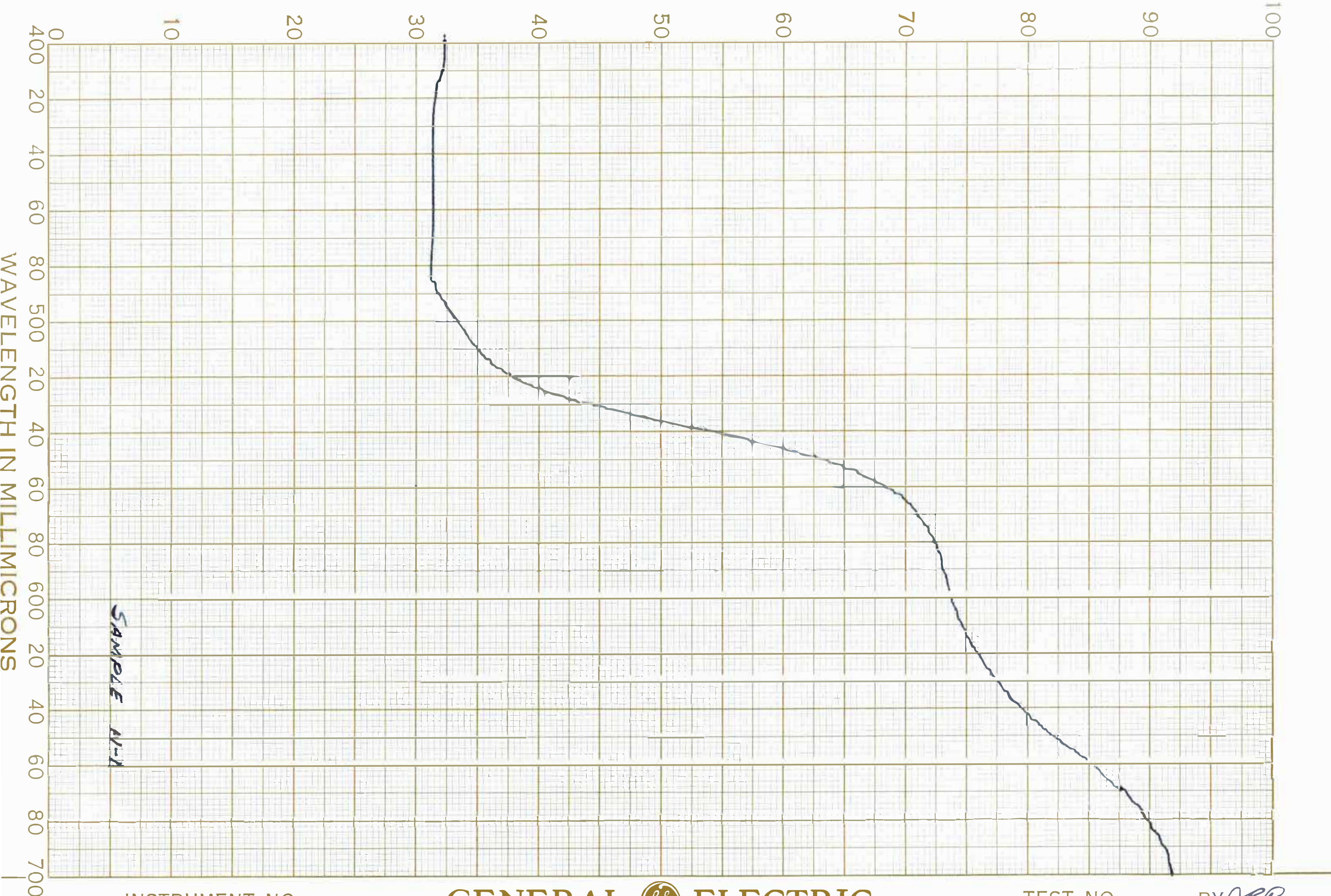
REFLECTANCE
TRANSMITTANCE (PERCENT)



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