

A MULTIPLIER PHOTOTUBE THICKNESS INDICATOR

by

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## III

INTRODUCTION

Carbon coated tissue paper used in printed, multiple copy, business form sets is designed to be used once and then discarded. For this reason the manufacturer is interested in coating the tissue paper with a standard amount of carbon ink. An excess coating of ink on the tissue above the standard amount causes smudging, blurred and feathered characters when the form set is used in a typewriter or business machine. Less than the standard amount of ink causes faint or non-legible characters in the copies of a form set.

The coating of the paper tissue with ink is done by machine. A large roll of tissue paper is mounted on a roller at the input of the coating machine. Paper from the roll is fed into the machine through a series of rollers and threaded through a hot carbon ink bath, where the ink is applied and distributed over the paper by so-called ink distribution rods. After coating, the web of paper passes over a large steel drum, cooled by refrigeration, which serves to cool and solidify the ink coating on the paper. After the ink solidifies, the paper is rewound into a roll and the process continues until the entire original roll of tissue paper is coated with ink. The velocity with which the web of paper moves through the machine varies from 500 to 600 feet per minute.

The carbon ink coating of the paper is subject to unevenness because of:

- (1) Variation in tension of the web of paper threaded through the coating machine.
- (2) Wearing down of the ink distribution rods.
- (3) Loose edges of the roll of tissue paper.
- (4) Bagging of the tissue roll.
- (5) Slime spots.

As a result the tissue web may have a greater or lesser amount of ink per unit area than the standard. The amount of ink per unit area on the web can be controlled by varying the tension of the web of paper. This is done by adding or subtracting weights from a counterbalancing mechanism in the machine. However, some form of monitoring device is needed to determine whether or not the ink coating is within the required limits. With a monitoring device, the coating machine operator could increase or decrease the web tension by adjusting the counterbalance weights. He could thereby compensate for any deviation of the weight per unit area of the ink from the standard as indicated by the monitor.

To develop a method and apparatus to continuously monitor the thickness of the carbon ink coating on a moving web of tissue paper was established as the purpose of this thesis project.

#### IV

#### REVIEW OF LITERATURE

Several procedures for the solution of this problem of monitoring the thickness of the carbon ink coating were suggested. Among these were:

- (1) Capacitance.
- (2) High frequency sound waves.
- (3) Radioactive thickness gauge employing beta rays.
- (4) Photoelectric cells with light source.

A search of the literature dealing with thickness measurements was made and particular attention was given to the four suggested methods listed above.

#### Capacitance.

The use of capacitance in the measurement of thickness of materials has been tried. One arrangement has been to have the material undergoing measurement flow between the plates of a capacitor. The capacitance of the capacitor is affected by the mass and nature of the dielectric between the plates. However, a useful relationship between thickness and capacitance is hard to obtain inasmuch as some materials affect the total capacitance of a given type of substance to a degree completely out of proportion to their concentration in the substance. An example of this would be water which has a dielectric constant of 81 present in paper which has a dielectric constant of from 2.0 to 2.5.<sup>1</sup> The use of capacitance in an attempt to solve the thesis problem was discarded after several experiments showed no detectable change in the capacity of a condenser consisting of two rectangular aluminum plates (seven inches by eleven and one-half inches, spaced one-eighth of an inch apart), when coated or uncoated carbon tissue was placed between the plates.

### High Frequency Sound Waves.

The reflection of high frequency sound waves has a useful application in the measurement of the thickness of many materials. A device called the Reflectogage has been developed using the principles of reflection and standing wave patterns that measures thicknesses from a few thousandths of an inch up to four inches. The use of the device is restricted, however, to metals, glasses, and plastics. Paper, coated or uncoated, is not included in the list of materials that the gauge can successfully measure.<sup>2</sup>

### The Beta Gauge.

A device that will measure the thickness of moving materials, including coated or uncoated tissue paper, is the so-called Beta-Ray Thickness Gauge or Beta Gauge. The material to be measured by the Beta Gauge is moved between an ionization chamber and a radio-isotope source of beta or gamma radiation. The material absorbs radiation in proportion to thickness. A meter connected to a basic electrometer amplifier circuit housed in the ionization chamber can be calibrated to read thickness directly.<sup>3</sup> A recorder is easily added. The device has found useful application in the paper and pulp industry. The initial cost of installation of the Beta Gauge is rather high and monthly maintenance charges are made by the manufacturer for calibration and adjustment of the device.

### Photoelectric Cells With Light Source.

The possibility of using photoelectric cells to measure the thickness of carbon ink on paper as a function of the light energy

absorbed by the carbon coating was considered. Initial experiments with a multiplier phototube offered promising possibilities. A discussion of photoelectric phenomena follows.

#### The Science of Photoelectricity.

The effect of light energy on electrical phenomena is known as the science of photoelectricity. Light effects electrical phenomena in three ways. These are (1) the generation of an electromotive force between two electrodes when either of them or the intervening medium is illuminated, (2) the reduction of the electrical resistance of materials by illumination, and (3) the emission of charged particles (electrons) from illuminated surfaces. The above three manifestations of the photoelectric effect are generally called the photovoltaic, the photoconductive and the photoemissive effects respectively.<sup>4</sup>

#### The Photovoltaic Effect.

In 1839 Edmond Becquerel first observed the action of light in generating an electric current or voltage. He immersed a pair of electrodes in an electrolytic solution forming a cell. He noted that when the cell was illuminated by sunlight that a measurable current could be detected by a galvanometer connected to the electrodes of the cell. Becquerel's work with wet photovoltaic cells eventually led workers in the twentieth century to the development of the dry photovoltaic or barrier layer cell which has many applications today in photography and photometry. The ordinary exposure meter used in photography is of this type.<sup>5</sup>

### The Photoconductive Effect.

In 1873 Willoughby Smith noted that the conductivity of selenium increased when its surface was illuminated with sunlight. Smith was using bars of selenium as high resistances in testing submarine cables while they were being submerged. The selenium bars had dimensions of from 5 to 10 centimeters in length and from 1 to 1.5 millimeters in diameter. These bars were hermetically sealed in glass tubes. Their resistance was on the order of about 1400 megohms. Smith noted that the resistance of the bars was reduced by 15 to 100 percent when the bars were placed in the sunlight. He also noted that placing the bars in water to cool them did not effect the phenomenon of changing resistance when the bars were exposed to light. He reasoned correctly that the decrease in resistance was due to the effect of light and not to any change in temperature.<sup>6</sup>

The phenomenon of photoconductivity was investigated thoroughly after Smith's discovery. Similar properties were discovered in other materials. For many years the selenium photoconductive cell was widely used. However, the development of photoemissive cells or phototubes and the improvement of the photovoltaic cell has made their use less widespread. Nevertheless, photoconductive cells were used to a great extent during World War II in infra red signalling and detecting devices.<sup>7</sup>

### The Photoemissive Effect.

Heinrich Hertz in the year 1887 discovered the photoemissive effect. While engaged in his researches on electric waves and

oscillations he noted that if the negative terminal of a spark gap were illuminated with ultraviolet light, a larger and longer spark could be produced than without such illumination. Hallwachs in 1838 found that if a polished zinc sphere were connected to an electrometer it would exhibit a positive charge after being illuminated with ultraviolet light. From his observations and those of Philipp Lenard and J. J. Thomson (1899), it was concluded that the phenomenon, now known as the "Hallwachs effect," was due to the loss of electrons by a body effected by the action of light.<sup>8</sup>

There are many substances which when illuminated with light energy of the proper frequency will emit electrons. The alkali metals exhibit this property to the highest degree, and oxides and hydrides of potassium, sodium, rubidium and caesium are used extensively in the manufacture of phototubes.

The photoelectric effect was left unexplained by the wave theory of light. Einstein in 1905 proposed using the quantum theory of Planck to account for this effect. He then derived his famous photoelectric equation:

$$\frac{1}{2}mv^2 = hf - hf_0$$

where

$v$  is the maximum velocity of emission;

$h$  is Planck's constant;

$f$  is the frequency of the incident light; and

$f_0$  is the threshold frequency for the substance;  
( $f_0$  equals  $5.15 \times 10^{14}$  for sodium)<sup>9</sup>

This equation fits nicely into the quantum theory and it explains the photoelectric effect very satisfactorily.

When a quantum  $hf$  of light energy is absorbed by an electron in a photoelectric substance, the electron will be emitted from the surface if the quantum exceeds the amount  $hf_0$ , the minimum energy required for an electron to break through the potential barrier at the surface. The remaining energy ( $\frac{1}{2}mv^2$ ) is the kinetic energy that the escaping electron possesses after it leaves the photosensitive surface.

#### Phototubes.

Phototubes, also known as photoemissive or photoelectric tubes, are the most used type of photoelectric devices. Phototubes contain two electrodes, a cathode and an anode. The cathode has a relatively large surface area so that maximum emission may be obtained. Geometrically it is in the shape of a half cylinder, ranging in size from 0.5 to 2.5 square inches. The half-cylinder cathode is coated with the photosensitive material, usually caesium oxide. A straight piece of metal wire having a small cross section forms the anode. It is placed at the center line of the half-cylinder cathode and it is made as small as possible so that shading of the cathode surface will be at a minimum.<sup>10</sup>

When a potential difference is applied between anode and cathode of a phototube (the positive side of the potential connected to the anode and the negative side to the cathode) electrons will flow from the cathode to the anode when light energy falls on the cathode surface. The magnitude of the current is a function of the magnitude of the light energy.

Phototubes are divided into two general types, namely the high vacuum phototube and the gas filled phototube. The high vacuum type consists of an anode and cathode placed in a glass envelope which has been exhausted to a pressure of one millionth of a millimeter of mercury. The current in this type of phototube is due only to the photoelectrons emitted from the cathode.<sup>11</sup>

In the gas filled type, air is first exhausted from the envelope and then an inert gas is pumped in under low pressure. Under the same operating conditions the gas filled phototube yields larger currents than the high vacuum type. However, the photoelectric current versus incident illumination curve of a gas filled phototube is much less linear than the high vacuum type. As a result gas phototubes are more suitable where large sensitivity is necessary and precision is not at a great premium. For work that requires higher precision than that obtainable with gas tubes, high vacuum tubes are used. Measurement of light intensities can be accomplished to a high degree of accuracy using high vacuum tubes. The high vacuum multiplier phototube is a linear device also and it is used to measure extremely low levels of light energy with great precision.

#### Spectral Response Characteristics of Phototubes.

A classification of phototubes based on their spectral response characteristics has been adopted jointly by the Radio Manufacturers' Association and the National Electrical Manufacturers' Association. The classifications are as follows: S-1, S-3, S-4, S-5, S-6 and S-8. S-1 refers to a silver-cesium oxide-cesium surface in an envelope of

lime glass with a maximum sensitivity in the infrared region of the spectrum. S-3 corresponds to a silver-rubidium oxide-rubidium surface exhibiting highest sensitivity in the 4200 Angstrom unit of the spectrum. Its spectral characteristic curve parallels closely the response curve of the human eye. The envelope is made of lime glass. S-4 consists of antimony-caesium material coating the cathode surface of the phototube. The tube exhibits a maximum response to blue light. The light sensitive surface type S-5 is enclosed in a bulb of ultraviolet transmitting glass. This surface is similar to the S-4 surface but has high sensitivity near the 2537 Angstrom unit line of mercury. S-6 is also a surface type sensitive to ultraviolet and it is composed of sodium. The S-8 type of cathode surface is coated with bismuth-caesium and it is very similar to S-4 except that its response is higher to longer wave lengths.<sup>12</sup>

#### The Multiplier Phototube.

Secondary emission multiplication applied to phototubes increases the current output without appreciably affecting the linearity of its phototube current versus light intensity curve. In addition greater amplification can be obtained by this type of phototube than with a gas phototube.

A schematic diagram showing the theory, circuit and construction of a multiplier phototube is shown in Figure 1-A. A series of electrodes mounted in a high vacuum chamber comprise the elements of the tube. The first electrode called the photocathode is coated with a light sensitive film. Electrons are emitted from this surface in proportion to

FIG. I-A PRINCIPLE OF A PHOTOELECTRIC ELECTRON-MULTIPLIER TUBE.

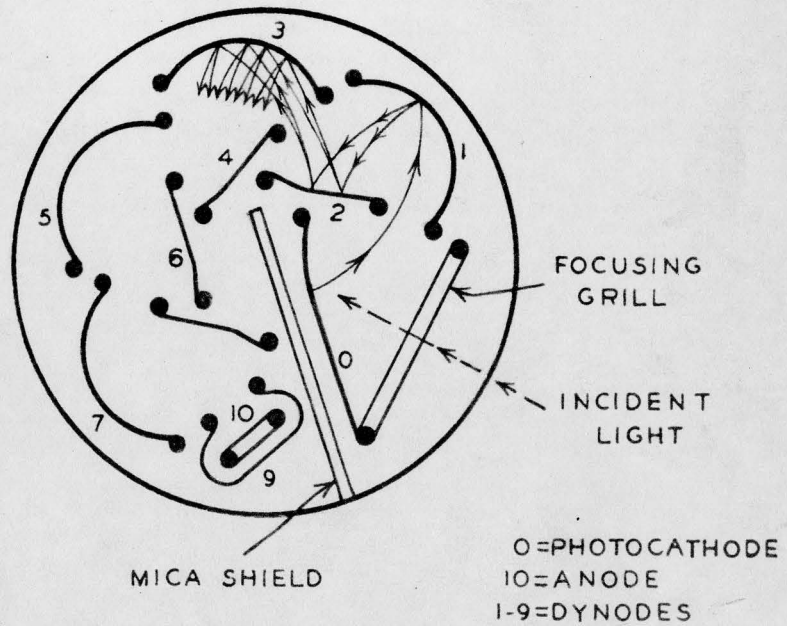
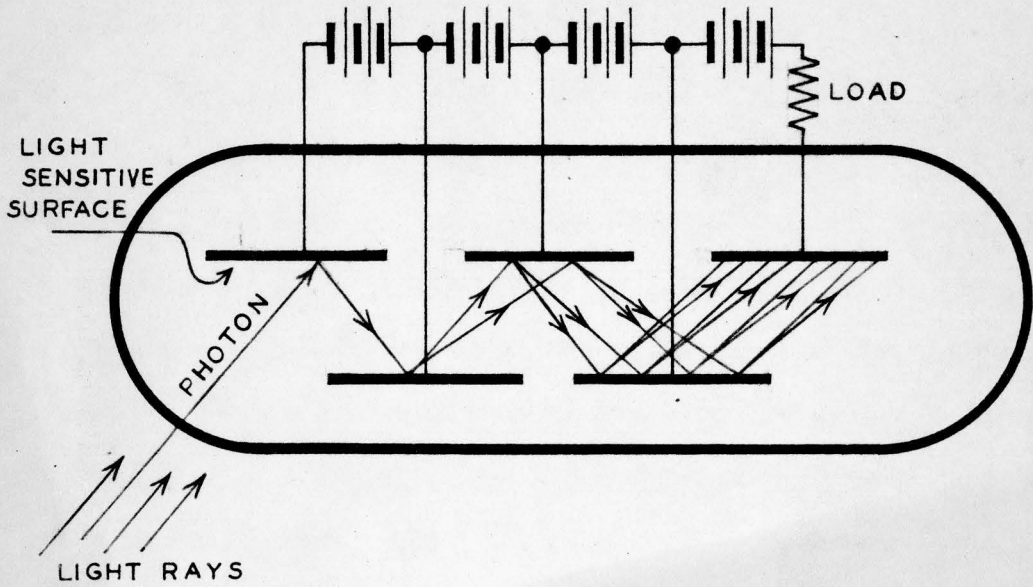


FIG. I-B SCHEMATIC DIAGRAM OF MULTIPLIER PHOTOTUBE.

the amount of incident light energy. These emitted electrons are attracted to a second electrode held at a higher positive potential. This positive potential is set high enough to give the attracted electrons enough velocity to dislodge electrons from the second electrode, thus causing secondary emission. The electrons of secondary emission are in turn drawn to a third electrode of still higher positive potential where an increased number of secondary electrons are emitted. One electron bombarding a surface may dislodge from one to ten secondary electrons. Thus, through a series of electrodes, each having a higher potential than the preceding one, a very high amount of current amplification is obtained. The amount of amplification is limited by space charge effects and power dissipation in the final stages.<sup>13</sup> A multiplier phototube can be considered as an ordinary phototube of the high vacuum type with its own built in direct current amplifier.

#### The 931-A Multiplier Phototube.

In this investigation a 931-A high vacuum multiplier phototube was used. This phototube has an S-4 response characteristic which covers the range from about 3000 to 6200 Angstrom units. Maximum sensitivity occurs at approximately 4000 Angstroms. Its response, therefore, is high to blue-rich light and zero to infrared radiation. When operated at 100 volts per stage, the 931-A can amplify currents produced by weak illumination an average of one million times. The resultant output current is a linear function of the exciting illumination under normal operating conditions.

Figure 1-B shows a cross-section of the structure of the 931-A multiplier phototube. It consists of eleven electrodes arranged in a circular array in order to obtain good electron focusing. The electrode 0 represents the photocathode. It is illuminated by light energy entering normal to the focusing grill. The electrodes numbered 1 to 9, the target electrodes, are called dynodes. The grid structure, numbered 10, is the collector or plate. This type of structure is representative of standard commercial multiplier phototubes.<sup>14</sup>

## V

INTRODUCTORY SUMMARYGeneral Description.

The device developed in this research to continuously measure the thickness of carbon ink on a moving web of paper utilizes basically (1) a 150 watt projection lamp housed in a Spencer lamp housing and equipped with an adjustable iris diaphragm, (2) a double convex lens to focus the light energy from the lamp into a spot one-half inch in diameter on one side of the carbon coated tissue paper, (3) a second double convex lens placed on the opposite side of the paper to pick up the light energy transmitted through the paper and focus it on the cathode of (4) the 931-A multiplier phototube, and (5) a 0 to 200 microammeter placed in the plate circuit of the phototube to measure the phototube current. A block diagram of this apparatus is shown in Figure 2. A 1000 volt power supply with a

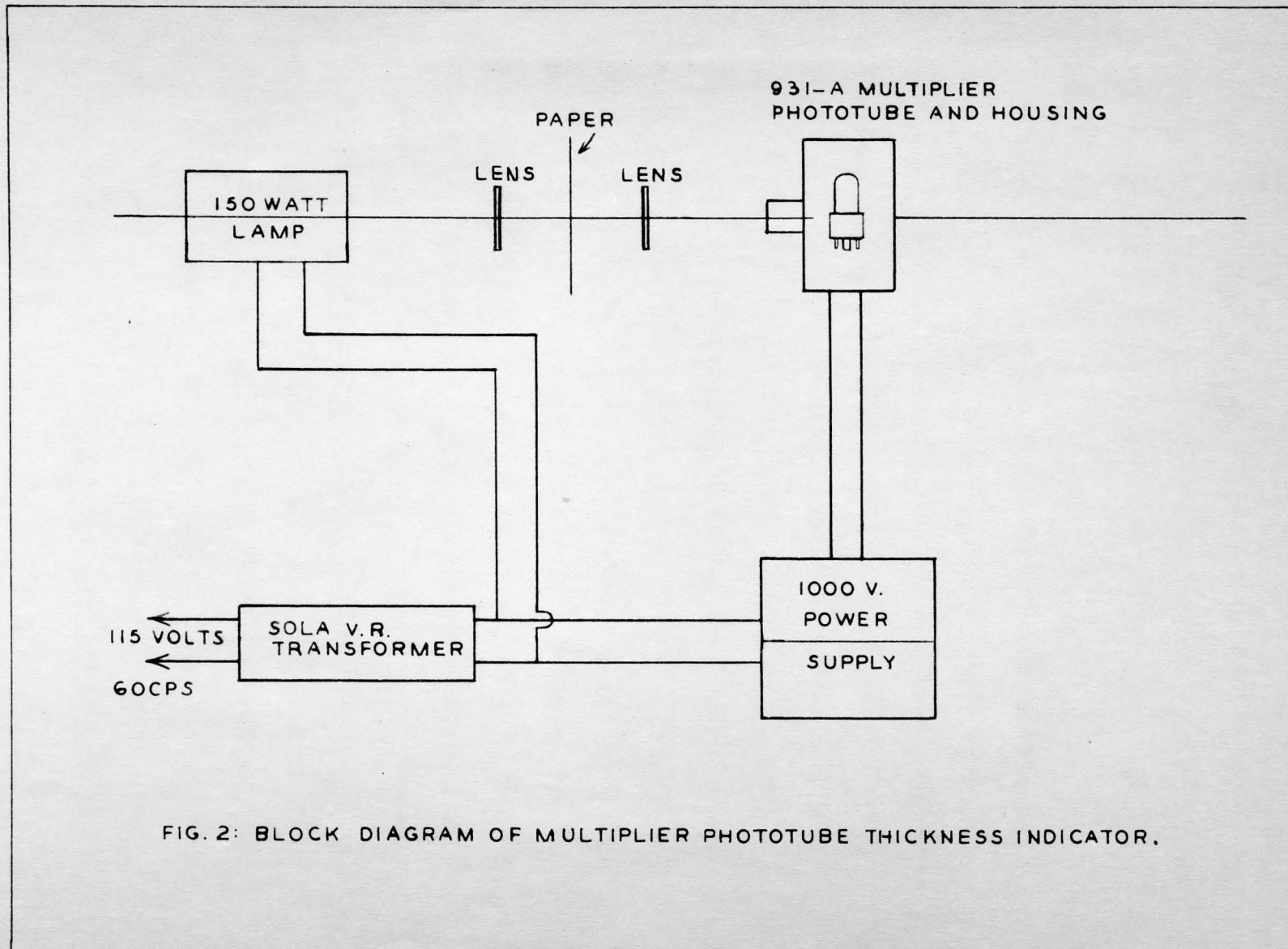


FIG. 2: BLOCK DIAGRAM OF MULTIPLIER PHOTOTUBE THICKNESS INDICATOR.

built in voltage regulator was used to supply the proper dynode and collector voltages for the 931-A tube. A Sola voltage regulating transformer was used to regulate the line voltage supplying the power supply and the 150 watt projection lamp.

#### Basic Operation.

The voltage regulated 150 watt projection lamp provided a constant source of visible light energy. This light energy was focused on the coated tissue undergoing test. The amount of light energy transmitted through the coated paper was in the main a function of the thickness of the carbon ink coating covered by the spot of light. The more light energy transmitted through the paper the thinner the carbon coating and vice versa. The transmitted light energy passing through the paper was picked up by a lens and then focused on the multiplier phototube cathode. The resultant phototube current either increased or decreased in magnitude depending upon whether the area of the coated paper under test was lightly or densely coated, thus indicating the relative thickness of the carbon ink coating.

Static measurements on the carbon coated tissue were taken at first. This was done by dividing the tissue up into small areas (one-half inch squares) and taking measurements on each of these small areas. The average for the whole tissue was computed from these values. Since in the carbon ink coating process the web velocity varies between 500 and 600 feet per minute, dynamic

measurements were made. Velocities from 480 to 1200 feet per minute were simulated, and measurements were taken. These measurements automatically gave the average value of the tissue undergoing test. This average value remained constant for a given area of coated tissue under test between the simulated velocities mentioned above.

#### The Effect of the Paper.

As previously stated, the amount of light energy transmitted through a carbon coated tissue is a function of the carbon ink coating and the density of the tissue paper. It is believed that the main effect on the transmission of the light energy through the coated tissue is due to the carbon ink coating. Nevertheless, the density (weight per unit area) of the tissue itself must be taken into account, in the final analysis, as the chief limiting factor of the device developed in this research. An absolute determination of how much effect the paper has on the limits between which the thickness of the carbon coating can be monitored was not determined in this research. However, the indirect methods used in this research to study the effect of the paper on the measurements of the thickness of the carbon ink coating indicate that the carbon coating itself on the paper lessens the effect of the density of the paper on the light transmitted through the coated tissue. Future work involving more direct methods of comparing separately the densities of the paper, the thickness of the carbon coating, and the combined effect of these two physical quantities on the transmission of

light should bring out the exact limits that the thickness of carbon ink coating on a moving web of paper can be successfully monitored by the multiplier phototube.

The weight per unit area of the tissue paper varies (1) from point to point on a given roll of tissue, (2) from one roll of tissue to another for a given type of tissue made by one manufacturer, (3) and from the type of tissue manufactured by one paper mill to another.

## VI

### EXPERIMENTAL INVESTIGATION

#### Description of Apparatus.

Refer to Figure 3. An optical bench was used to mount the 150 watt projection lamp and the multiplier phototube. In addition a paper holder and two double convex lenses were mounted on the bench track as outlined schematically in Figure 2. The apparatus was spaced as follows. The projection lamp filament center line was placed at the 43 centimeter mark of the bench, the first lens at the 73 centimeter mark, the paper holder at the 91 centimeter mark, the second lens at the 92.5 centimeter mark, and the phototube at the 112.5 centimeter mark.

The paper holder consisted of a three-eighths of an inch cane board frame, eleven inches by eight inches, with a rectangular opening, nine inches by six inches, mounted on a block of wood. See Figure 4. One side of the rectangular opening was cross-

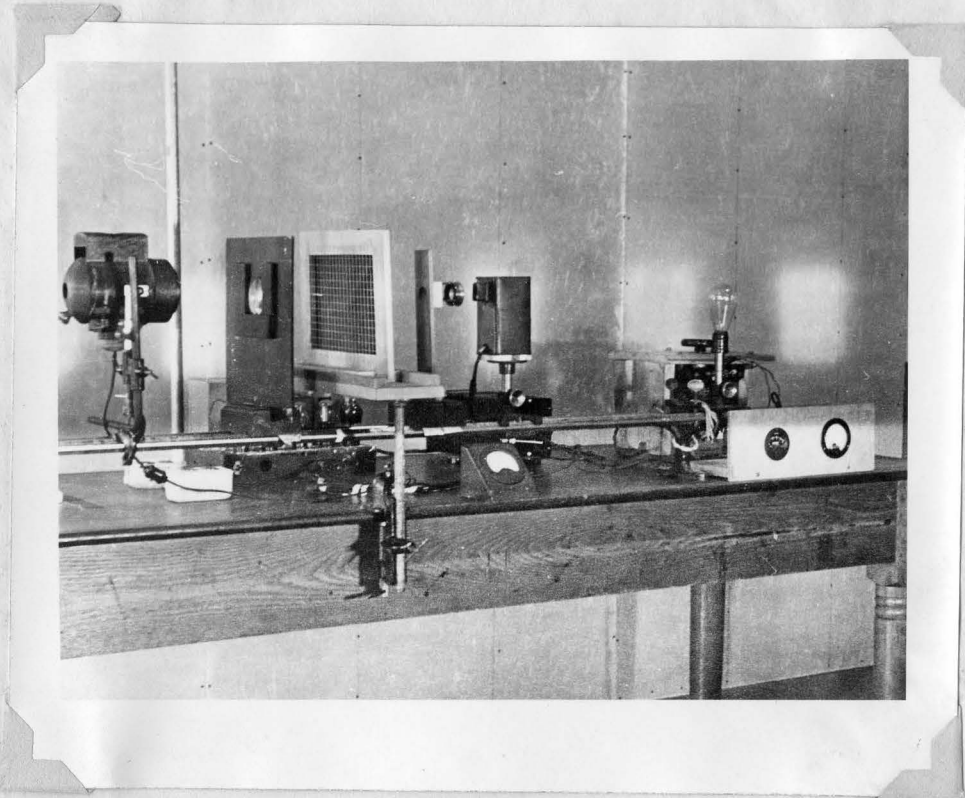


Figure 3. View of Apparatus for Static Measurement Mounted on an Optical Bench.

hatched into a grid by means of lengths of white thread spaced one-half inch apart horizontally and vertically. The other side of the opening was then covered by the carbon tissue to be tested. The tissue was secured to the frame by means of thumb tacks. Thus, a view of the carbon tissue mounted on the frame (the carbon side of the tissue facing the grid and the light source) from the grid side showed the carbon tissue divided into 216 squares, each having an area of one quarter of a square inch. The beam of light from the lamp was focused into a spot approximately three-eighths of an inch in diameter. The spot was focused through one of the grid squares on to the carbon coated side of the tissue mounted on the paper holder. No light was allowed to hit the threads bounding the area undergoing test.

The spot of light shining through the carbon paper was picked up on the other side by a lens which focused this transmitted light energy on the cathode of the multiplier phototube. The paper holder was placed on a track so that horizontal movement could be obtained, and the track itself was mounted so that it could be raised or lowered. Consequently, two degrees of freedom in a plane perpendicular to the beam of light were obtained. Any one of the 216 square areas of the carbon tissue spaced off by the grid could then be placed normal to the light beam, and it was possible to test an area totalling 54 square inches on each carbon tissue mounted in the cane board frame.

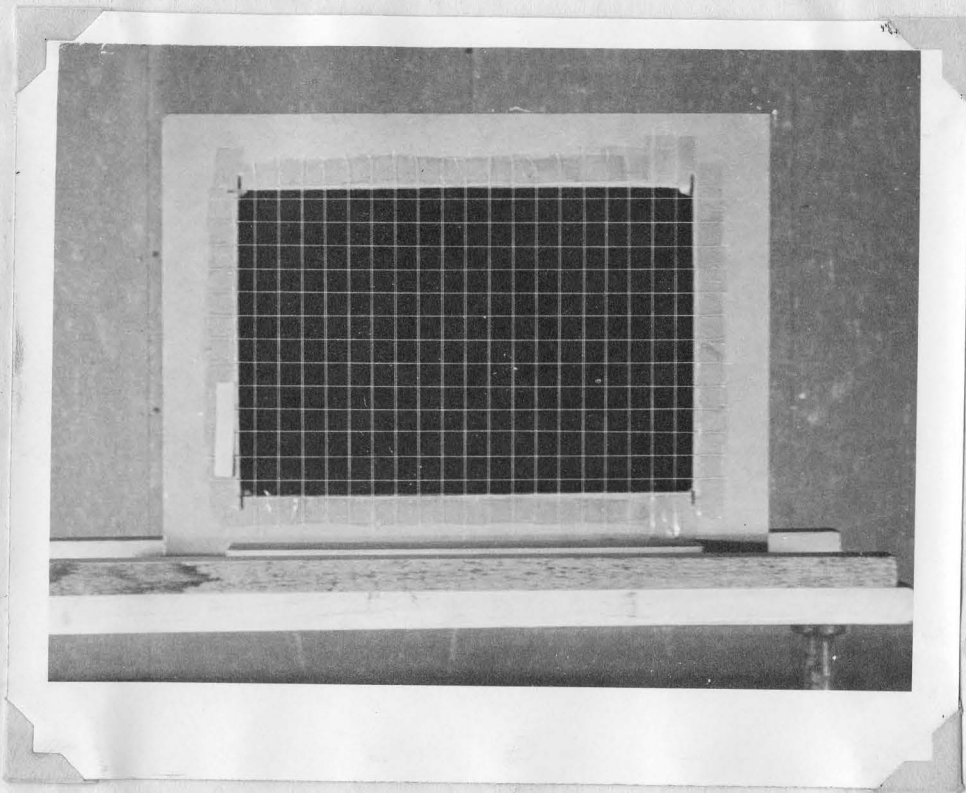


Figure 4. View of the Light Side of the Paper Holder and cross-hatched Grid.

The 931-A multiplier phototube was placed in a thin metal housing. This housing was light tight except for the aperture opening that permitted incident light to be focused on the cathode of the phototube. Figure 5 shows a view of the phototube housing, the 1000 volt voltage regulated power supply, the 0-200 microampere ammeter and the Sola voltage regulating transformer.

The power supply for the 931-A phototube consisted of two 2X2 high vacuum rectifier tubes used in a voltage doubler circuit. The output of the power supply was rated at 1000 volts at four milliamperes. A voltage regulating circuit utilizing two VRL50 voltage regulating tubes and a 6L6 beam power amplifier tube as a control tube were incorporated in the power supply circuit.

A voltage dividing network of ten 22,500 ohm resistors was used to provide the proper voltages to the dynodes and collector of the 931-A phototube. The microammeter was connected in the plate circuit of the phototube to measure the current. A schematic circuit diagram of the power supply, the voltage dividing network, and the phototube and microammeter connections is shown in Figure 6.

#### Manufacturer's Method of Determining Carbon Ink Thickness.

The manufacturer's method of determining the amount of carbon ink in a ream of coated tissue paper will be described. A ream of paper is defined as 500 sheets for physical testing purposes.<sup>15</sup> A measured area of coated tissue taken from the roll after a run is weighed on a jolly balance and the weight in grams is recorded. Also a measured area of uncoated tissue equal to the area of the coated

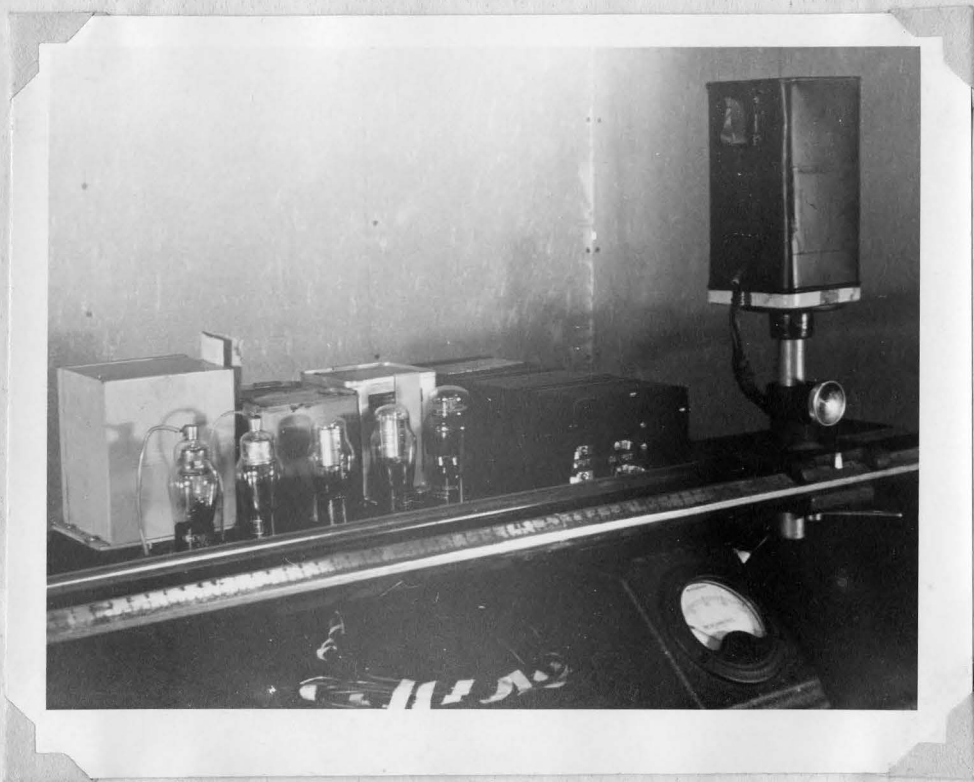


Figure 5. View of Phototube Housing, Power Supply, and Voltage Regulator Transformer.



Key to Figure 6

R1 - 15,000 ohms 4 watts

R2 - .5 megohms 1 watt

R3 - 20,000 ohms 1 watt

R4 - .7 Megohms 1 watt

R5 - 1 megohm potentiometer

R6 - .27 Megohms 1 watt

R7 - 10 ohms 10 watts

C1 - 1 microfarad 3000V

C2, C3 - 2 microfarads 3000V

Voltage Dividing Network: Ten 22,500 ohm 1 watt resistors

tissue mentioned is weighed in the jolly balance and the value in grams is recorded. The value for the areas of the coated and uncoated tissue samples is substituted in the following formula:

$$\frac{20'' \times 30'' \times 500 \text{ sheets}}{454 \text{ gm/lb} \times \text{area of sheet (in}^2)} = \text{a conversion factor}$$

This conversion factor is then multiplied by the weights in grams of the coated and uncoated tissue respectively, and the value obtained for the uncoated tissue is subtracted from the value obtained for the coated tissue. This difference is the number of pounds per ream of carbon ink in the roll after the run. These difference values will be hereinafter referred to as jolly balance values in this thesis. The limits set up by the manufacturer for a satisfactory thickness coating using the jolly balance measurements were 3.5 to 5.0 pounds per ream.

#### Method of Procedure.

The method of procedure used in this investigation can be divided under the following headings, (1) static measurements of coated tissue, (2) static measurements of uncoated tissue, (3) dynamic measurements of coated tissue, (4) dynamic measurements of uncoated tissue, and (5) evaluation of data.

#### 1. Static Measurements of Coated Tissue.

Three carbon tissues (paper made by the International Paper Company) were numbered 1, 2, and 3. These tissues were within, below and above the jolly balance limits respectively, and had

corresponding jolly balance values of 3.9, 3.2, and 5.4 pounds per ream.

Carbon tissue No. 1 was placed in the paper holder. The spot of light from the lamp was focused through each of the 216 grid squares onto the coated side of the paper. Readings of the microammeter were taken in each case and the values were recorded. See Table 2. The microampere values in each row were averaged and then a total average of the entire tested area of the tissue was computed and recorded. A similar procedure was employed on carbon tissues Nos. 2 and 3. The results are summarized:

Table 1.

Carbon Tissues Nos. 1, 2, and 3 Data.

Carbon Tissue Number	Jolly Balance	Total Average (Microamperes)	Pounds Per Ream
1	Within Limits	141.91	3.9
2	Below Limits	163.3	3.2
3	Above Limits	124.33	5.4

The above results show that the average phototube current readings were in line with the relative thicknesses of the tissues as measured by the jolly balance. The total average readings in microamperes of the measurements taken on the carbon tissues were plotted against jolly balance values. See Figure 7.

While taking measurements on the above tissues it was noticed that the pointer of the microammeter had a tendency to creep up two or three microamperes when the spot of light rested on any particular

Table 2.

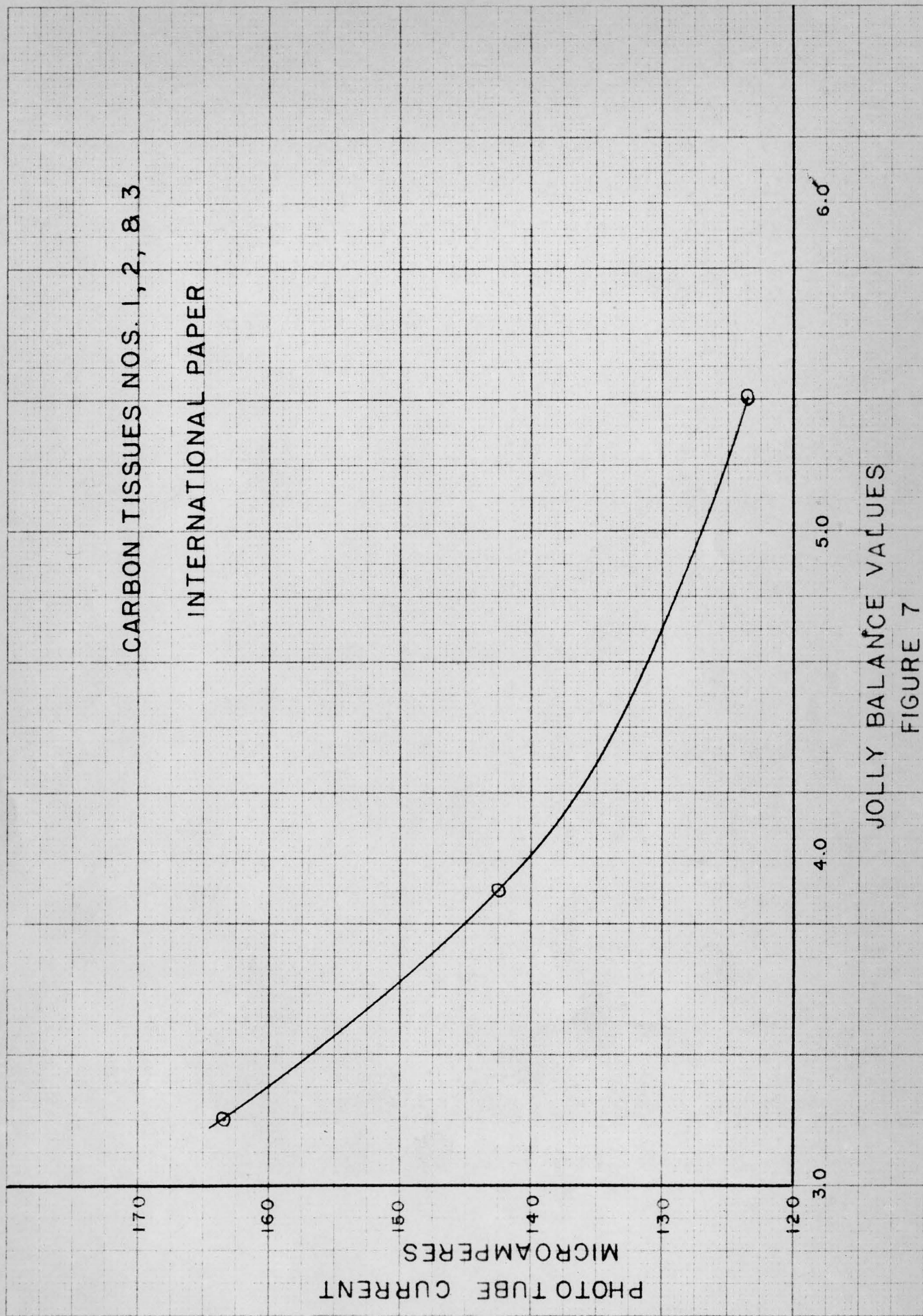
Showing Readings in Microamperes of the  
216 Square Areas of Carbon Tissue No. 1

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	107	125	168	110	135	132	124	99	110	105	119	116	107	114	150	120	114	115
Row 2	160	145	160	190	152	120	165	140	145	125	150	160	128	125	160	160	170	127
Row 3	148	190	180	192	135	160	190	155	140	115	190	152	120	140	180	160	170	150
Row 4	140	152	135	150	150	155	140	140	153	130	112	120	155	150	156	125	145	150
Row 5	150	142	151	170	155	163	165	130	117	130	136	138	125	122	130	150	138	140
Row 6	145	145	148	162	150	150	140	130	130	126	140	125	130	125	140	145	140	155
Row 7	170	148	180	158	145	160	138	130	135	160	140	115	120	165	160	150	150	135
Row 8	132	130	150	145	120	160	140	165	152	120	130	116	118	123	150	162	152	142
Row 9	135	150	148	135	138	230	205	140	145	140	140	120	115	170	160	140	145	148
Row 10	150	123	134	155	165	140	145	153	138	115	140	142	139	120	128	165	171	120
Row 11	145	170	155	135	150	180	140	145	127	135	131	120	125	150	150	145	122	150
Row 12	165	138	147	125	145	115	120	140	158	108	120	132	138	130	170	140	155	135

Total Average: 141.91 Microamperes  
Jolly Balance: 3.9 lbs. per ream, within limits  
Type Tissue: International

CARBON TISSUES NOS. 1, 2, & 3  
INTERNATIONAL PAPER



JOLLY BALANCE VALUES  
FIGURE 7

PHOTO TUBE CURRENT  
MICROAMPERES

area for several seconds. Investigation showed that the spot of light focused on the tissue was actually melting the coating, causing carbon particles to flow away from the spot under test, thus allowing more light energy to pass through. In some instances and increase of five microamperes was noted in a single reading. The cause of this was eliminated by placing an infrared filter in the lamp and no further creeping of the scale pointer was noted on subsequent readings.

Three carbon coated tissues (8-pound paper made by the Kraftex Paper Company) were tested as above. The results are tabulated in Table 3.

Table 3.

## Carbon Tissues Nos. 4, 5, and 6 Data

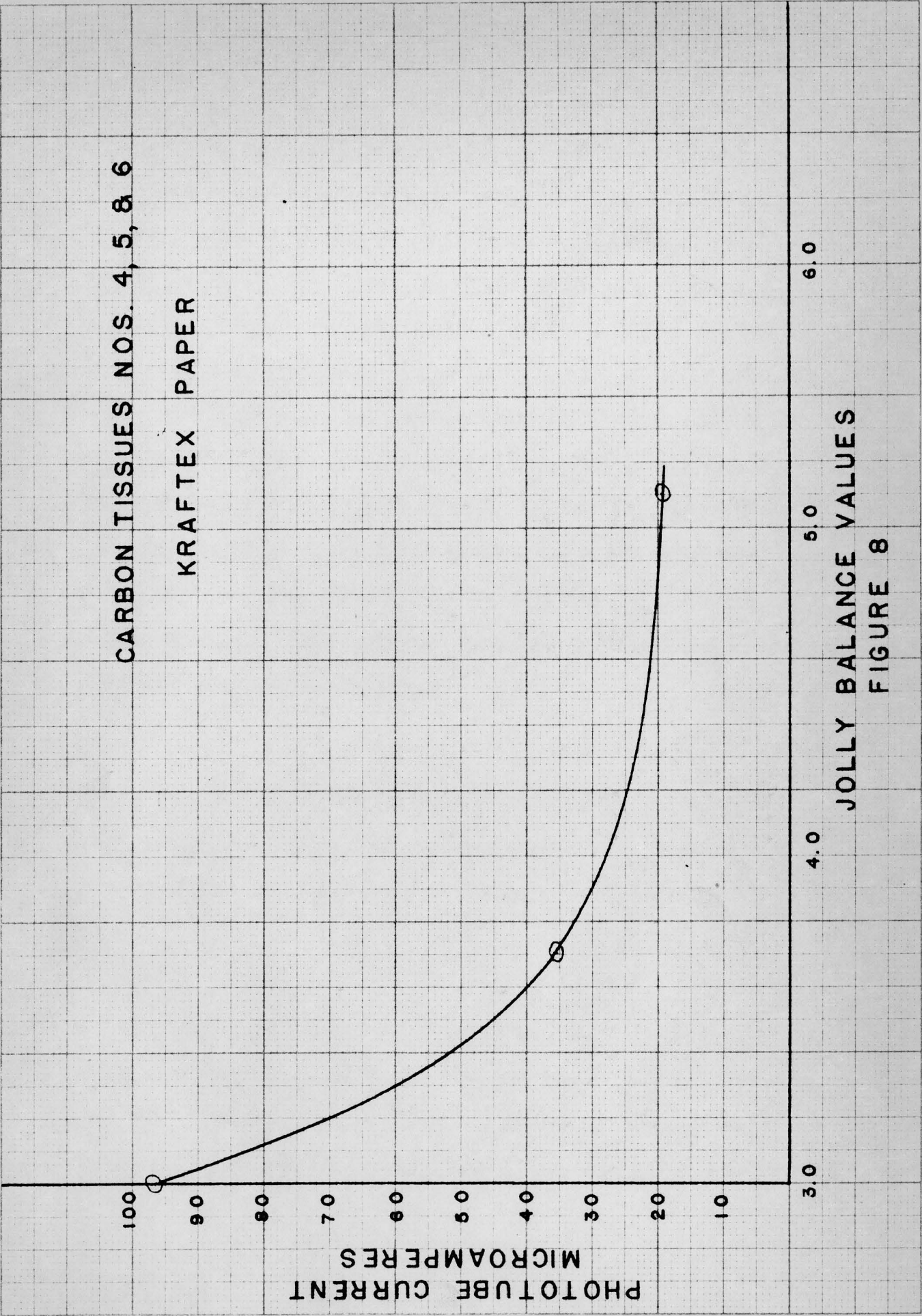
Carbon Tissue Number	Jolly Balance	Total Average (Microamperes)	Pounds Per Ream
4	Below Limits	96.51	3.0
5	Within Limits	35.32	3.7
6	Above Limits	19.71	5.1

The total average readings of phototube current (microamperes) for the 216 areas tested on each carbon tissue were plotted against the jolly balance values. See Figure 8. This curve, like the curve in Figure 7, indicates an inverse relationship between jolly balance values and the phototube current total averages.

Three more coated tissues labelled below, within, and above the jolly balance limits respectively were tested. The tissue

CARBON TISSUES NOS. 4, 5, 8 & 6

KRAFTX PAPER



6.0

4.0

3.0

JOLLY BALANCE VALUES  
FIGURE 8

PHOTOTUBE CURRENT  
MICROAMPERES

paper was made by the International Paper Company, but this paper was different from the International paper of Tissues Nos. 1, 2, and 3. These coated tissues were numbered 7, 8, and 9. Tissues 8 and 9 were in line with the jolly balance indications but tissue No. 7, which was below limits according to the jolly balance readings, did not plot out that way. See Figure 9. Visual comparison of Tissues 7 and 8 (holding both tissues up to a strong, uniform source of light) showed that Tissue 7 had a thicker coating of ink than Tissue 8. This was borne out in the phototube averages as Tissue 7 permitted less light to be transmitted than Tissue 8 (26.17 microamperes for Tissue 7 versus 38.33 microamperes for Tissue 8). The above observations indicate that the jolly balance value for Tissue 7 was in error. The data for Tissue Nos. 7, 8, and 9 are summarized in Table 4.

Table 4.  
Carbon Tissues Nos. 7, 8, and 9 Data

Carbon Tissue Number	Jolly Balance	Total Average (Microamperes)	Pounds Per Ream
7	Below Limits	26.17	3.2
8	Within Limits	38.33	3.8
9	Above Limits	10.98	5.6

Fourteen coated tissues (paper manufactured by the Brownsville Paper Company) were tested. These tissues were numbered from 10 to 23 inclusive. For each jolly balance value obtained by the manufacturer, two pieces of coated and uncoated tissue were

used. The two pieces of coated tissue, taken from the same roll, used to obtain the jolly balance value were called "mates". Tissue Nos. 10 and 11 were such a pair. In like manner, Tissue Nos. 12 and 13 were taken from the same roll to obtain the jolly balance value for a run. This roll, however, was different from the roll that Tissue Nos. 10 and 11 were taken from. Likewise, Tissues 14 and 15 were taken from a third roll, 16 and 17 from another, 18 and 19 from another, etc., and these pairs were also called "mates". Table 5 summarizes the data obtained.

Table 5.

## Carbon Tissues Nos. 10 - 23 Data

Carbon Tissue Number	Jolly Balance	Total Average (Microamperes)	Pounds Per Run
10	Below Limits	74.93	3.3
11	Below Limits	68.8	3.3
12	Within Limits	57.46	4.6
13	Within Limits	59.66	4.6
14	Above Limits	17.69	5.6
15	Above Limits	15.57	5.6
16	Below Limits	130.94	3.3
17	Below Limits	131.14	3.3
18	Within Limits	62.25	4.2
19	Within Limits	65.85	4.2
20	Below Limits	122.02	3.3
21	Below Limits	123.61	3.3
22	Within Limits	114.19	4.4
23	Within Limits	78.89	4.4

CARBON TISSUES NOS. 7, 8, & 9  
INTERNATIONAL PAPER

MICROAMPERES  
PHOTOTUBE CURRENT

100  
90  
80  
70  
60  
50  
40  
30  
20  
10  
3.0

6.0

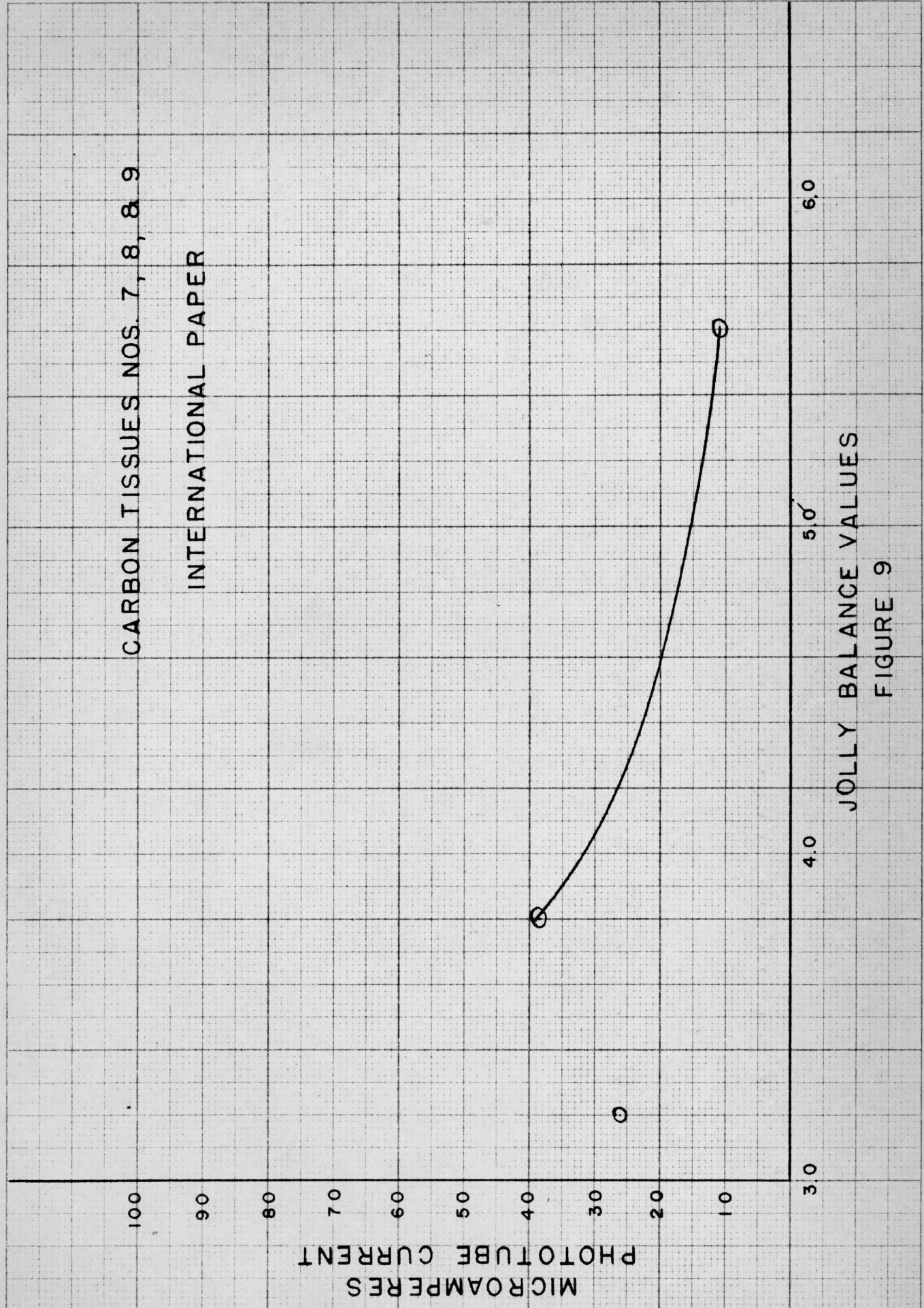
5.0

4.0

JOLLY BALANCE VALUES  
FIGURE 9

NO 340 20 DIETZGEN GRAPH PAPER  
20 X 20 PER INCH

EUGENE DIETZGEN CO.  
MADE IN U. S. A.

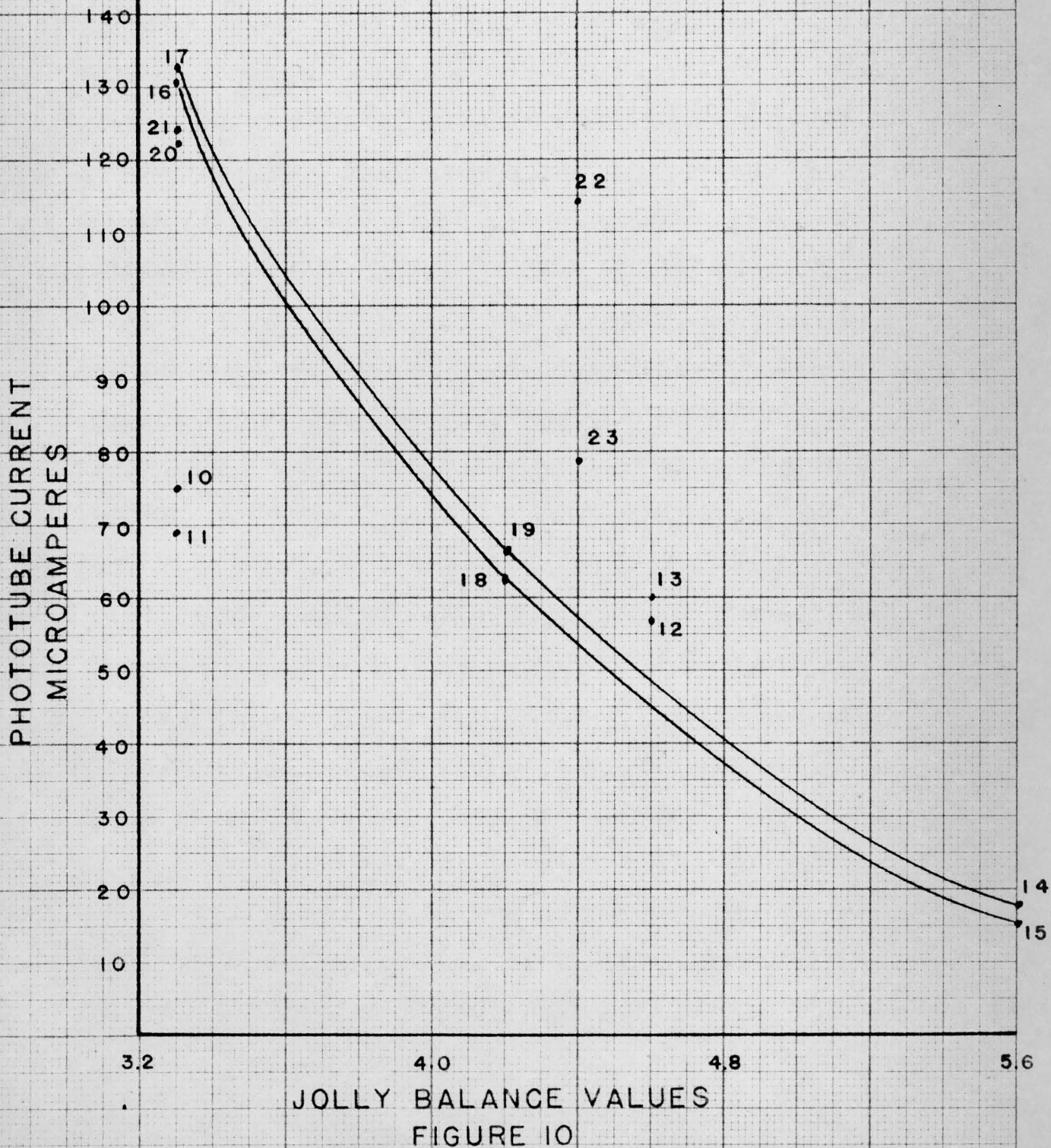


The phototube current total averages for these fourteen tissues were plotted against jolly balance readings. See Figure 10. All of the "mates" plot closely together with the exception of Tissues 22 and 23. Visual inspection of these two tissues showed that Tissue 23 had a denser coating than Tissue 22. The phototube current average also indicated this. Thus, an error in the jolly balance readings was presumed. Reference to Figure 10 shows three sets of "mate" values for the jolly balance value 3.3. Tissue 10, the "mate" of 11, was visually compared to Tissue 21, the "mate" of Tissue 20. This comparison demonstrated that Tissue 10 was definitely more thickly coated with ink than Tissue 20. Also, Tissue 10 was compared to Tissue 17, the "mate" of Tissue 16, and the result showed Tissue 10 more densely coated than Tissue 17. Finally, a comparison of Tissues 21 and 17 showed 21 to be a little darker than 17. The above observations were confirmed by the phototube current readings. Most of the total average values of the 23 tissues tested compared very favorably with the jolly balance values. The exceptions, noted above, were obviously errors in the jolly balance figures, which were discovered with the phototube.

With one exception, all the pairs of "mates" tested had total averages of phototube current that were strikingly close, and the one exception (Tissues 22 and 23) proved the jolly balance values to be at fault. The above measurements indicated very definitely that the phototube does detect variations in the thickness of coating of carbon ink on tissue paper.

CARBON TISSUES NOS. 10-23

BROWNSVILLE PAPER



EUGENE DIETZGEN CO.  
MADE IN U. S. A.

NO 340 20 DIETZGEN GRAPH PAPER  
20 X 20 PER INCH

The static measurements data taken on the 216 square areas of coated Tissue Nos. 2 to 23 inclusive have been placed in Appendix A. The data for Tissue 1 were placed in Table 2, page 32.

## 2. Static Measurements of Uncoated Tissue.

In these measurements an attempt was made to differentiate as nearly as possible between the carbon ink deposit and the paper. A coated tissue designated Tissue A (paper made by the International Paper Company) was placed in the cane board paper holder. For reference purposes, the squares of the grid of the paper holder were divided into rows and columns. Looking at the grid side of the paper holder (See Figure 4), the rows were numbered 1 through 12 from top to bottom and the columns were numbered from 1 through 18 from left to right. Measurements were taken of the square areas of coated tissue outlined by the first 8 rows and all 18 columns of the grid. The values of phototube current in microamperes obtained were recorded in the top series of figures of Rows 1 through 8 of Table 6.

When these measurements were completed, the same coated tissue (Tissue A) was then backed up with an uncoated tissue made by the International Paper Company. Measurements were then repeated over the areas measured previously thus measuring the amount of light transmitted through the coated tissue and the uncoated tissue. The values of phototube current obtained were recorded in the bottom set of figures in Rows 1 through 8 of Table 6. From the data of Table 6, eight sets of graphs were plotted. See Figures 11A, 11B, 11C, and 11D. Column numbers were plotted as abscissae (1 to 18)

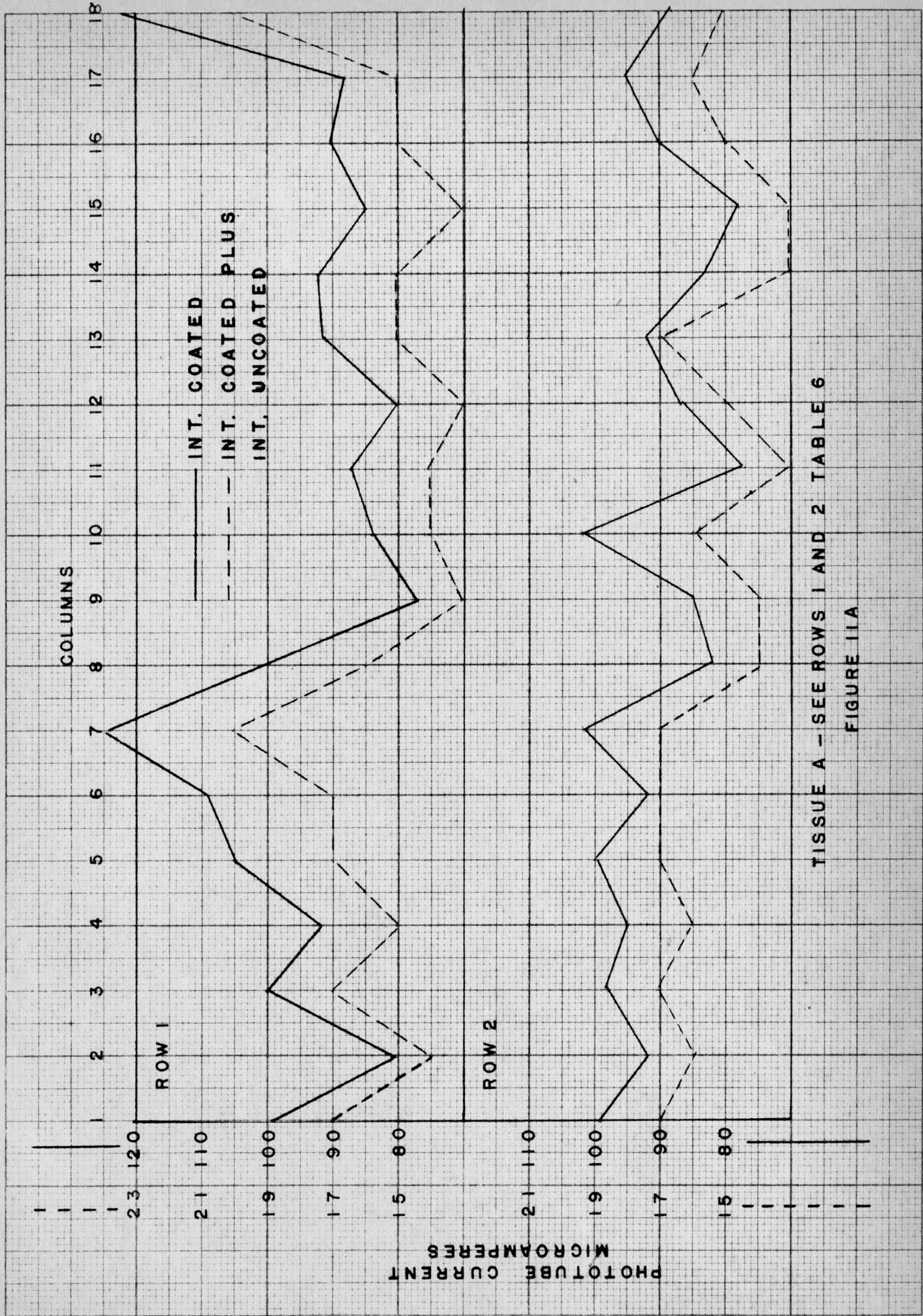
Table 6.  
Tissue A Data

Columns

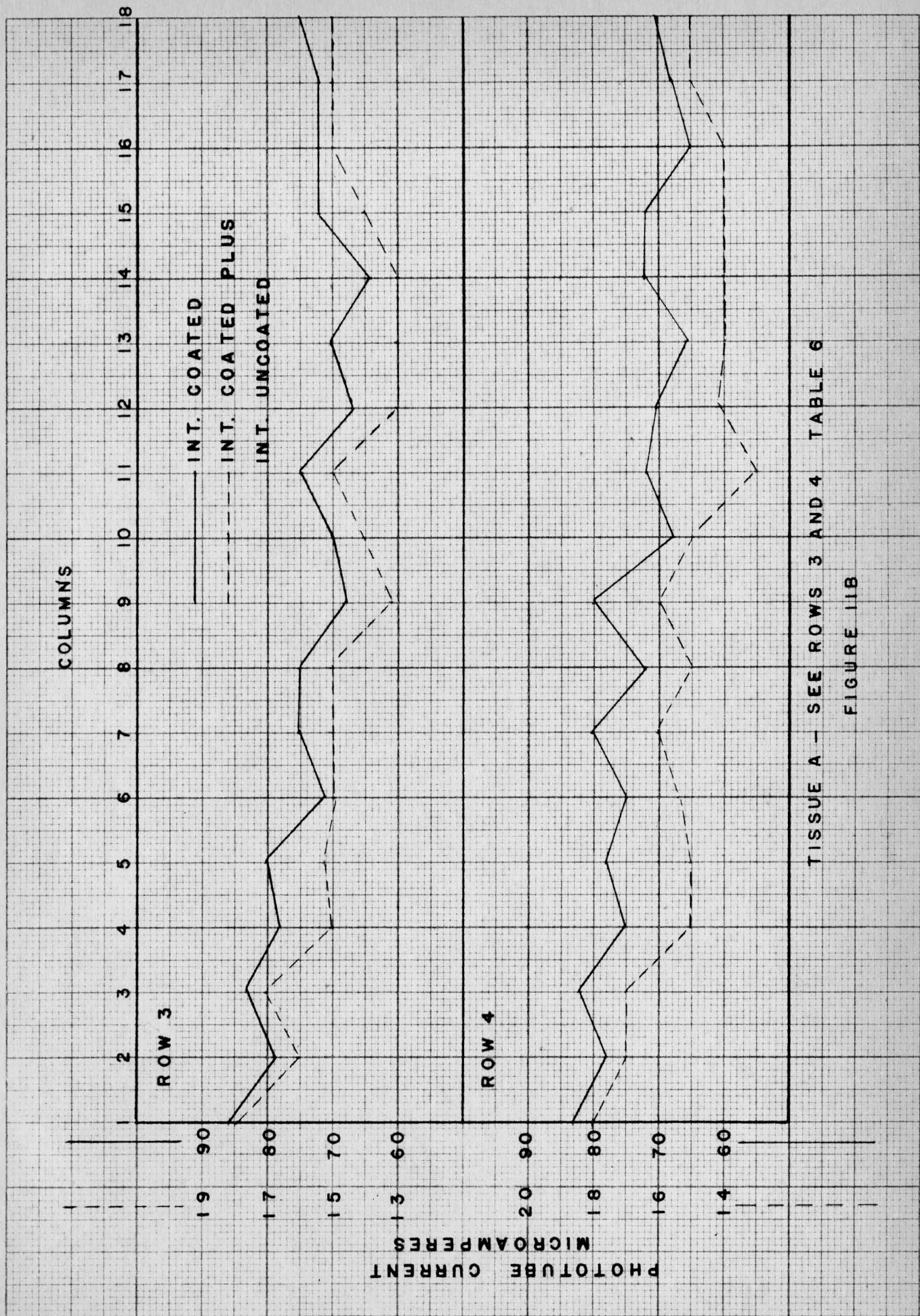
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1	99	80	100	92	105	109	125	101	77	84	87	80	91	92	85	90	88	122
	17	14	17	15	17	17	20	16	13	14	14	13	15	15	13	15	15	20
2	99	92	98	95	100	92	102	82	85	102	77	87	92	83	78	90	95	88
	17	16	17	16	17	17	17	14	14	16	13	15	17	13	13	15	16	22
3	86	79	83	78	80	71	75	75	68	70	65	67	70	64	72	72	72	75
	18	16	17	15	15e	15	15	15	13	14	15	13	13	13	14	15	15e	15
4	83	78	82	75	78	75	80	72	80	68	72	70	66	72	72	65	68	70
	18	17	17	15	15	15e	16	15	16	15	13	14e	14	14	14	14	15	15
5	96	100	80	99	92	86	80	78	85	78	79	72	77	80	65	75	83	88
	20	21	17	20	19	18	17	15	17	15	17	15	15	17	15	15	17	19
6	95	82	82	98	80	73	82	78	73	68	70	67	67	64	75	68	65	84
	20	17	18	19	18	15	17	17	16	14	15	15	15	14	17	15	14	18
7	99	91	92	83	93	82	78	65	72	78	72	70	72	80	78	63	78	70
	20	18	18	16	18	17	16	15	15	16	15	13	15	15	17	13	15	15
8	90	87	75	92	85	75	78	87	70	72	68	82	74	69	77	72	72	78
	20	18	15	18	17	17	16	18	15	15	14	16	15	13	15	14	15	16

The above figures represent the readings in micromeres taken on Tissue A, an International Coated Tissue. In each row the top figures represent the readings in micromeres obtained with the coated tissue only. The bottom figures are the readings in micromeres obtained with the coated tissue backed up by a piece of International uncoated tissue. The bottom figure readings were taken as close as possible to the areas of the tissue that the top figures readings were taken.

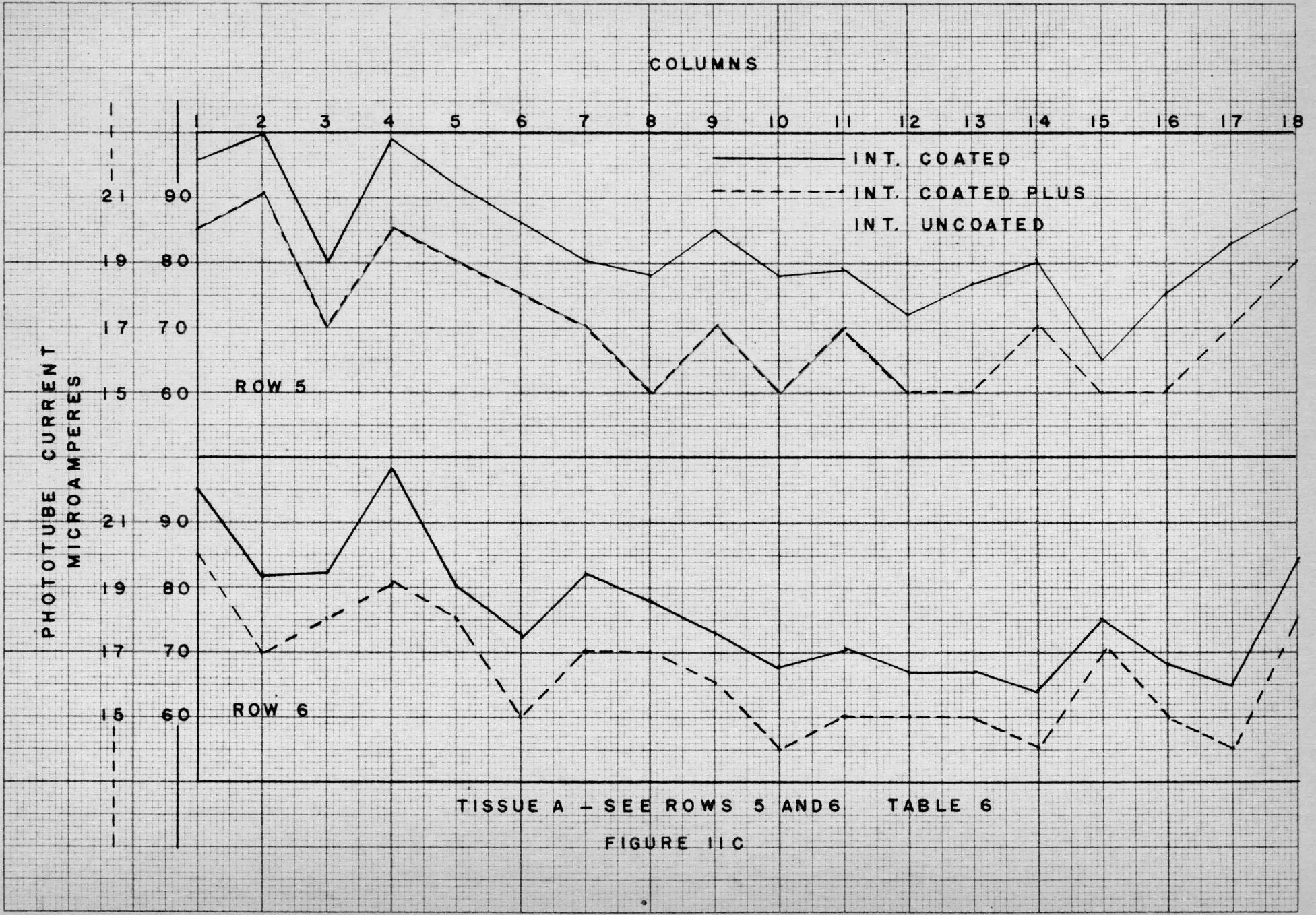
Note: 13. means 13.5; 21e means 21 plus.



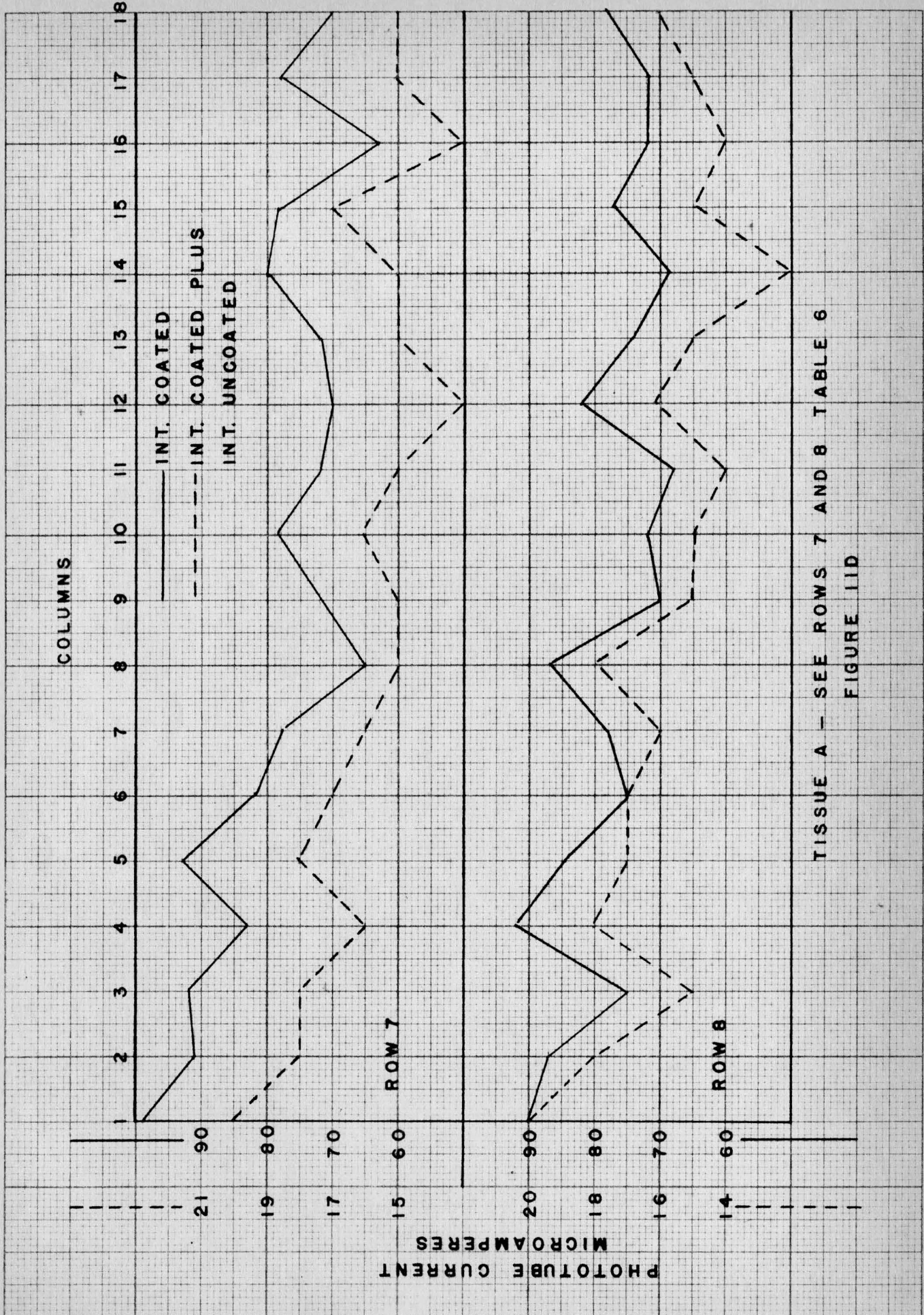
TISSUE A - SEE ROWS 1 AND 2 TABLE 6  
FIGURE 11A



TISSUE A - SEE ROWS 3 AND 4 TABLE 6  
FIGURE 11B



45



TISSUE A - SEE ROWS 7 AND 8 TABLE 6  
FIGURE IID

and the microammeter readings as ordinates. For each row two graphs were drawn, one graph to represent the coated tissue readings alone, the other graph to represent the coated tissue backed up with the uncoated tissue. Straight lines were drawn from point to point rather than a smooth curve. The solid graph lines represent readings on the coated tissue alone and the broken graph lines represent readings taken with the coated tissue backed up with the uncoated tissue.

The ordinates of the two sets of values were scaled so that a ready comparison of the two graph lines in each row could be obtained. Comparison of the solid and broken graphs plotted for each of the eight rows shows a definite parallelism. The majority of the pairs of points plotted for each area tested show changes in the same direction or nearly so. The parallelism of the graphs in Rows one, two, five, six, seven and eight is quite evident. The discrepancies in parallelism noted in Rows three and four may be due to errors in reading the microammeter scale at the lower values, not having the light spot in the exact same position for coated tissue alone and the coated tissue plus uncoated tissue readings, and non-uniformities of the coated and uncoated tissue papers.

These graphs indicate that the changes in light intensity as the spot is moved from area to area on the coated tissue are a function, in the main, of the thickness of the carbon deposit. The paper does decrease the level of light intensity, but apparently it

does so in a reasonably uniform manner for a given length of tissue on a roll. However, the density of a given type of tissue varies from roll to roll and the exact effect of this changing density on the thickness measurements indicated by the phototube is not known. It is believed, however, that future investigation will show this changing density of the tissue can be neglected or compensated for.

A second series of measurements was made on a Brownsville coated tissue alone and then this tissue (Tissue B) was backed up with an uncoated Brownsville tissue and the process repeated. This procedure was identical with the one used on Tissue A, explained above. The data obtained was recorded in Table 7. The upper figures in each row of Table 7 are the phototube currents in microamperes that were recorded for the coated tissue alone. The lower figures in each row represent the microampere measurements on the Brownsville coated tissue plus the Brownsville uncoated tissue. Graphs were plotted in the same manner as for Tissue A. See Figures 12A, 12B, 12C, and 12D. These graphs, like the graphs for Tissue A, show a definite parallelism indicating that the uncoated Brownsville tissue was very uniform for the area tested.

A third series of measurements were made. A Kraftex coated tissue (Tissue C) was measured as above. This tissue was backed up with a Kraftex uncoated tissue and the measurements were repeated as outlined for Tissues A and B. The Kraftex uncoated tissue was removed and replaced by an International uncoated tissue and measurements were again taken. All measurements are recorded in Table 8.

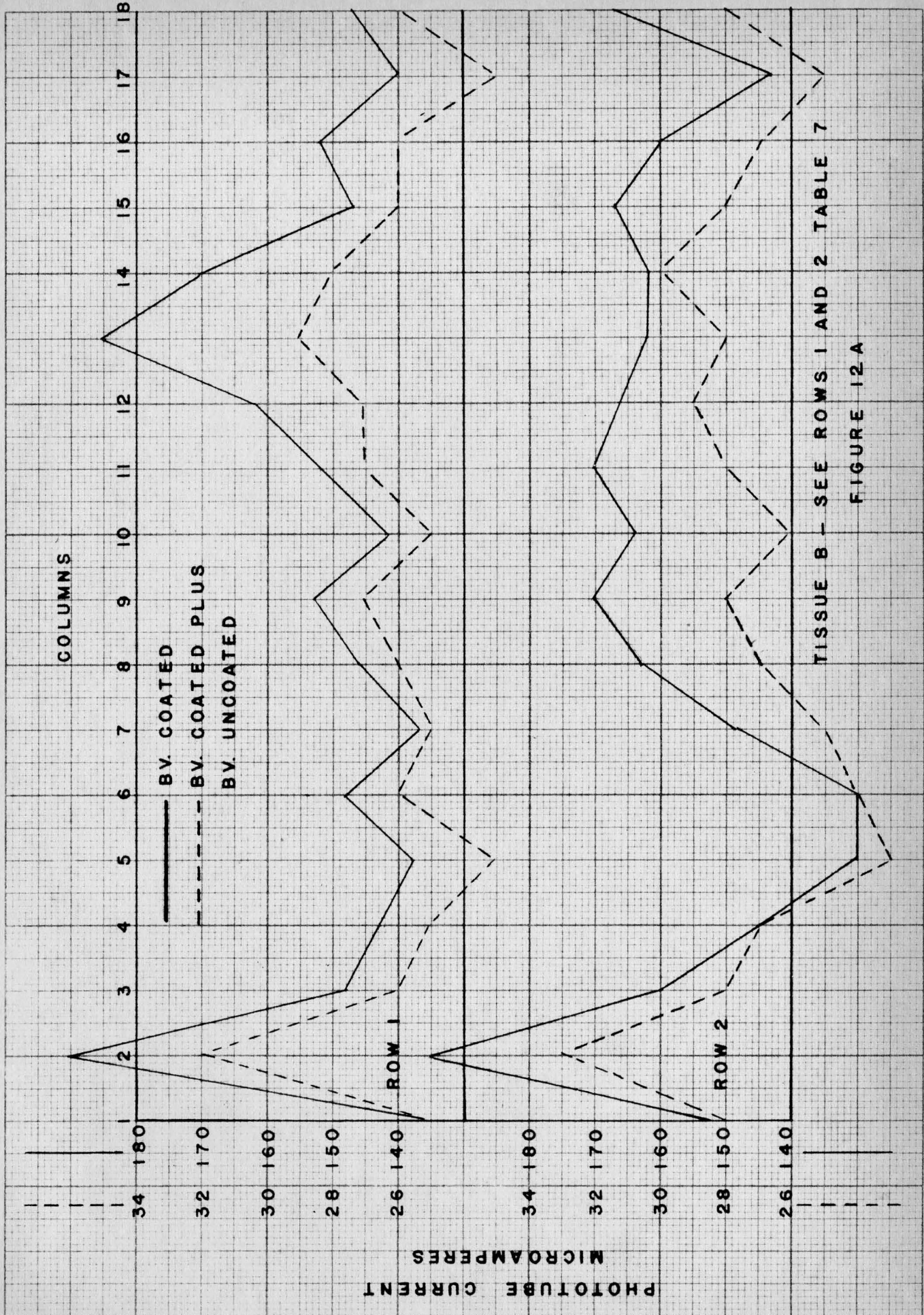
Table 7.  
Tissue B Data

Columns

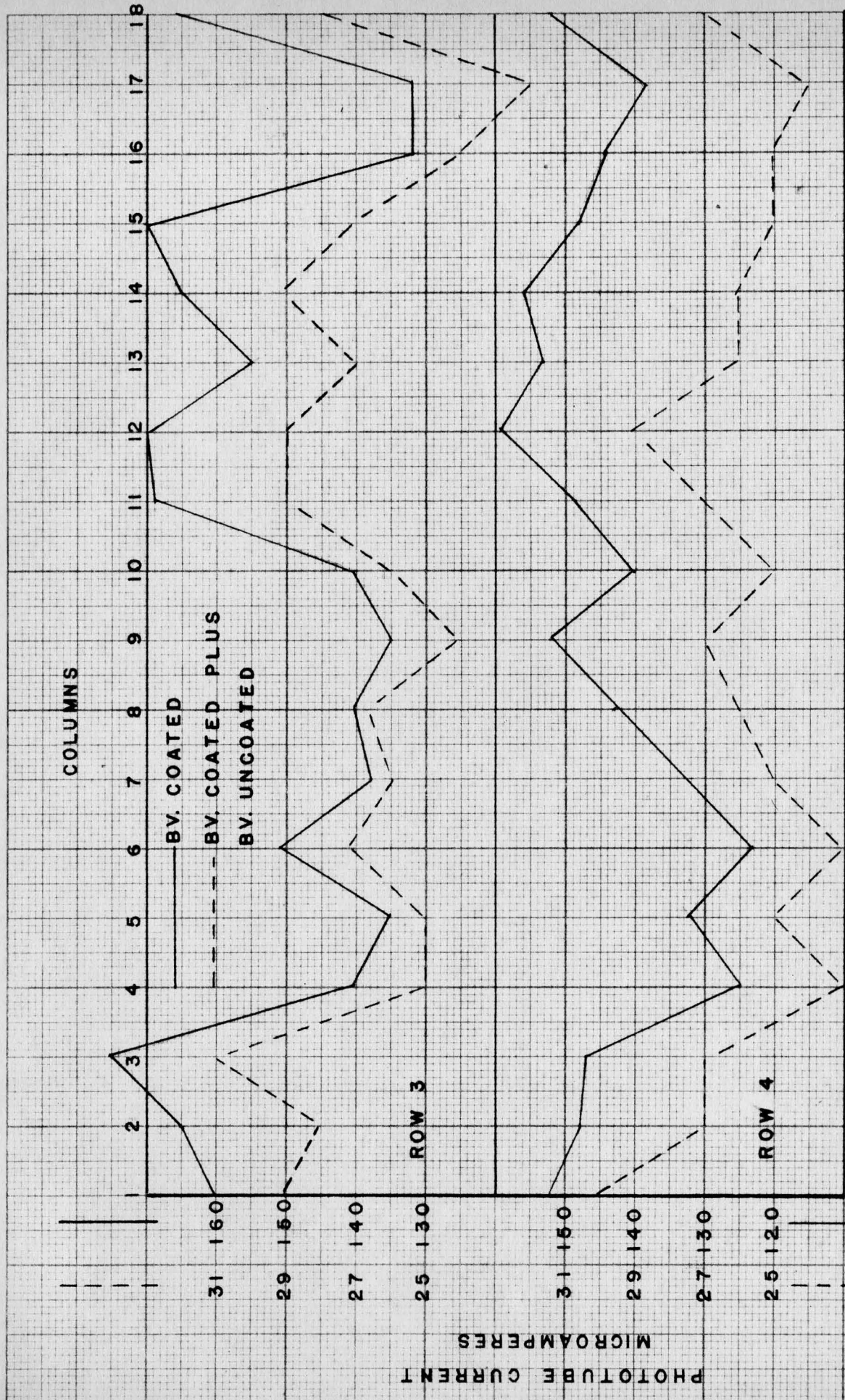
Rows	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	135	190	148	143	138	148	137	146	153	142	152	162	185	170	147	152	140	147
	25	32	26	25	23	26	25	26	27	25	27	27	29	28	26	26	23	26
2	152	195	160	145	130	130	148	163	170	164	170	166	162	162	167	160	143	167
	28	33	28	27	23	24	25	27	28	26	28	29	29	30	28	27	25	28
3	160	165	175	140	135	150	138	138	135	140	169	170	155	165	170	132	132	165
	29	28	31	25	25	27	26	27	24	26	29	29	27	29	27	24	22	28
4	152	148	167	125	132	123	132	143	152	140	169	159	153	156	143	144	139	152
	30	27	27	23	25	23	25	26	27	25	27	28	26	26	25	25	24	27
5	135	150	118	121	127	132	134	142	144	137	170	155	132	151	133	122	130	142
	26	28	24	24	26	26	27	28	28	26	31	29	24	28	23	22	23	25
6	135	153	148	138	132	125	135	142	172	153	140	166	145	145	138	140	137	155
	21	25	24	23	23	22	22	25	29	25	23	25	22	22	22	24	23	27
7	130	118	107	105	116	106	110	120	115	116	114	120	121	130	125	114	127	130
	23	22	19	19	21	19	20	21	21	21	20	21	21	22	22	20	22	23
8	115	110	94	98	89	96	112	110	118	115	116	112	114	116	116	98	108	135
	21	20	16	19	17	18	21	20	22	21	21	19	20	20	18	19	22	

The above figures represent the readings of phototube current (microamperes) taken on Tissue B, a Brownsville coated tissue. In each row the top figures are readings in microamperes obtained with the coated tissue only. The bottom figures are readings in microamperes obtained with the coated tissue backed up with an uncoated Brownsville tissue.

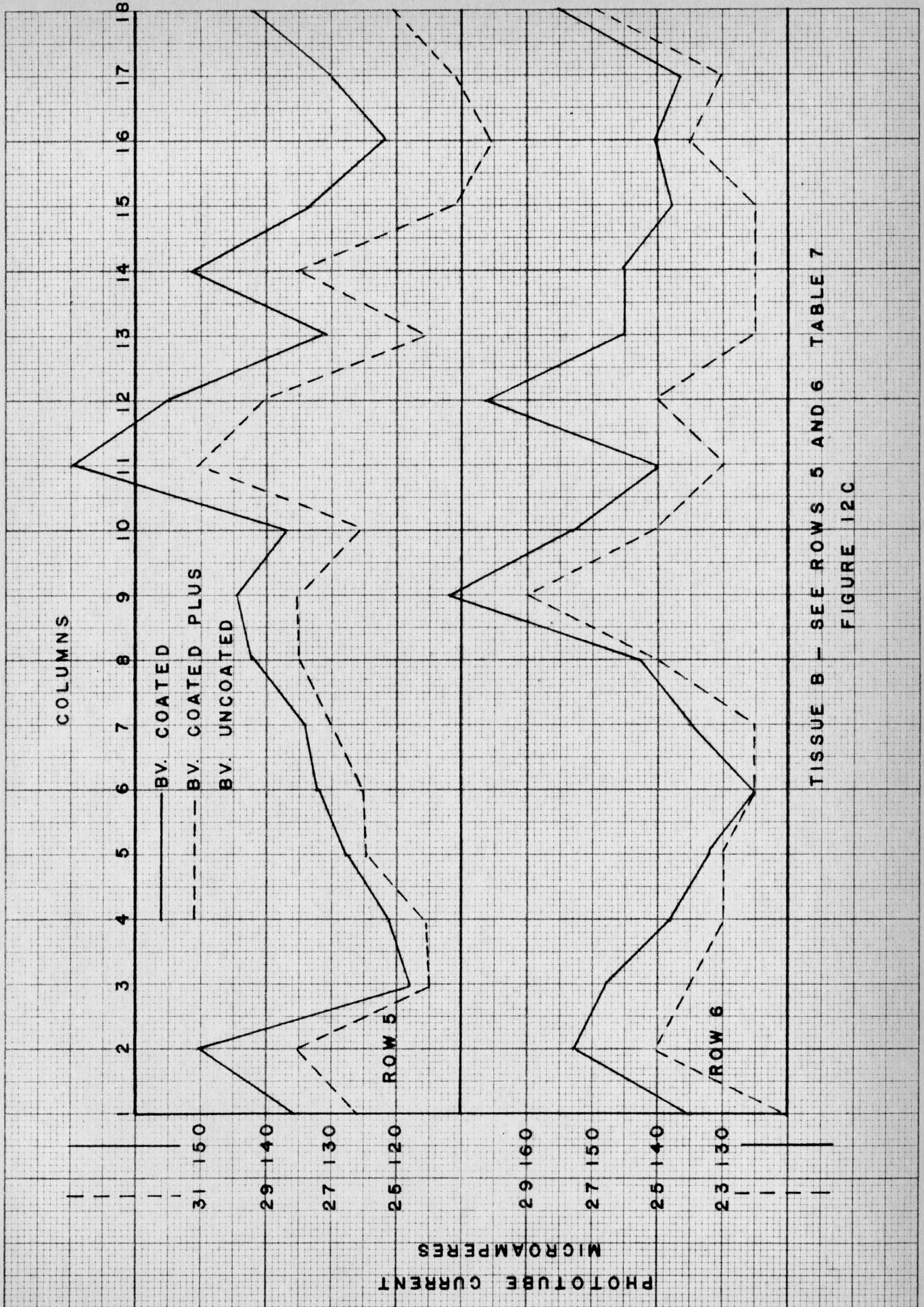
Note: 21. means 21.5; 21e means 21 plus.



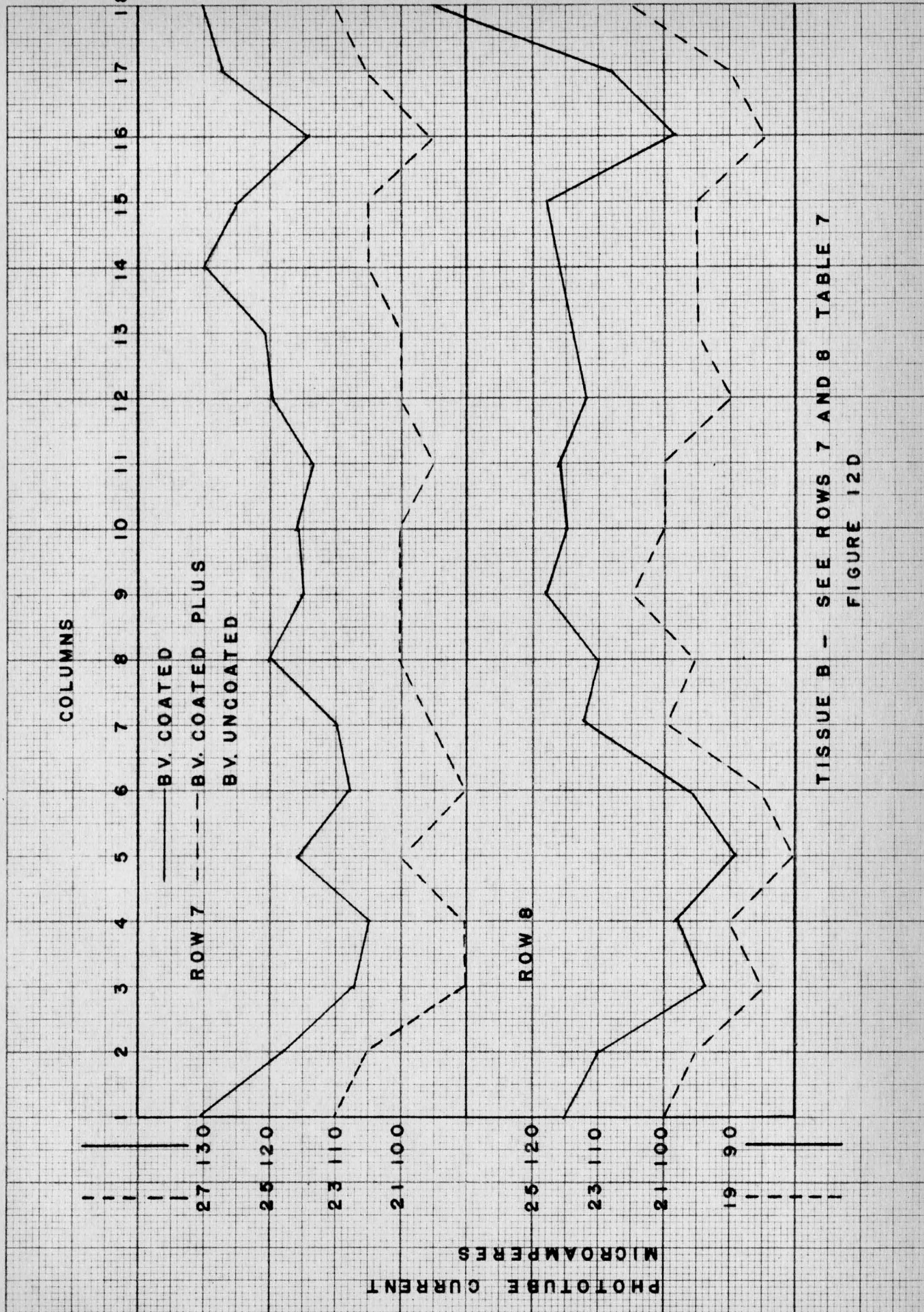
TISSUE B - SEE ROWS 1 AND 2 TABLE 7  
FIGURE 12A



TISSUE B - SEE ROWS 3 AND 4 TABLE 7  
FIGURE 12 B



TISSUE B - SEE ROWS 5 AND 6 TABLE 7  
FIGURE 12C



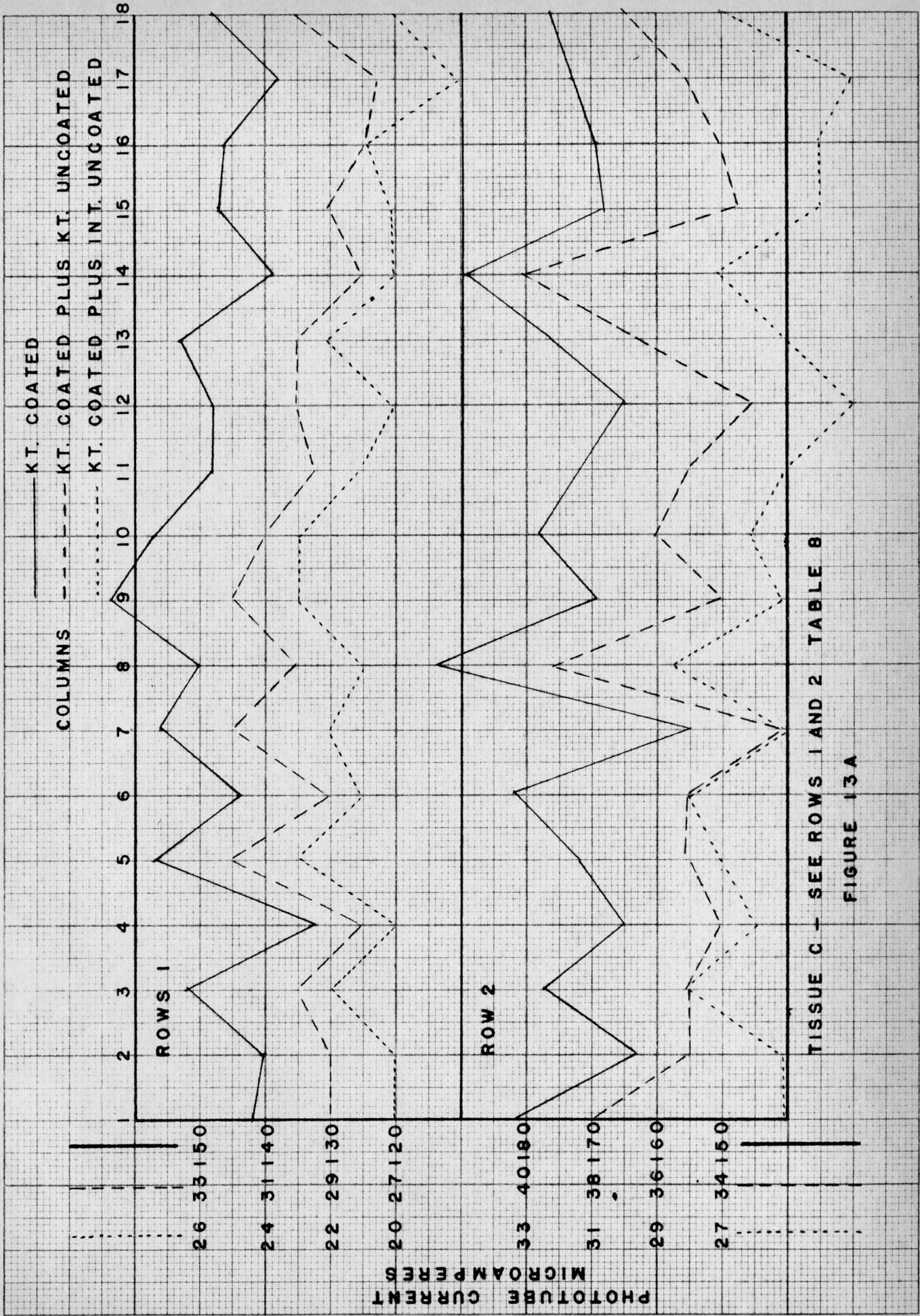
TISSUE B - SEE ROWS 7 AND 8 TABLE 7  
FIGURE 12D

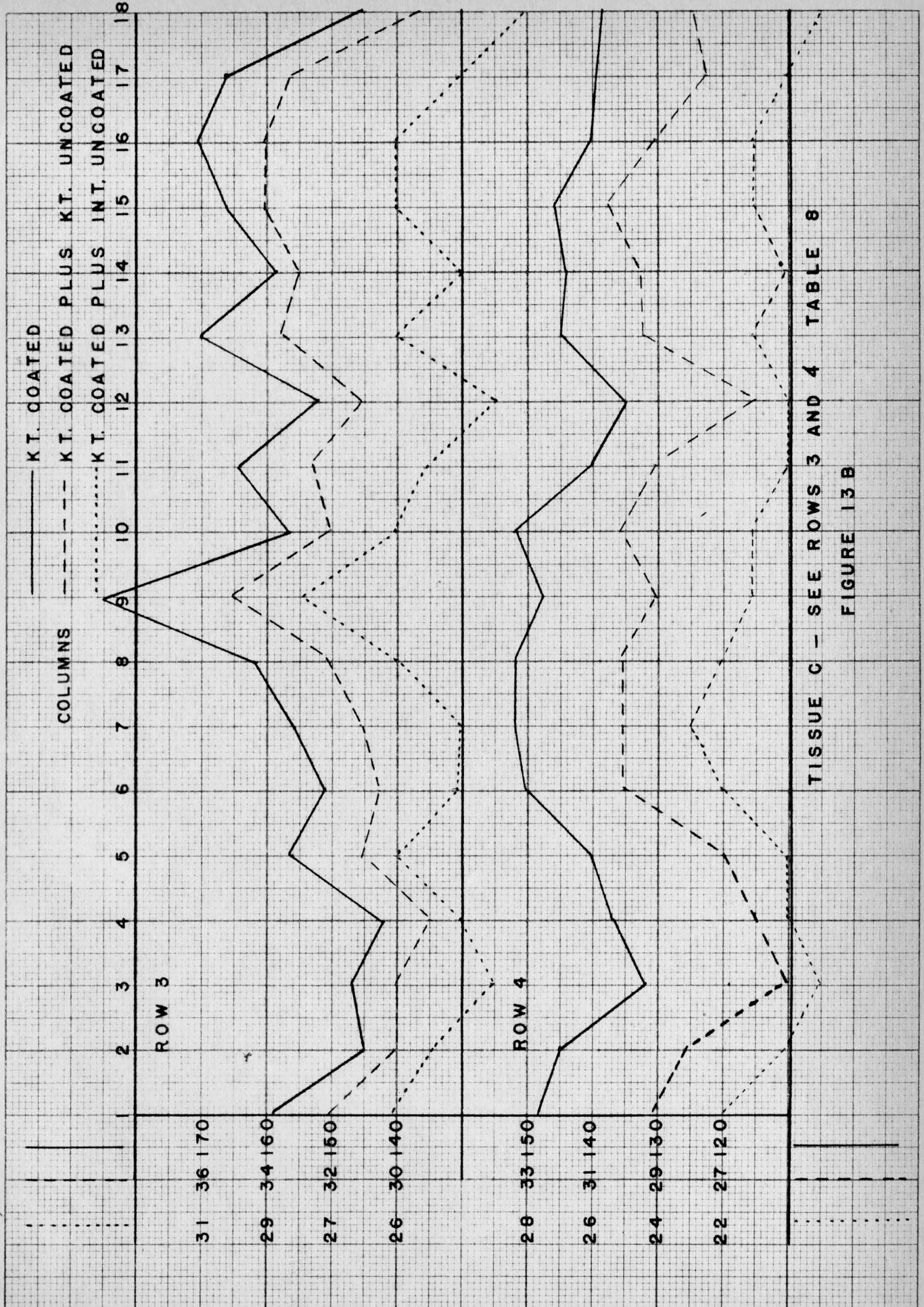
**Table 8.**  
Tissue C Data  
Columns

Rows	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
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	29	29	30	28	32	29	30	30	32	31	29	30	30	28	29	28	27	30
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2	182	163	177	165	172	182	155	194	169	178	172	165	177	190	168	169	173	176
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3	159	145	147	142	156	151	156	161	185	156	164	152	170	158	166	170	166	143
	32	30	30	29	31	30	31	32	35	32	32	31	33	33	34	34	33	29
	25	24	22	23	25	23	23	25	28	25	24	22	25	23	25	25	23	21
4	148	145	132	137	140	150	152	152	148	152	140	135	144	144	145	140	139	139
	29	28	25	26	27	30	30	30	29	30	29	26	29	29	30	29	27	28
	22	20	19	20	20	22	23	22	21	21	20	20	21	20	21	21	20	19
5	135	123	125	142	150	142	148	151	147	155	141	151	174	171	159	142	153	145
	29	27	27	30	31	30	30	32	30	31	29	30	35	35	33	30	32	30
	20	19	18	22	22	21	21	23	21	22	21	19	23	23	22	21	22	21
6	150	142	138	162	149	158	151	138	142	155	140	153	149	140	145	139	148	138
	30	28	28	32	30	32	30	28	29	31	29	31	30	29	31	30	32	30
	23	21	21	24	24	24	21	22	20	21	20	21	21	19	22	20	21	21
7	149	131	136	152	157	119	125	145	139	150	142	149	142	135	127	149	140	132
	30	28	28	30	32	27	28	32	30	30	28	30	29	28	28	30	30	28
	22	20	20	21	23	14	19	21	20	21	21	21	20	20	20	22	21	20
8	147	125	127	126	128	128	118	152	128	134	136	133	129	132	128	127	134	135
	33	28	28	28	28	28	25	34	28	30	29	28	27	29	28	28	29	29
	22	20	21	20	20	20	18	23	20	21	21	20	19	20	20	20	21	20

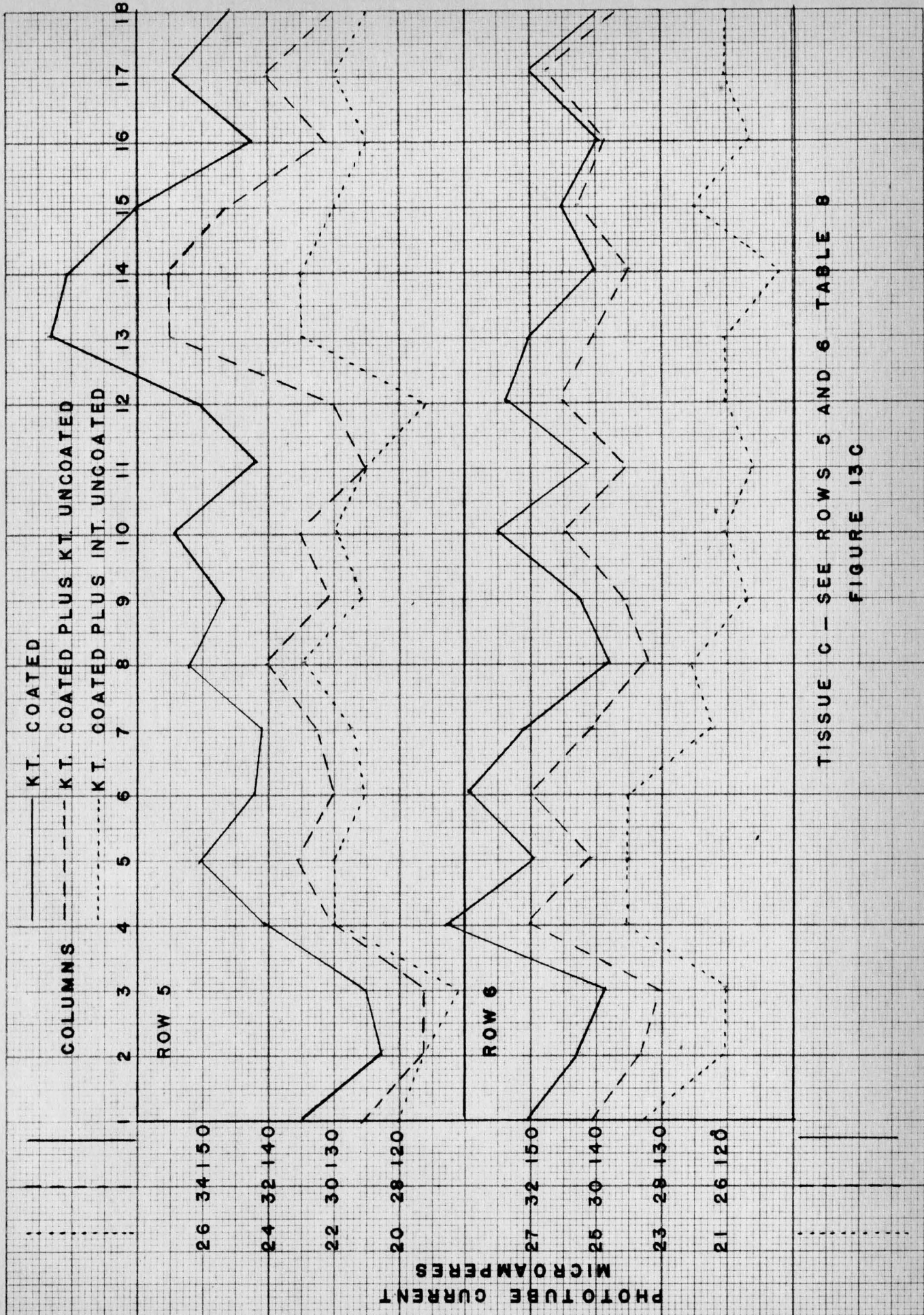
In each row: Top figures; Readings in microamperes on Kraftex coated tissue only.  
 Middle figures; Readings in microamperes on Kraftex coated backed up with Kraftex uncoated tissue.  
 Bottom figures; Readings in microamperes on Kraftex coated backed up with International uncoated tissue.

Note: 33. means 33.5; 33e means 33 plus.

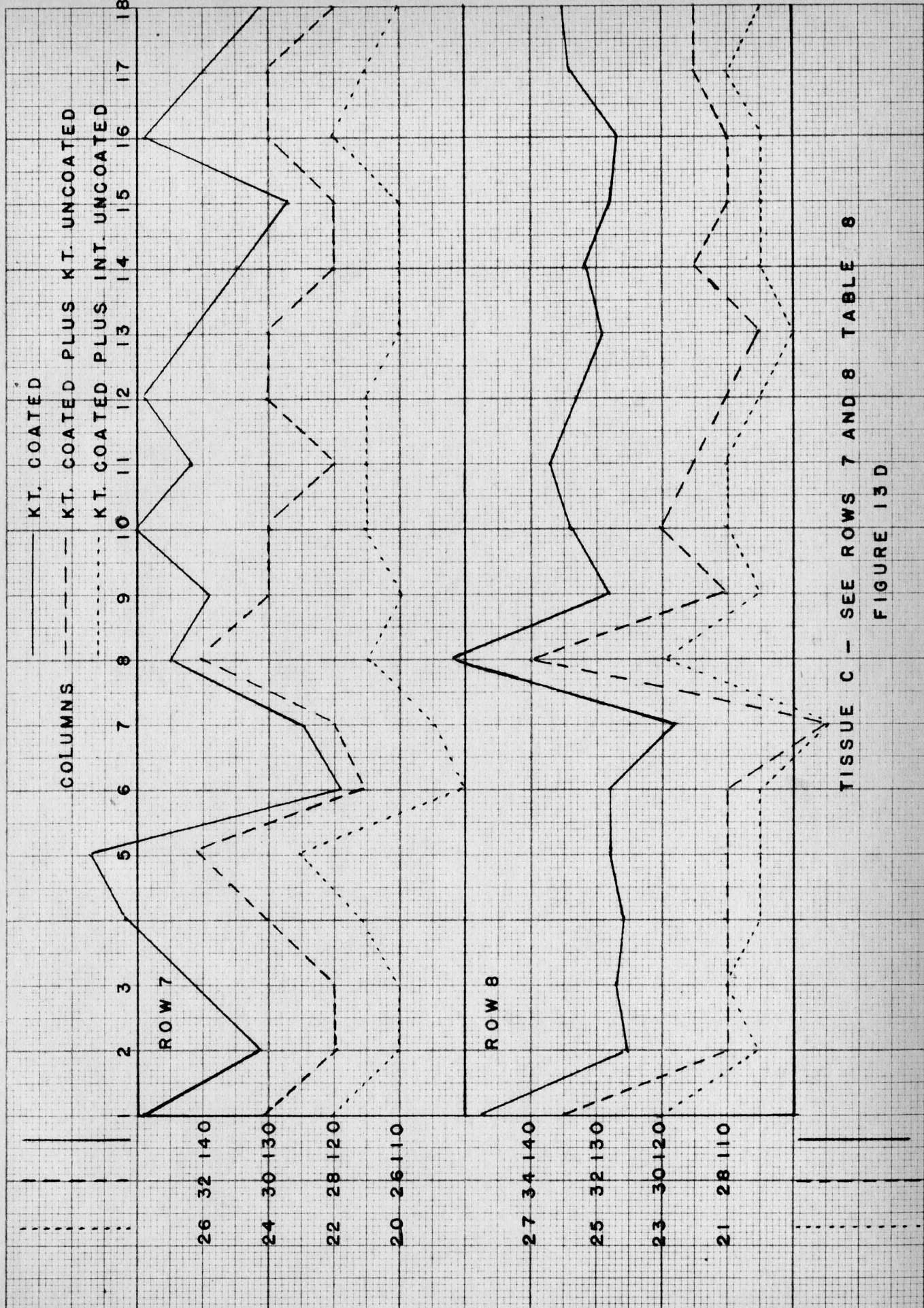




TISSUE C - SEE ROWS 3 AND 4 TABLE 8  
FIGURE 13 B



TISSUE C - SEE ROWS 5 AND 6 TABLE 8  
FIGURE 13C



TISSUE C - SEE ROWS 7 AND 8 TABLE 8  
FIGURE 13D

The top figures in each row of Table 8 represent Kraftex coated tissue alone, the middle figures Kraftex coated plus Kraftex uncoated, and the bottom figures Kraftex coated plus International uncoated. Graphs were plotted from the data. See Figures 13A, 13B, 13C, and 13D. The solid graph line represents Kraftex coated alone, the broken graph line Kraftex coated plus Kraftex uncoated, and the dotted graph line Kraftex coated plus International uncoated.

Reference to these graphs (Figure 13) shows that all three graphs vary the same way in the majority of points plotted. It is interesting to note that the International uncoated tissue cuts down the intensity of the light energy more than the Kraftex uncoated tissue. The difference in level for Row 1 is about nine microamperes. As pointed out previously, the different types of tissue paper affect the levels of the readings of the multiplier phototube. Evidence of this fact is contained in the above results.

The above experiments on uncoated tissue were continued using different samples of uncoated tissue and cellophane coated with carbon ink. The coated cellophane sample was labelled Tissue D. The area of this sheet of cellophane was 18 square inches. The coated cellophane sample was placed in the paper holder and measurements were made on the seventy-two squares (8 rows and 9 columns) as outlined previously. These measurements are recorded in Table 9. The upper figures in each row listed in Table 9 are the readings in microamperes of phototube current that were observed in this

Table 9. Tissue D Data

Rows	Columns								
	1	2	3	4	5	6	7	8	9
1	98	91	100	118	94	100	200e	82	101
	19	17.5	20	25	19	21	35	17	19
	13	11	13.5	15	12.5	14	21	11	13
	13	11	13	15	12.5	14	21	11	13
2	96	95	101	115	93	100	200e	83	101
	19	19	21	25	19	21	35	17	19
	13.5	11	13.5	15	13	13.5	22.5	11	13
	13	12	13.5	16	13	13.5	21	11	13
3	93	87	93	107	86	90	200e	78	95
	19	17.5	19	22	18	19	35	17	18
	13	11.5	12.5	15	13	13	23	11	13
	13	12	12.5	15	13	13	22.5	11	13
4	87	78	83	108	80	101	200e	83	83
	18	16.5	17	30	18	20	33	17	17
	12.5	10	12	19	12	13	22	12.5	12.5
	11	9	10	19	12	13	22	12.5	12.5
5	90	81	96	115	90	103	195	91	87
	20	18	21	27	20	21	35	20	19
	14	12.5	13.5	18	15	15	24	14	12.5
	13	10	12	18	15	15	25	13	12
6	98	85	110	118	101	102	199	125	90
	22	19	22	29	22.5	22.5	39.0	27.5	19
	15	13	15	19	15	15	25	17.5	13.5
	15	12.5	15	19	15	15	25	17.5	13
7	118	100	111	130	122	114	203e	113	92
	27	21	24	32	29	26.5	46	25	20
	17	14	16	20	18	17.5	30	16	13
	17	14	16	20	17.5	17	28	15	13
8	140	130	132	178	142	157	200e	140	102
	30	27	27	42	33	35	53	27	22
	20	16	17.5	26	20	21	33	18	15
	20	16	17.5	25	20	21	32.5	17.5	15

In each row: First Figures; Readings in microamperes on the coated cellophane tissue alone.

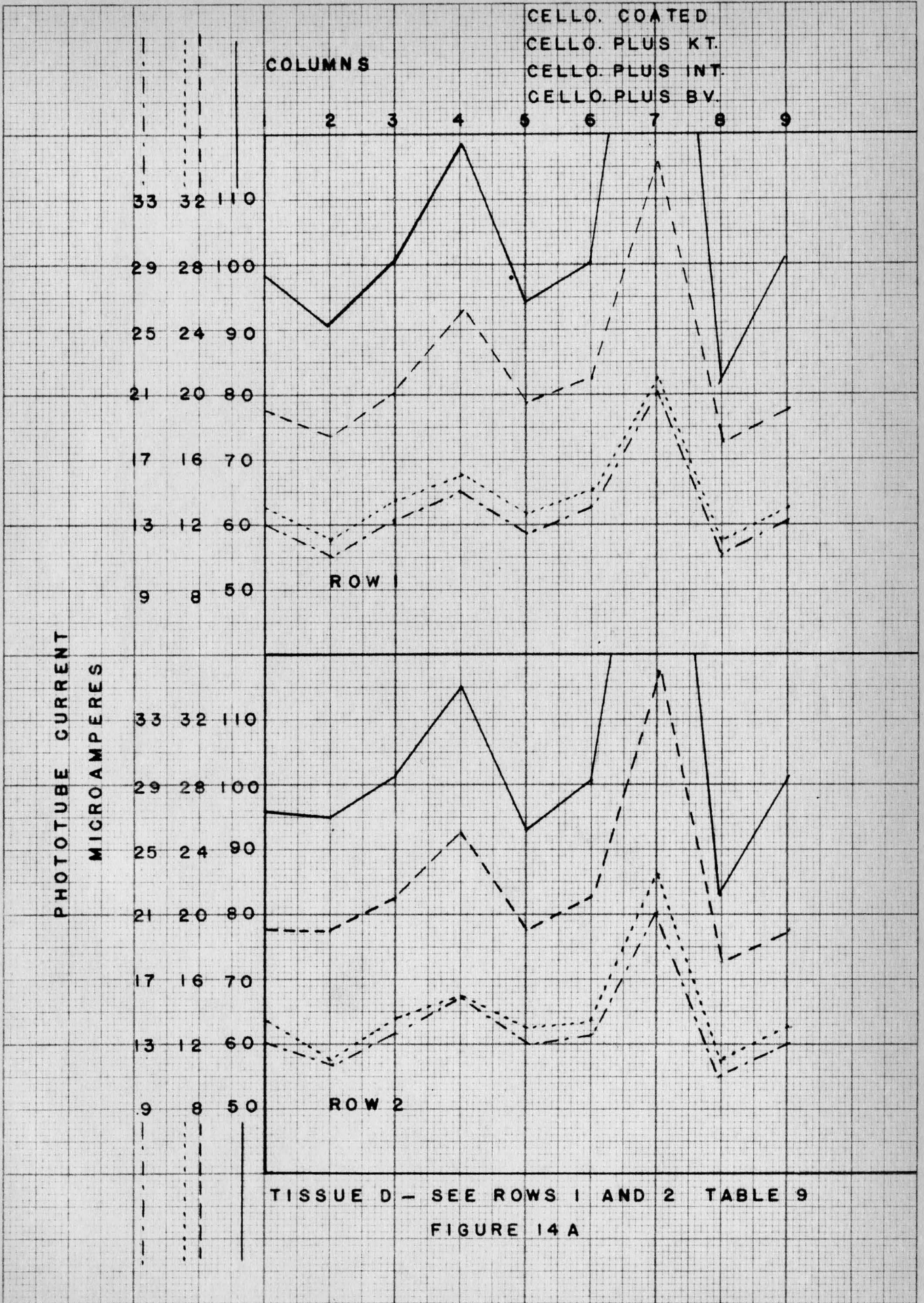
Second Figures; Readings in microamperes on the cellophane tissue plus Kraftex tissue.

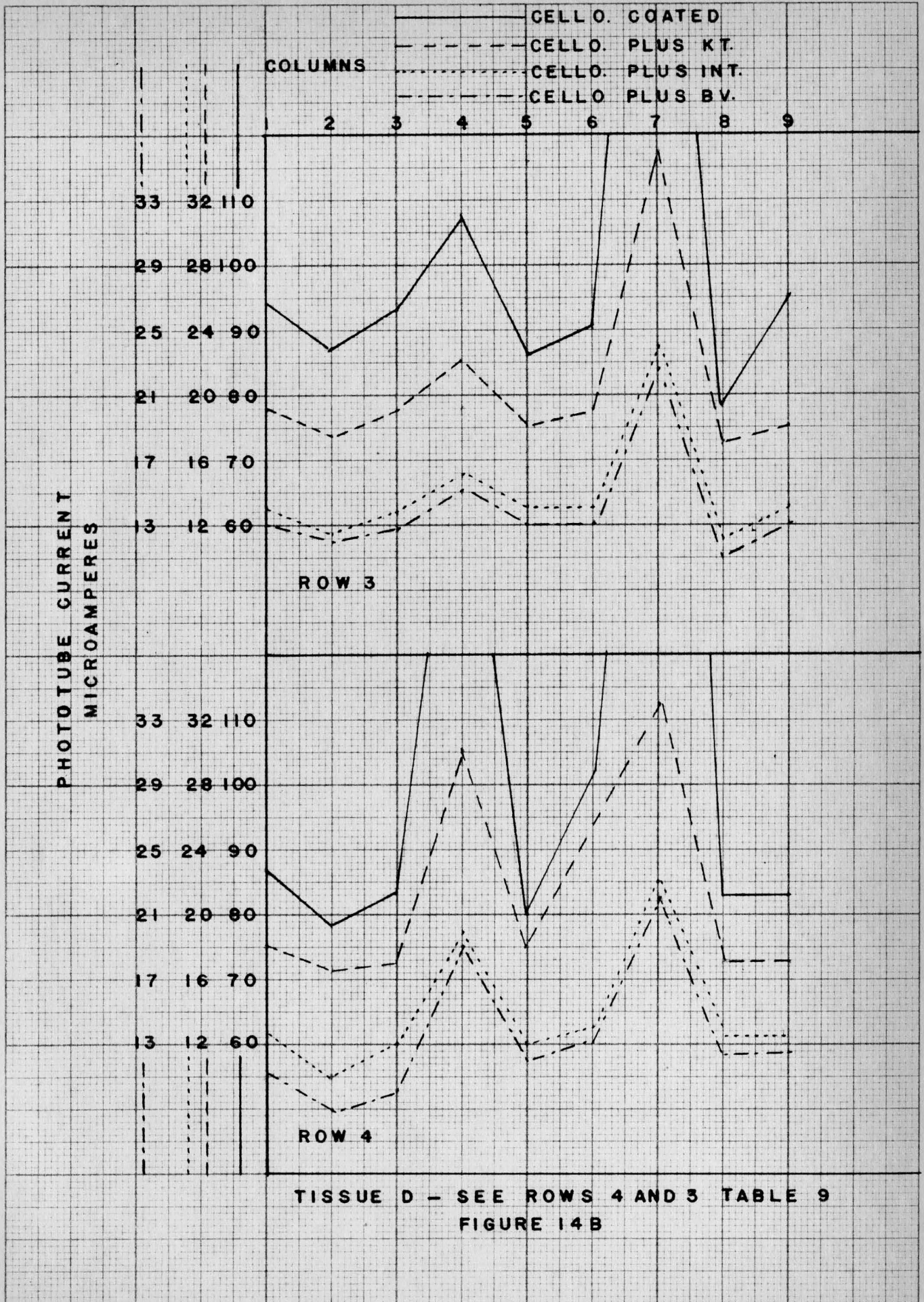
Third Figures; Readings in microamperes on the cellophane tissue plus International tissue.

Fourth Figures; Readings in microamperes on the cellophane tissue plus Brownville.

Note: 200e means 200 plus.

The above data shows the measurements recorded for Tissue D, a cellophane tissue coated with carbon ink.





COLUMNS

— CELLO. COATED  
 - - - CELLO. PLUS KT.  
 ···· CELLO. PLUS INT.  
 - · - CELLO. PLUS BV.

PHOTOTUBE CURRENT  
MICROAMPERES

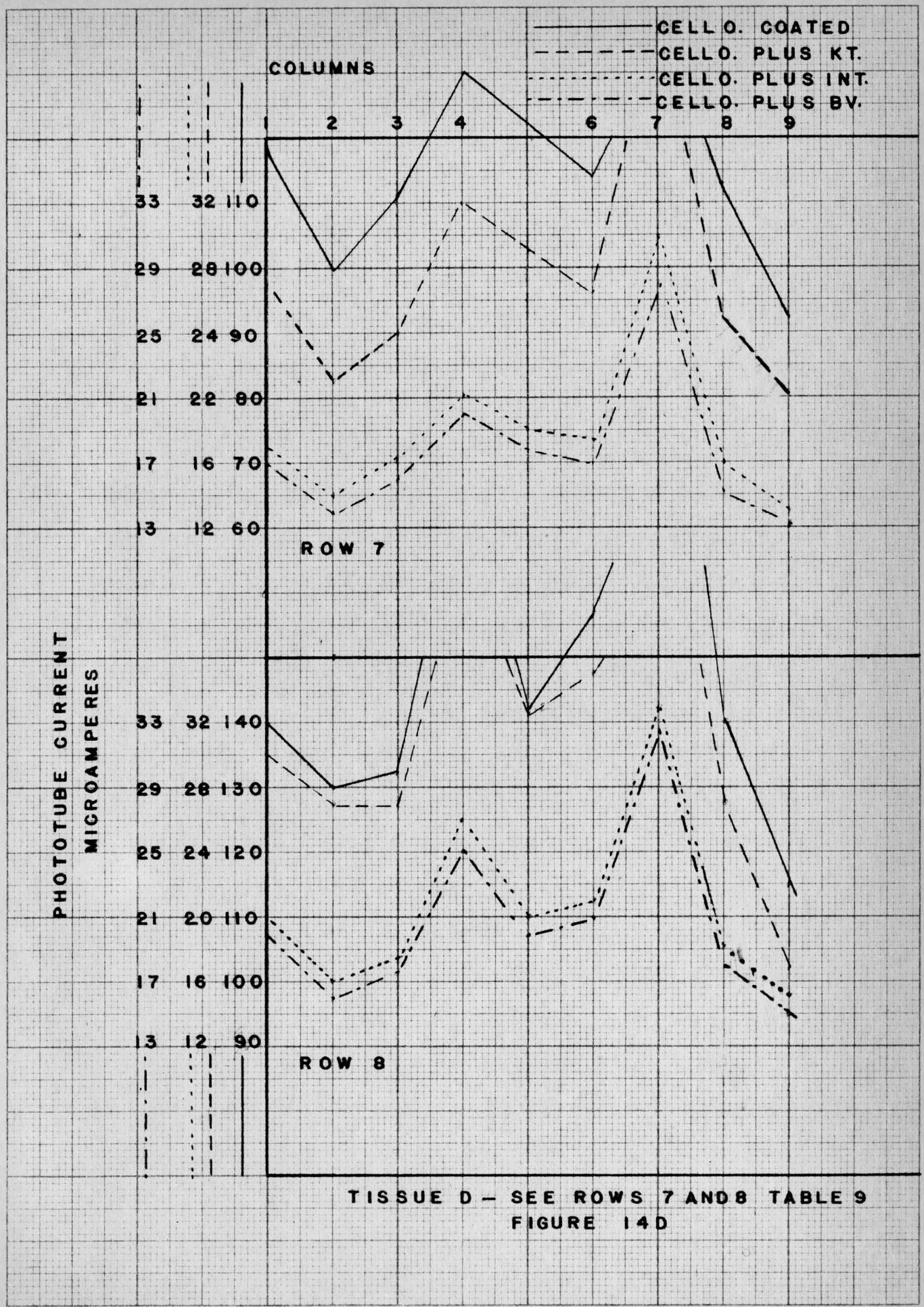
33 32 110  
29 28 100  
25 24 90  
21 20 80  
17 16 70  
13 12 60

ROW 5

33 32 110  
29 28 100  
25 24 90  
21 20 80  
17 16 70  
13 12 60

ROW 6

TISSUE D - SEE ROWS 5 AND 6 TABLE 9  
FIGURE 14 C



TISSUE D - SEE ROWS 7 AND 8 TABLE 9  
FIGURE 14D

test. When these measurements were completed, the coated cellophane tissue (Tissue D) was then backed up with an uncoated Kraftex tissue. Measurements were then repeated over the areas measured previously and the values were recorded in the second set of figures in each row of Table 9. In the same manner measurements were taken on the cellophane backed up successively with uncoated International and Brownsville tissues, and the results were recorded in the third and fourth set of figures in each row respectively.

Graphs were plotted from the data of Table 9. Column numbers were plotted as abscissae (1 to 8) and the microammeter readings as ordinates. Straight lines were drawn from point to point. The solid graph line represents readings on the coated cellophane alone. The broken line represents the cellophane backed up with a Kraftex uncoated tissue. The dotted graph line and the combination dotted and broken graph line represent the cellophane backed by International and Brownsville uncoated tissues respectively. See Figures 14A, 14B, 14C, and 14D. The four ordinate scales were proportioned so that ready comparison of the curves could be obtained.

The lower values of the readings obtained when the coated tissues are backed up with the uncoated tissues as compared to the readings that were obtained with the coated tissue alone indicated that the uncoated tissue attenuates the low level of light energy passing through the coated tissue. This attenuating effect is due to absorption, reflection and scattering of the light energy by the uncoated paper. The data obtained using the coated cellophane

indicates that the Kraftex tissues apparently attenuates the light energy to a lesser degree than the Brownsville and International tissues. The Brownsville and International values plot very closely together as indicated in Figures 14A, 14B, 14C, and 14D.

### 3. Dynamic Measurements of Coated Tissue.

The static measurements described above proved that the multiplier phototube definitely detects changes in thickness of the carbon ink coating on tissue paper. Since the moving web of paper moves at velocities of from 500 to 600 feet per minute when the paper is being coated, an experiment was devised to determine whether or not the multiplier phototube current values changed when the velocity of the web changed.

The velocity of a moving web of carbon ink coated tissue was simulated in the following manner. A sewing machine motor, of the universal (AC -DC) series field type, was obtained. Seven inch in diameter circular pieces of coated tissue were cut out of the sample carbon coated tissues on hand. A quarter inch hole was punched in the center of these circular samples so that they could be individually mounted on the shaft of the motor. A given sample was secured to the shaft of the motor by means of two brass fittings. By using a variac (a variable transformer used to vary the voltage supplied to the motor from 0 to 120 volts RMS) it was possible to vary the speed from 300 to 1500 revolutions per minute. Thus, a circular piece of tissue mounted on the shaft of the motor by means

of its one-fourth inch punched hole and secured by two brass fittings could be revolved between the above values of RPM very easily. Values below 300 RPM caused the tissue to flutter because the centrifugal force was not high enough to keep the tissue smooth. Values above 1800 RPM were considered unsafe, as the centrifugal forces involved were high (the series motor having such a light load). Figure 15 shows a view of the series motor with a seven-inch circular piece of coated tissue mounted on the motor shaft. The connections of the motor to the variac are also shown.

With the above apparatus velocities from 471 feet per minute to 2826 feet per minute were obtained at a distance of 3 inches from the center of the shaft at the above values of RPM. Since the linear velocity of a point on the circular piece of paper at a distance of 3 inches or one-fourth of a foot from the center in feet per minute is obtained by:

$$v = 6.28fr$$

where

$f$  is the frequency in RPM,  
 $r$  is the radius in feet

then at 300 RPM, where  $f = 300$ ,

$$v = 6.28fr = 6.28 \times 300 \times \frac{1}{4} = 471 \text{ feet per minute.}$$

At 1800 RPM,

$$v = 6.28 \times 1800 \times \frac{1}{4} = 2826 \text{ feet per minute.}$$

Thus velocities from 471 to 2826 feet per minute were obtained.

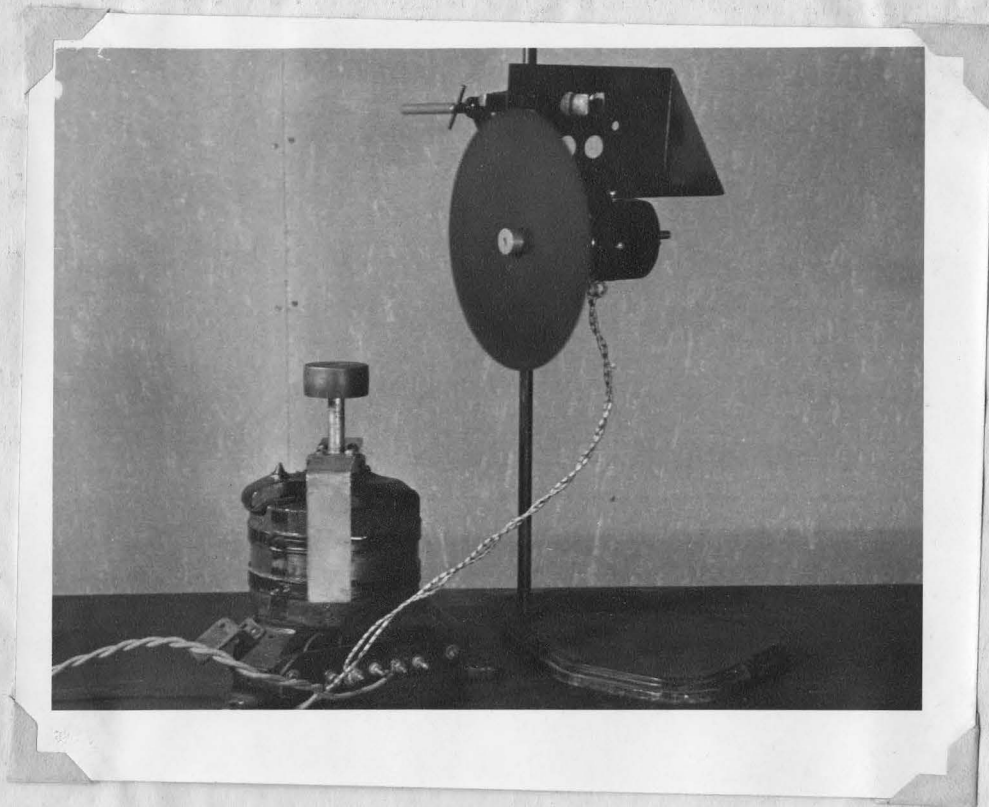


Figure 15. View of Motor, Variac, and Revolving Coated Tissue.

The speed of the motor was measured by the means of a revolution counter attached to the motor shaft and noting the number of revolutions counted in one minute.

The apparatus was set up as shown in Figure 16. Tests were made on samples of tissues cut from rolls of light, medium, and heavy coated tissue. A seven-inch in diameter circular piece of coated tissue, taken from the roll of light coated tissue, was mounted on the shaft of the motor and secured with the brass fittings. The motor was switched on and the speed was set at 300 RPM by means of the variac. The 150 watt projection lamp was switched on and a spot of light was focused on the revolving tissue at a distance of three inches from the center of the tissue. The spot of light had a diameter of one-half inch. Thus, an area in the shape of a flat ring one-half inch wide was swept by the light spot. The inner radius of the ring measured two and three quarter inches. The outer radius measured three and one quarter inches. The area swept was the difference in area of the two circles with the above radii. This area was 9.42 square inches.

The reading recorded in microamperes of phototube current at 300 RPM was 185 microamperes. The speed of the motor was gradually increased by stepping up the voltage applied to the motor until a speed of 1800 RPM was reached. No change in reading of the microammeter reading of the phototube current was noted. It still indicated 185 microamperes. The speed was decreased from 1800 RPM to 300 RPM and the microammeter indication remained constant at 185 microamperes.

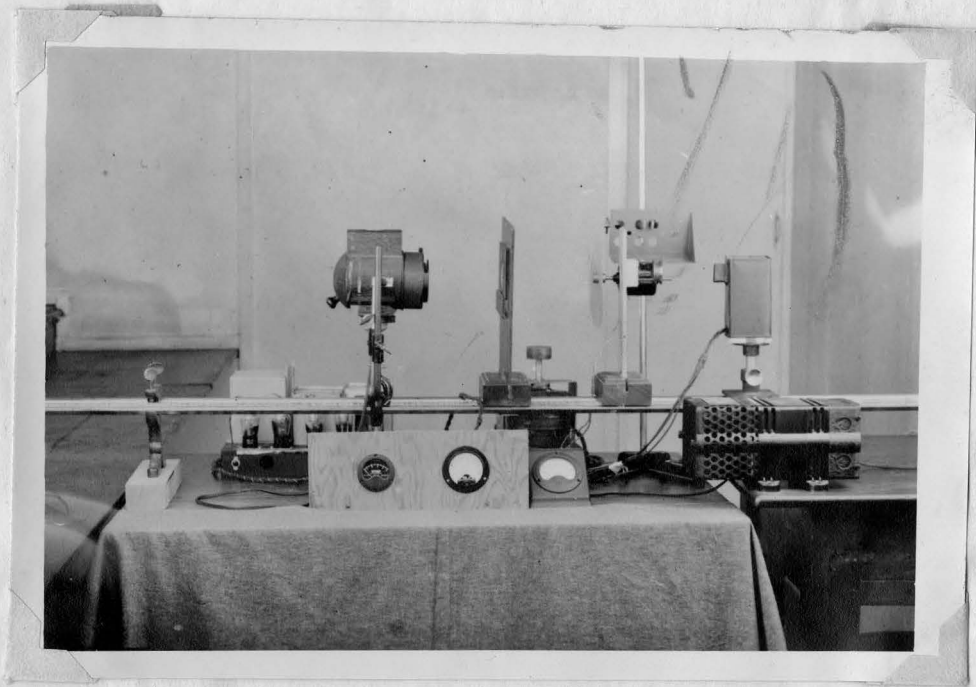


Figure 16. View of Apparatus for Dynamic Measurements on Coated Tissue.

The speed was reduced to values below 300 RPM. This caused the tissue to flutter as the centrifugal force was no longer great enough to keep the tissue smooth. As a result, the meter deflection no longer remained constant at 185 microamperes, but values which varied continuously in the region of 185 microamperes were noted, ranging from 180 to 190. However, as long as the tissue surface remained normal to the light beam (speeds of 300 RPM or above), no change in reading was noted.

Next, a seven-inch in diameter coated tissue was cut from the roll of medium coated tissue. The microammeter reading on this sample was 96 microamperes and it remained steady as long as the RPM of the rotating tissue was maintained between values of 300 and 1800 RPM. Fluttering of the paper occurred below 300 RPM and the readings were not steady but in the vicinity of 96 microamperes, plus or minus 4 microamperes.

A seven-inch tissue was cut from the heavy coated roll of tissue and it was secured to the shaft of the motor. The speed of the motor was varied as with the light and medium coated tissues. The reading on this sample was 28 microamperes. No variation in reading occurred when the speed was varied between 300 and 1800 RPM. However, below 300 RPM, fluttering occurred and the reading was 28 plus or minus 2 microamperes.

Nine more samples from each of the light, medium, and heavy coated tissue rolls were tested as above. No change was noted in the readings in each case as long as the speed remained between

300 and 1800 RPM. The readings in microamperes of the ten tissues tested from each roll are recorded in Table 10.

Table 10.

Light, Medium, and Heavy Coated Samples Data

Light Coated Samples	Medium Coated Samples	Heavy Coated Samples
185	96	28
180	101	29
183	106	29
183	104	27
185	95	28
175	97	26
181	96	22
200	93	25
195	98	25
202	104	25
Avg: 187.9	Avg: 99.0	Avg: 26.4

The above values are in microamperes.

The above results show a good degree of consistency. Maximum reading for the light coated tissue was 202 and the minimum reading was 175, a difference of 27 microamperes. The maximum difference noted in the medium coated tissue was 106 minus 93 microamperes. Finally, the maximum difference for the heavy coated tissue was 29 minus 22 or 7 microamperes.

These variations in readings taken on the individual rolls of light, medium, and heavy coated tissue are due to changes in thickness of the carbon ink coating and changes in the density of the paper. It is thought that the latter factor affects the changes in the phototube current much less than the changes in the thickness

of the carbon ink coating inasmuch as it is believed that a given change in the weight per unit area of the carbon ink coating has a much greater effect on the transmission of light through the coated tissue than the same change in weight per unit area (density) of the paper.

Dynamic measurements were also taken on four sets of coated tissues received from the manufacturer. These four sets of tissues had the amount of ink in pounds per ream determined by the jolly balance method as described previously. The paper in each of the four sets of tissue was made by the Kraftex, International, and Brownsville Paper Companies. In two of the sets the paper was made by International, but the paper in each case was of a different type. One paper was brown; the other was a greyish brown.

The first set tested consisted of Kraftex coated tissues. For each jolly balance value obtained by manufacturer, two pieces of coated and uncoated tissue were used. These coated and uncoated tissues were cut from the same roll of tissue and used to calculate the jolly balance values (number of pounds per ream) in the roll of coated tissue after a run on the coating machine, as mentioned previously. Seven-inch circular samples were cut from the coated tissues and mounted on the shaft of the sewing machine motor. Measurements were taken of the average amount of light transmitted through the coated tissue by means of the multiplier phototube at a motor speed of 400 RPM. Refer to Table 11. The jolly balance values and the corresponding readings of phototube current in

microamperes are listed in this table.

Table 11.

Kraftex Coated Tissue "Mates" Readings Versus Jolly  
Balance Readings.

Jolly Balance (Lbs. Per Ream)	Phototube Current of "Mates" (Microamps.)	
4.0	99	99
4.3	175	110
4.4	118	109
4.5	105	165
4.6	107	112
4.7	90	91
4.9	100	94
4.9	81	90
5.2	98	99
5.3	80	80
5.4	69	60
6.1	46	45
6.9	33	38
7.1	23	30

Visual comparison of the coated tissue "mates" for jolly balance readings 4.3 and 4.5 showed in each case that one tissue was darker than its "mate" and this was borne out in the phototube current reading.

It will be noted that all of the "mate" values (microamperes of phototube current) in Table 11 are very close in value with the exception of the "mates" for jolly balance values 4.3 and 4.5. Visual comparison of these 4.3 and 4.5 jolly balance "mates" in each case showed very definitely that one tissue was darker than its "mate". This was confirmed by the phototube current readings. The microampere values of phototube current for the "mates" in this group of Kraftex tissues were plotted against the jolly balance figures. See Figure 17. Straight lines were drawn from point to

point for the higher values of phototube current plotted. Also, straight lines were drawn from point to point of the lower values. The "mate" values plot closely together very consistently except for the two jolly balance values already noted.

Another set of coated tissues was tested. The paper in this group was manufactured by the International Paper Company. Its color was greyish brown. Dynamic measurements were taken on these coated tissues. The jolly balance values and the phototube current figures for the "mates" are recorded in Table 12.

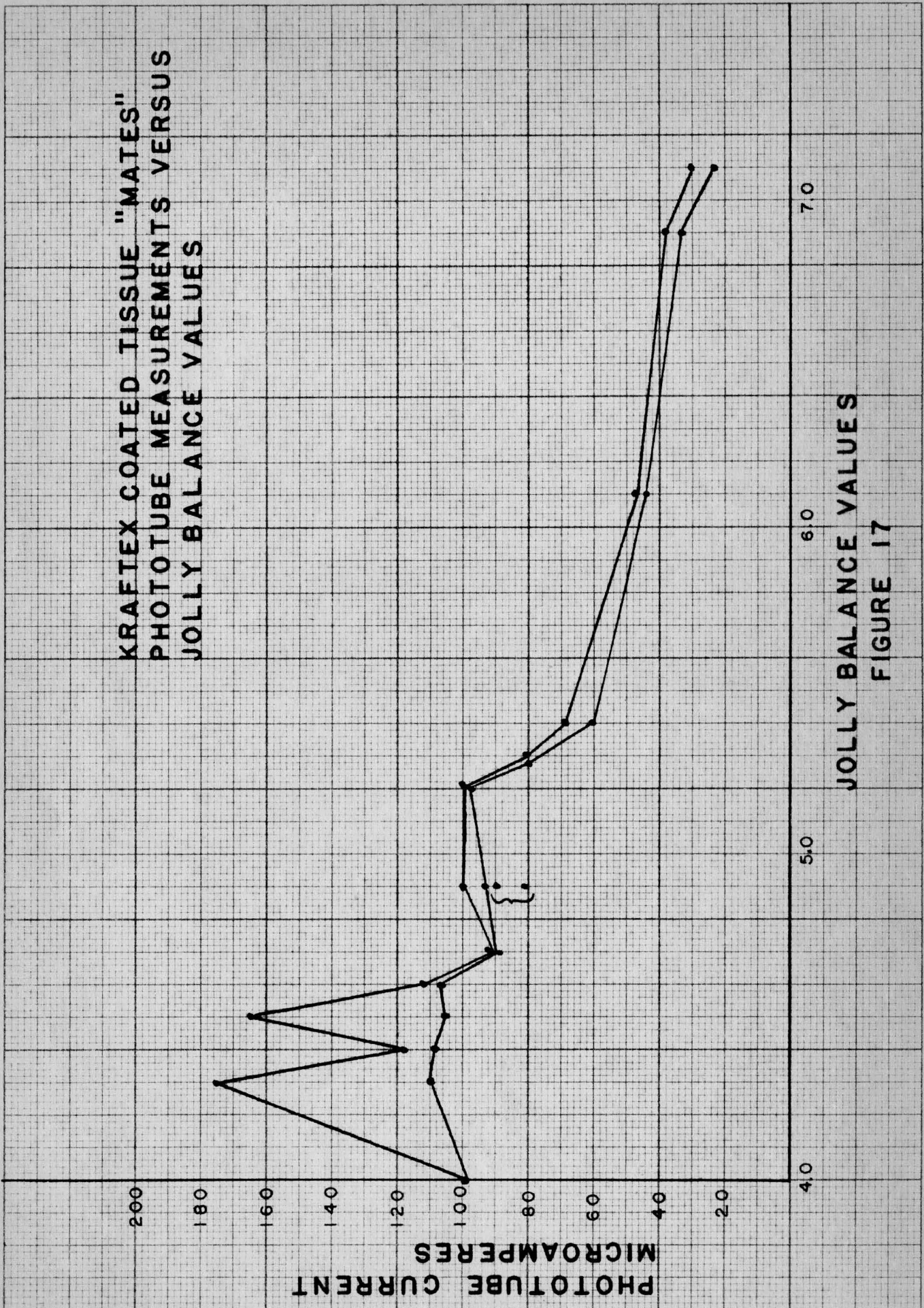
Table 12.

International (Greyish Brown) Coated Tissue "Mates"  
Versus Jolly Balance Figures.

Jolly Balance (Lbs. Per Ream)	Phototube Current of "Mates" (Microamps.)	
4.6	60	75
4.7	76	83
5.0	43	41
5.1	78	76
5.5	37	42
5.6	38	37
5.7	59	66
5.8	44	54
6.1	57	55
6.1	31	35

The microampere values of phototube current for the "mates" in this group of International tissues were plotted against the jolly balance figures. Straight lines were drawn from point to point for the higher values of phototube current plotted and from point to point for the lower values as well. See Figure 18. Here again the

KRAFTEX COATED TISSUE "MATES"  
PHOTOTUBE MEASUREMENTS VERSUS  
JOLLY BALANCE VALUES



JOLLY BALANCE VALUES  
FIGURE 17

PHOTOTUBE CURRENT  
MICROAMPERES

7.0

6.0

5.0

4.0

200

180

160

140

120

100

80

60

40

20

consistency with which the "mate" values of phototube current plot closely together was apparent. The exceptions noted were the 4.6 jolly balance "mates". No difference in density could be detected by visually comparing the two coated tissue "mates" although the difference in phototube current readings was 15 microamperes.

A third set of coated tissue "mates" was tested as above. The paper in this set was made by the Brownsville Paper Company. Jolly balance values and the phototube current readings for this group of coated tissues were recorded in Table 13.

Table 13.

Brownsville Coated Tissue "Mates" Readings Plotted  
Against Jolly Balance Readings.

Jolly Balance (Lbs. Per Ream)	Phototube Current of "Mates" (Microamps.)	
3.0	136	134
3.2	132	133
3.3	178	178
3.4	155	158
3.5	120	135
3.6	157	163
3.7	141	151
3.8	118	126
3.9	85	71
3.9	65	67
4.3	172	170
4.6	146	156
4.6	105	102
4.8	67	67
4.8	140	149

A graph was plotted showing the microampere values of the "mates" versus the jolly balance figures. See Figure 19. The

INTERNATIONAL GREYISH BROWN  
COATED TISSUE "MATE" PHOTOTUBE  
MEASUREMENTS VERSUS JOLLY  
BALANCE VALUES

PHOTOTUBE CURRENT  
MICROAMPERES

4.6

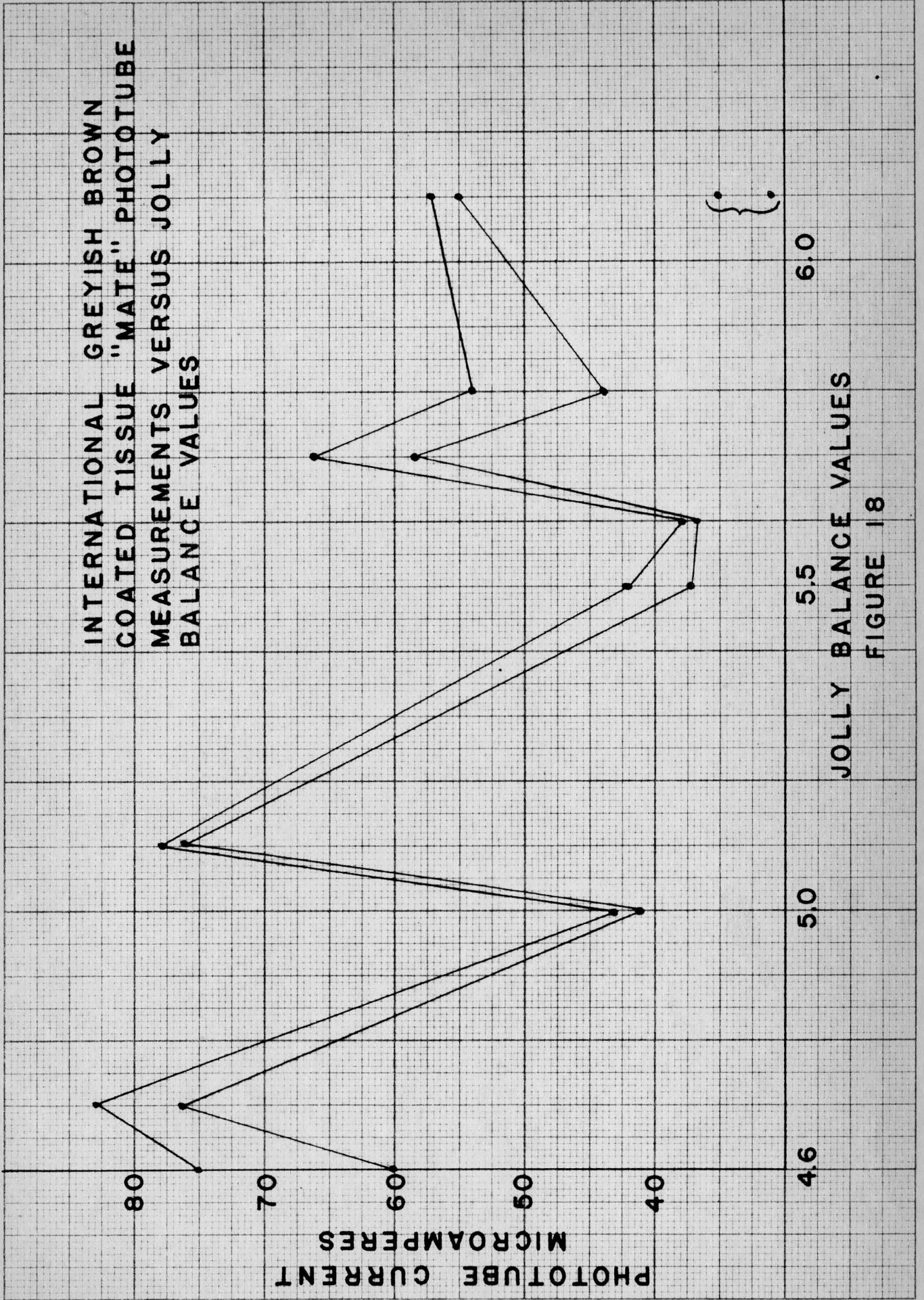
5.0

5.5

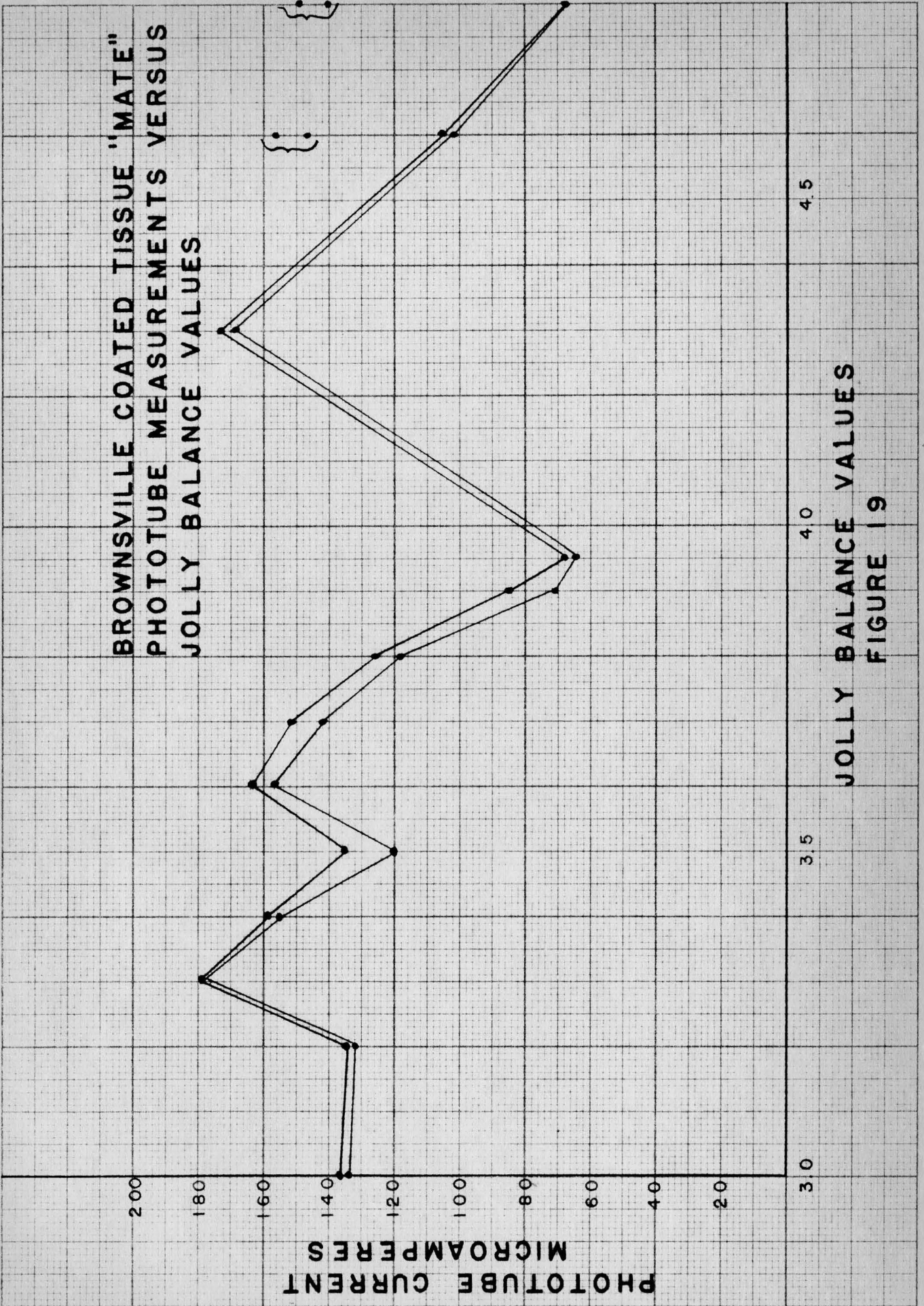
6.0

JOLLY BALANCE VALUES

FIGURE 18



BROWNSVILLE COATED TISSUE "MATE"  
PHOTOTUBE MEASUREMENTS VERSUS  
JOLLY BALANCE VALUES



JOLLY BALANCE VALUES  
FIGURE 19

"mate" values for this set of tissues consistently plotted together very closely as shown.

A fourth set of coated tissues (paper made by the International Paper Company) was tested. This paper was light brown in color as distinguished from the greyish brown hue of the other set of International coated tissues, tested above. The phototube current versus jolly balance data is shown in Table 14.

Table 14.

International Coated Tissue (Brown) "Mates" Readings  
Plotted Against Jolly Balance Readings.

Jolly Balance (Lbs. Per Bean)	Phototube Current of "Mates" (Microamps.)	
3.4	116	121
3.5	71	60
3.6	113	113
3.8	123	132
4.1	85	90
4.3	80	85
4.3	47	50
4.5	40	22
4.6	33	35
4.7	57	47
5.0	59	61
5.0	66	68
5.1	127	131
5.2	85	68
5.3	37	37
5.3	49	43
5.5	95	90
5.5	104	114
5.6	51	62
6.0	48	10
6.3	32	29

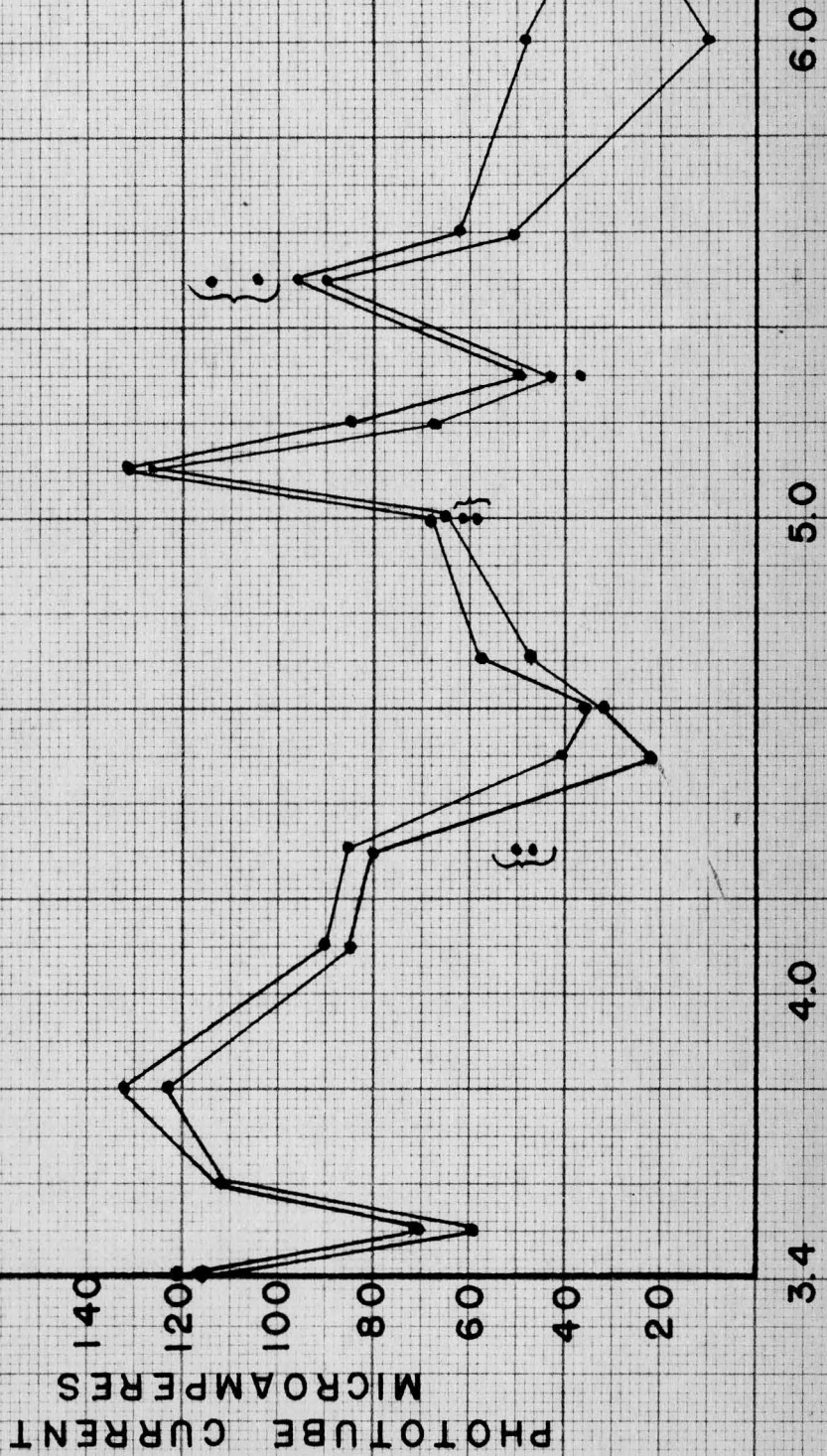
Visual comparison of the tissue "mates" for jolly balance reading 6.0 showed that one tissue was darker than its "mate" and this was borne out in the phototube current readings.

The data was plotted, phototube current values versus jolly balance figures as shown in Figure 20. All "mate" values plotted closely together with the exception of the 6.0 jolly balance "mates". Visual comparison showed that one tissue was darker than its "mate" and this was borne out in the phototube current readings.

The above tests on the four sets of tissues show a very marked consistency with which the "mate" values agree. This is especially apparent in the four graphs plotted from the four sets of data. See Figures 17, 18, 19, and 20. It is believed that this consistency in agreement of the "mate" value readings demonstrates that the two tissue "mates" compared in each case (with the exception of the 6.0 jolly balance "mates" of the International brown paper, the 4.3 and 4.5 jolly balance "mates" of the Kraftex paper and the 4.6 jolly balance "mates" of the International greyish brown paper) have approximately the same thickness coating of carbon ink. Since in each case the "mate" tissues were cut from the same roll of tissue, it was also concluded that the effect of the varying density of the paper was at a minimum.

Reference to Figures 17, 18, 19, and 20 shows very definitely that the phototube current readings are not an inverse function of the jolly balance values. An attempt to discover the reason for this was made. All of the circular samples of coated tissue of the International (brown) tissues were weighed on an analytical balance. In addition, all of the uncoated tissues in this set were cut up into seven inch circular samples and weighed on the analytical

INTERNATIONAL BROWN COATED  
TISSUE "MATE" MEASUREMENTS  
VERSUS JOLLY BALANCE VALUES



JOLLY BALANCE VALUES  
FIGURE 20

balance. The weights in milligrams of these coated and uncoated "mates" tissues are recorded along with the corresponding jolly balance and phototube current values in Table 15. The areas of all the uncoated and coated tissues weighed were all equal, each sample weighed being circular in shape, having a diameter of 7 inches, and an area of 38.465 square inches.

Reference to the weights of uncoated tissue in Table 15 shows a considerable variation in density (weight per unit area) of the "mates". Even though the two uncoated tissues comprising the "mates" were taken from the same tissue roll, the difference in weights is considerable, as high as 36.2 milligrams as noted for the 5.6 jolly balance figure. From these differences in weight of the uncoated tissues it follows that an error in the jolly balance figures could be traced to the fact that the uncoated tissues do not weigh the same as the coated tissues before they were coated. Thus when the coated tissues and the uncoated tissues from the same roll are weighed and the difference in weights obtained by subtracting the weight of the uncoated tissue from the weight of the coated tissue, this difference does not necessarily equal the weight of the ink coating. The error will more than likely be greater if the coated tissue and the uncoated tissue are taken from widely separated points on the same tissue roll. The only way this error could be avoided would be to weigh the tissue before it is coated and then weigh it after it is coated. The difference in weights would then be the true weight of the ink coating on the coated tissue.

Table 15.  
International (Brown) Coated and Uncoated Tissues

Jelly Balance (Lbs. Per Room)	Phototube Current (Microamperes of Coated Tissue "Water")	Weight of Coated Tissue "Water" (Mg.)	Weight of Uncoated Tissue "Water" (Mg.)	Difference in Weight of Un- coated Tissue
2.9	115	792.7	687.3	105.4 Mg.
3.4	121	800.8	677.4	123.4 Mg.
3.5	71	792.7	664.9	127.8 Mg.
3.6	113	795.9	660.0	135.9 Mg.
3.8	123	807.6	671.7	135.9 Mg.
4.1	90	823.6	684.3	139.3 Mg.
4.3	85	816.5	661.3	155.2 Mg.
4.3	50	833.7	674.5	159.2 Mg.
4.5	40	830.0	681.5	148.5 Mg.
4.6	35	833.4	686.9	146.5 Mg.
4.7	57	841.4	655.8	185.6 Mg.
5.0	61	846.5	655.5	191.0 Mg.
5.0	66	875.3	682.3	193.0 Mg.
5.1	131	862.1	660.5	201.6 Mg.
5.2	85	826.0	626.5	199.5 Mg.
5.3	37	869.1	662.9	206.2 Mg.
5.3	43	861.9	648.6	213.3 Mg.
5.5	104	892.2	676.7	215.5 Mg.
5.6	62	859.9	636.1	223.8 Mg.
6.0	48	836.3	643.4	192.9 Mg.
6.3	29	871.9	625.0	246.9 Mg.

Reference to the weights of the coated tissue "mates" of Table 15 shows that although the weights of the "mates" vary, the phototube current readings are in close correspondence as shown in Figure 20. As mentioned before, it is believed that since the phototube current values for the "mates" agree so closely the amount of ink deposited on each of the tissues in a pair of "mates" is approximately the same. The difference in weights of the coated tissues "mates" can be traced to the varying density (weight per unit area) of the basic uncoated tissue, which, it is believed, affects the phototube current readings to a minor degree.

The set of coated Kraftex tissues tested previously (see Table 11 and Figure 17) were also weighed on the analytical balance. The uncoated tissue "mates" for each jolly balance value were cut into seven-inch circular pieces and weighed also. The weights in milligrams of the coated and uncoated tissues, along with the jolly balance values and phototube current readings are shown in Table 16. The weights of the uncoated tissues were averaged as shown in the table. Two of the uncoated "mates" were damaged in cutting so that they could not be weighed, the average weight in these two cases being taken as the weight of the undamaged tissue. Since the Kraftex tissue was proved to be the most translucent of the tissues tested (as shown in the Static Measurements on Uncoated Tissues section) and since reference to the weights of the uncoated "mates" in Table 16 showed that the differences in weights were in the main rather small the following was done. The average weights of the

Table 16.

## Kraftex Coated and Uncoated Tissues

Jolly Balance (lbs. Per Hour)	Phototube Current (Microamperes) of Coated Tissue "Mites"	Weight of Coated Tissue "Mites" (gr.)	Weight of Uncoated Tissue "Mites" (gr.)	Average Weight of Uncoated "Mites"
4.0	99	856.5	713.5	704.5
4.3	175	816.5	654.5	656.25
4.4	118	848.0	671.0	667.7
4.5	105	824.5	648.0	648.45
4.6	107	832.0	668.1	668.1
4.7	90	837.0	666.3	663.25
4.9	100	826.5	638.0	641.5
4.9	81	867.0	672.3	680.15
5.2	98	847.5	654.9	648.25
5.3	80	863.5	664.7	661.65
5.4	69	878.0	677.2	674.75
6.1	46	891.0	685.0	659.7
6.9	23	929.0	689.1	683.0
7.1	23	915.5	626.3	628.45

uncoated tissues were subtracted from the weights of the coated tissue "mates". The resultant weights (the approximate weight of the ink coating) were paired off with the phototube current readings taken on the coated tissues. The heavier weight obtained was paired with the lower value of the phototube current and the lighter weight obtained was paired off with the higher value of phototube current. See Table 17. A sample calculation follows.

Sample Calculation:

<u>Jolly Balance</u> (Lbs. Per Read)	<u>Phototube Current</u> (Microamperes)	<u>Weight of Coated Tissue</u> (Milligrams)
4.3	175    110	816.5    830.9
	<u>Weight of Uncoated Tissue</u> (Milligrams)	<u>Average Weight of Uncoated Tissue</u> (Milligrams)
	654.5    658.0	656.25

The average weight value of the uncoated tissues (656.25 Mg.) was subtracted from each of the coated tissue weights as follows:

816.5	830.90
- 656.25	- 656.25
<u>160.25</u>	<u>174.65</u>

These two values (the approximate weights of the ink coatings) were paired off with the phototube current values 175 and 110 (Microamperes), the lighter weight with the higher phototube current reading and vice versa:

<u>Phototube Current</u> (Microamperes)	<u>Approximate Weight</u> <u>Of Ink Coating (Milligrams)</u>
175	160.25
110	174.65

The above procedure was carried out for each of the jolly balance values in the Kraftex set of tissues, and the approximate weights of the coatings and corresponding phototube current values are shown in Table 17. The phototube current values of the above table were plotted against the approximate weights of the ink and a curve was drawn through or near the majority of the points. See Figure 21. Enough points plot near enough to the curve to indicate that despite experimental errors and errors involved in approximating the weights of the ink coating, the phototube current variations (for the Kraftex tissue at least) are definitely a function of the thickness of the carbon ink. The varying density of the Kraftex type paper seems to be a minor factor.

It is suggested that the above methods with the following refinements be used in the future to absolutely determine the effect of the density of the paper on the thickness measurements of the ink. First, that uncoated tissues from each of the manufacturers be prepared by cutting out circular pieces from each of the samples. These samples could be weighed and as wide a spread of densities procured as possible. These weight values would be recorded and the tissues coded for future reference. Light transmission measurements could then be made on the tissues as outlined above and in the following section under Dynamic Measurements on Uncoated Tissue. The circular samples of tissue could then be coated with varying thicknesses of ink using a paint sprayer or a method could be worked out using the coating machine of the manufacturer. After coating,

the tissue samples could then be weighed and the weight of ink per unit area determined exactly, by subtracting the weight of the tissue before coating from the weight of the tissue after coating.

Table 17.

Approximate Weight of the Ink Coating on Kraftex Tissues  
Versus Phototube Current Readings.

Phototube Current (Microamperes)	Approximate Weight Of Ink Coating (Milligrams)
99	152.0
99	158.0
175	160.25
110	174.65
118	161.3
109	180.3
105	176.05
165	165.55
107	175.9
111	163.9
90	181.75
91	173.75
100	185.0
94	187.5
81	186.85
90	182.35
98	199.25
99	197.0
80	201.85
80	191.35
69	203.25
60	210.75
46	225.3
45	231.3
33	246.0
38	242.0
23	287.05
30	278.55

WEIGHTS OF INK COATING ON  
KRAFTEX TISSUES VERSUS  
PHOTOTUBE MEASUREMENTS

PHOTOTUBE CURRENT  
MICROAMPERES

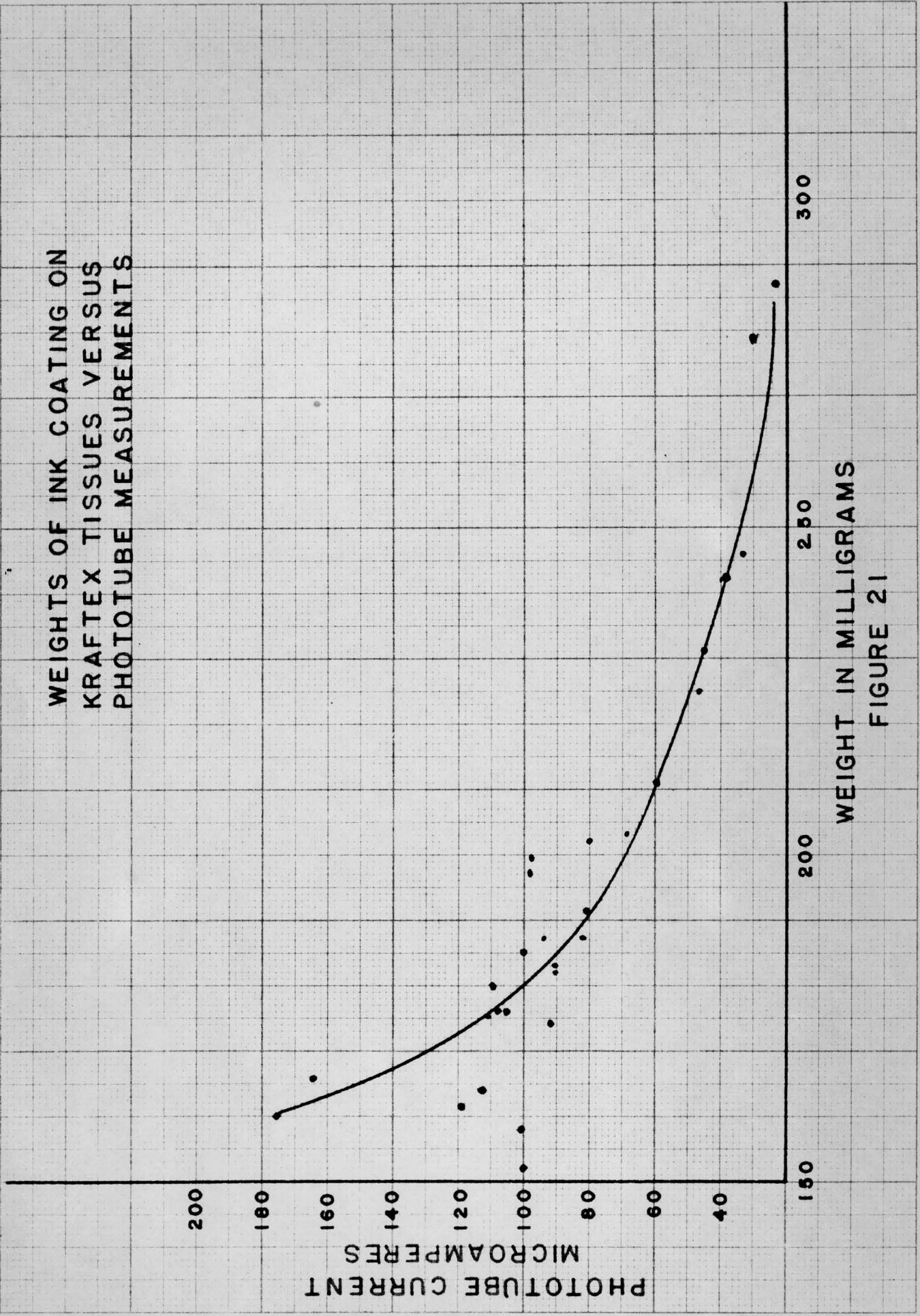
200  
180  
160  
140  
120  
100  
80  
60  
40  
150

300

250

200

WEIGHT IN MILLIGRAMS  
FIGURE 21



Then measurements with the multiplier phototube thickness indicator could be taken and the effect of the paper could readily be evaluated from the data obtained as above.

#### 4. Dynamic Measurements on Uncoated Tissue.

Dynamic measurements were taken on uncoated tissues in the same manner as the method used on the coated tissue. The apparatus was set up as shown in Figure 22. The lamp was set at the zero mark on the optical bench. The first lens was placed at the 79 centimeter mark, the paper at the 91 centimeter mark, the second lens at the 92.5 centimeter mark and the multiplier phototube at the 112.5 centimeter mark. The previous arrangement for measurements on coated tissue had the lamp placed at the 43 centimeter mark, the first lens at the 73 centimeter mark and the paper, second lens, and phototube unchanged. Thus the intensity of the light was reduced to about one-fourth its previous value at the surface of the paper inasmuch as the distance between the light and the paper was doubled.

Six rolls of International (greyish brown) uncoated tissue were received from the manufacturer. Forty seven-inch circular samples were cut from each of the six rolls, making a total of 240 tissues in all. These tissues were mounted one by one on the shaft of the sewing machine motor and readings were taken of the amount of light energy transmitted through the tissues as a function of the density of the tissues as picked up by the phototube and indicated on the scale of the microammeter. All of the above tissues were revolved at 400 RPM, simulating a tissue velocity of 628 feet

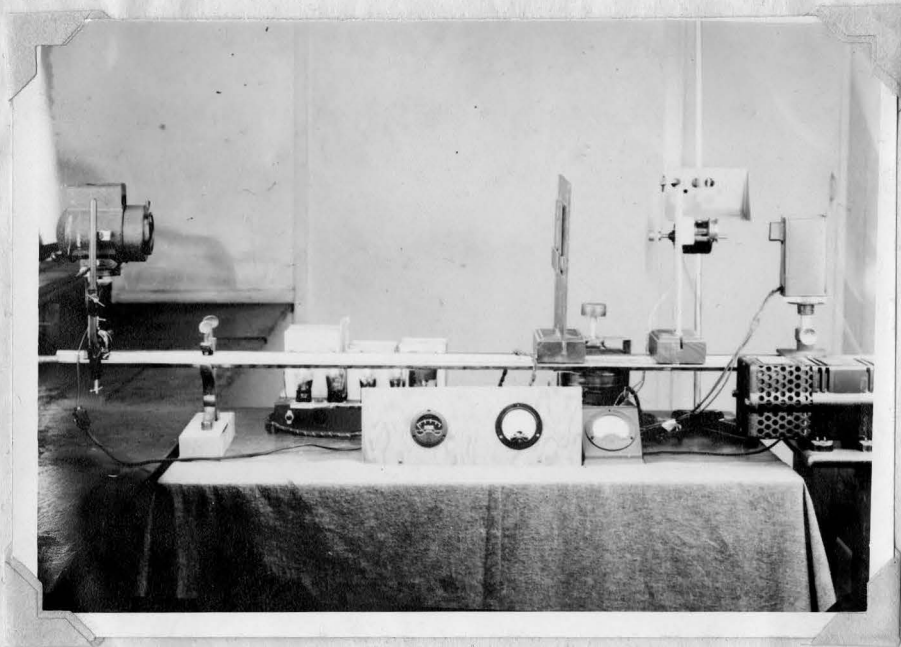


Figure 22. View of Apparatus for Dynamic Measurements of Uncoated Tissue.

per minute. Refer to Table 18. The phototube current readings in microamperes are listed for each roll along with the average value for each roll and the maximum and minimum values. The total average for the six rolls was 143.4 microamperes. The maximum value recorded for the six rolls was 170 microamperes and the minimum value 120. The mean value between 170 and 120 is 145 and 143.4 is close to this value. Thus the limits for the six rolls were approximately 145 plus or minus 25 microampetes. The limits are closer for the individual rolls. The highest difference noted between maximum and minimum values for an individual roll was 33 microamperes for roll No. 5, versus 50 microamperes for the entire group of six rolls. The lowest difference noted between maximum and minimum values was 13 microamperes for roll No. 2. The data in Table 18 shows that the density variations of the tissue are less in the same roll of tissue, but that tissues taken from different rolls and compared may be considerably different in density.

Two circular samples were cut from each of the six rolls of tissue mentioned above. These samples were given light transmission measurements and the tissues were also weighed on the analytical balance. The weights of the tissues in milligrams and the phototube current readings are shown in Table 19.

The phototube current values of the tissues were plotted against the weights of the tissues in milligrams. An interesting curve was the result. See Figure 23. The curve shows that the multiplier phototube detects variations of the density of the paper and that

Table 18.

Data on International Uncoated Tissue Taken from the  
Six Rolls of Tissue Received from the Manufacturer

Roll No. One	Roll No. Two	Roll No. Three	Roll No. Four	Roll No. Five	Roll No. Six
128	135	155	150	140	147
125	135	153	147	143	150
128	135	153	157	145	143
127	143	153	155	157	141
123	135	160	145	150	152
123	135	160	143	150	144
125	135	152	140	160	143
124	138	154	147	158	147
122	131	151	145	160	148
127	131	158	153	149	138
126	132	157	145	153	136
127	143	157	146	162	149
128	135	157	148	165	140
129	135	153	154	158	143
127	143	158	151	160	141
123	140	170	153	165	145
122	140	158	153	153	143
125	140	158	143	155	144
124	139	153	151	157	142
123	135	170	154	168	145
126	141	153	149	145	147
128	138	153	150	150	145
128	143	158	146	145	147
124	144	155	150	143	145
128	137	145	143	138	145
130	144	140	143	145	143
125	140	147	145	145	150
120	140	145	143	145	145
128	139	152	143	143	146
131	135	155	140	147	144
128	140	151	151	150	150
126	140	150	140	144	145
125	142	152	147	145	145
135	140	147	144	140	143
139	140	151	145	140	150
130	140	146	147	135	145
140	143	150	145	142	148
129	144	150	142	143	145
134	144	150	144	141	140
133	140	149	140	135	148
Avg. 127.325	Avg. 139.725	Avg. 153.325	Avg. 146.925	Avg. 149.225	Avg. 144.875
Max. 140	Max. 144	Max. 170	Max. 157	Max. 168	Max. 152
Min. 120	Min. 131	Min. 140	Min. 140	Min. 135	Min. 136
Diff. 20	Diff. 13	Diff. 30	Diff. 17	Diff. 33	Diff. 16

Total Average for the Six Rolls: 143.400  
Maximum : 170.00  
Minimum : 120.00

The above figures are in microamperes.

Table 19.

Weight in Milligrams of Uncoated Samples of International  
(Greyish Brown) Versus Phototube Current Measurements  
in Microamperes.

Roll No.	Weight In Milligrams	Phototube Current (Microamperes)
1	758.0	120
2	698.0	145
3	653.6	160
4	675.4	153
5	732.6	129
6	684.5	150
1	744.1	127
2	692.8	145
3	669.7	159
4	700.0	144
5	656.0	156
6	711.4	140

this varying density can be monitored by the multiplier phototube.

As the density of the paper increases, the phototube current indications decrease and vice versa.

The above experiment was repeated on Kraftex uncoated tissues taken from the jolly balance sets of tissues. These seven-inch circular uncoated samples were weighed on the analytical balance and then dynamic measurements were taken with the multiplier phototube. The weights and phototube current readings are recorded in Table 20.

A curve was plotted from the data of Table 20, using the weights in milligrams of the tissues as abscissae and the phototube current values as ordinates. See Figure 24. This curve also indicates that the multiplier phototube can detect variations in thickness of the uncoated tissue and give relative measurements.

WEIGHTS OF UNCOATED INTERNATIONAL  
GREYISH BROWN TISSUES VERSUS  
PHOTOTUBE MEASUREMENTS

PHOTOTUBE CURRENT  
MICROAMPERES

650

700

750

800

WEIGHT IN MILLIGRAMS  
FIGURE 23

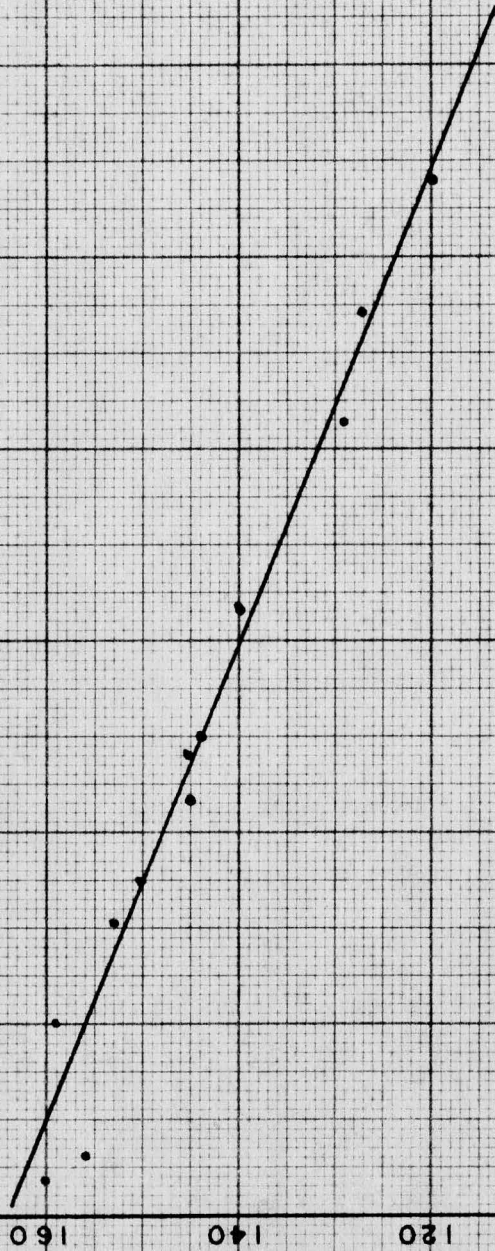


Table 20.

Weight in Milligrams of Uncoated Samples of Kraftex Tissue  
Versus Phototube Current Measurements  
in Microamperes

Weight In Milligrams	Phototube Current (Microamperes)
664.4	150
671.0	148
648.0	160
648.9	157
660.2	152
666.3	150
638.0	161
645.0	159
672.3	146
638.0	141
641.6	158
654.9	155
626.3	163
630.6	160
654.5	152
658.0	150

Reference to Figure 24 shows that although the uncoated tissues were taken from different tissue rolls, the microampere readings were all within the limits of 141 and 163 microamperes, a difference of 22 microamperes.

Uncoated tissues of Brownsville paper were weighed and measured with the phototube as above. The weights and phototube current values are shown in Table 21. The curve drawn from the data plotting weights in milligrams as abscissae and phototube current figures as ordinates is shown in Figure 25. Although the points do not plot near the curve as well as the points plotted in Figures 23 and 24 (International Greyish Brown and Kraftex paper), nevertheless the multiplier

**WEIGHTS OF KRAFTEX UNCOATED  
TISSUES VERSUS PHOTOTUBE  
MEASUREMENTS**

**PHOTOTUBE CURRENT  
MICROAMPERES**

**WEIGHT IN MILLIGRAMS**

**FIGURE 24**

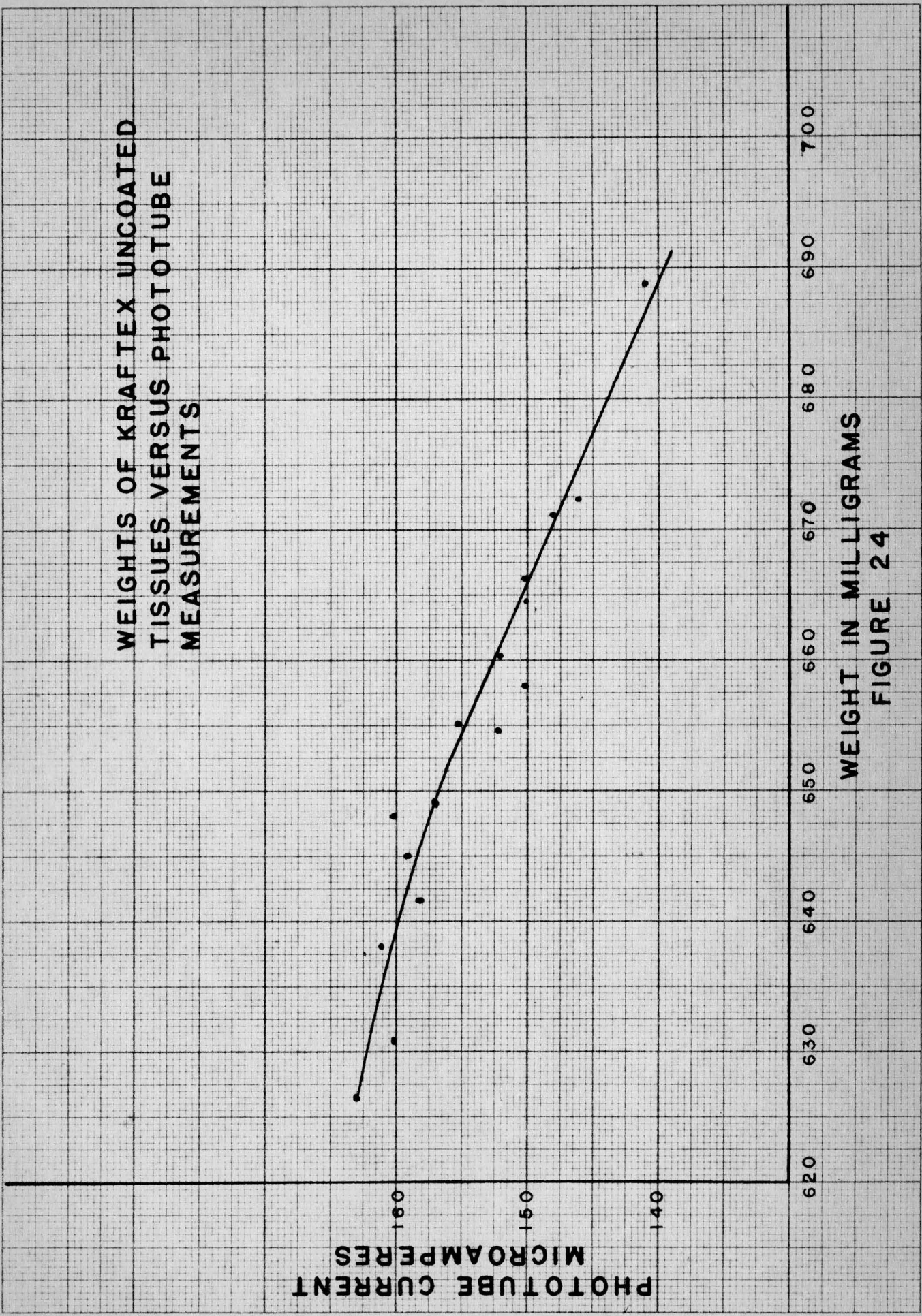


Table 21.

Weight in Milligrams of Uncoated Samples of Brownsville  
Tissue Versus Phototube Current Measurements  
in Microamperes

Weight In Milligrams	Phototube Current (Microamperes)
710.9	165
720.3	165
721.7	163
708.2	167
723.9	162
725.2	162
714.6	163
725.6	161
760.2	153
762.7	151
716.5	164
720.7	160
686.9	179
688.9	177
702.7	172
706.3	170
680.3	190
681.0	188
723.9	167

phototube does indicate the relative thickness of the tissues tested allowing for experimental errors.

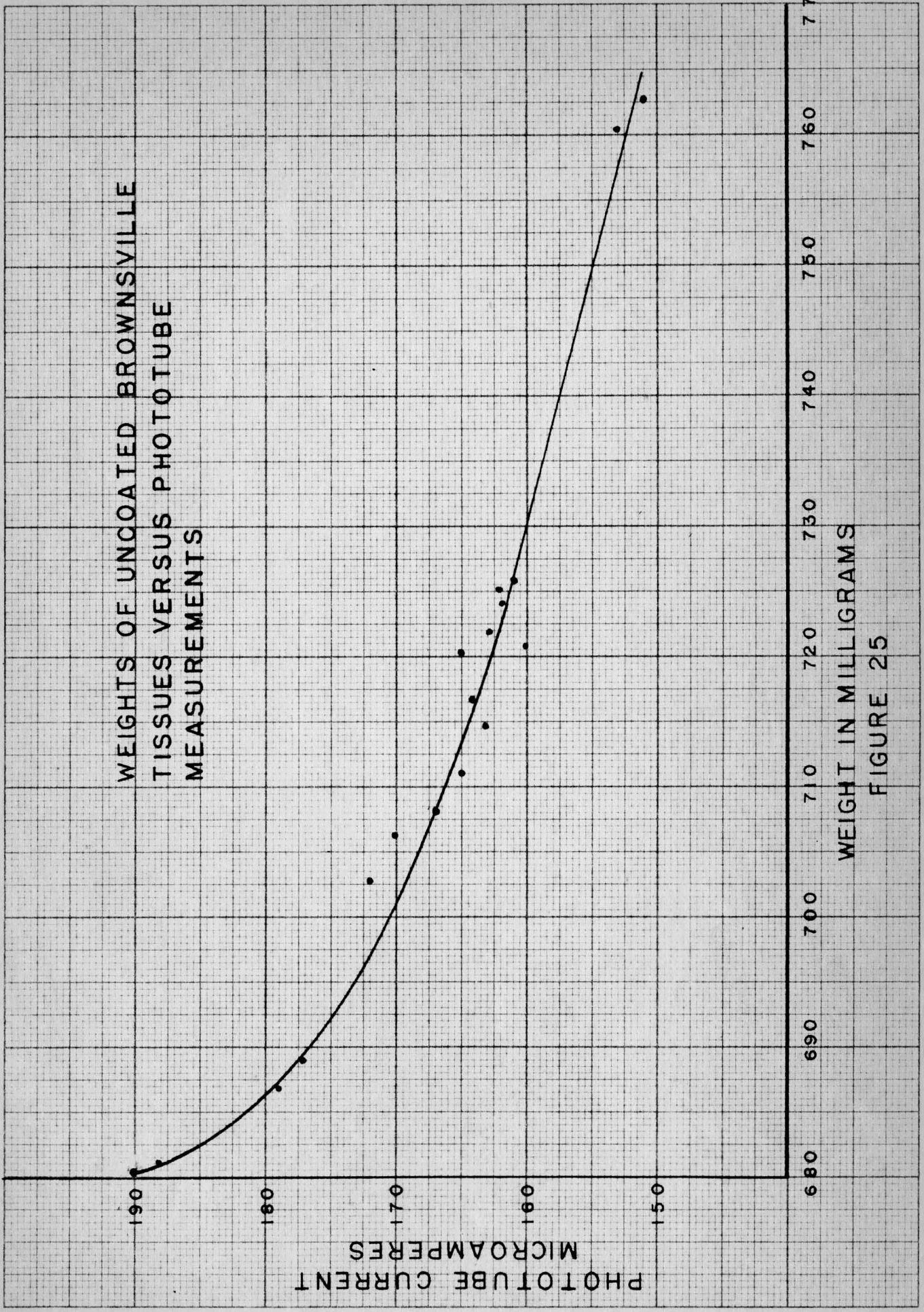
Although the Brownsville tissues tested were taken from different tissue rolls, most of the phototube current readings plotted between 160 and 180 microamperes, indicating that the tissue variation in density from roll to roll is not very great.

Lastly, uncoated International brown tissues were weighed and measured with the phototube. The values are recorded in Table 22. The curve plotted from the data is shown in Figure 26. This curve, as well as the curves in Figures 23, 24, and 25 indicate very

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20 X 20 PER INCH

EUGENE DIETZGEN CO.  
MADE IN U. S. A.

WEIGHTS OF UNCOATED BROWNSVILLE  
TISSUES VERSUS PHOTOTUBE  
MEASUREMENTS



WEIGHT IN MILLIGRAMS  
FIGURE 25

Table 22.

Weight in Milligrams of Uncoated Samples of International  
Brown Tissue Versus Phototube Current  
Measurements in Microamperes

Weight In Milligrams	Phototube Current (Microamperes)
687.3	127
702.0	124
677.4	141
689.3	140
684.3	131
690.0	129
661.3	149
669.3	146
674.5	145
680.9	140
681.5	137
689.7	135
646.9	163
634.3	165
643.8	162
660.5	146
671.6	140

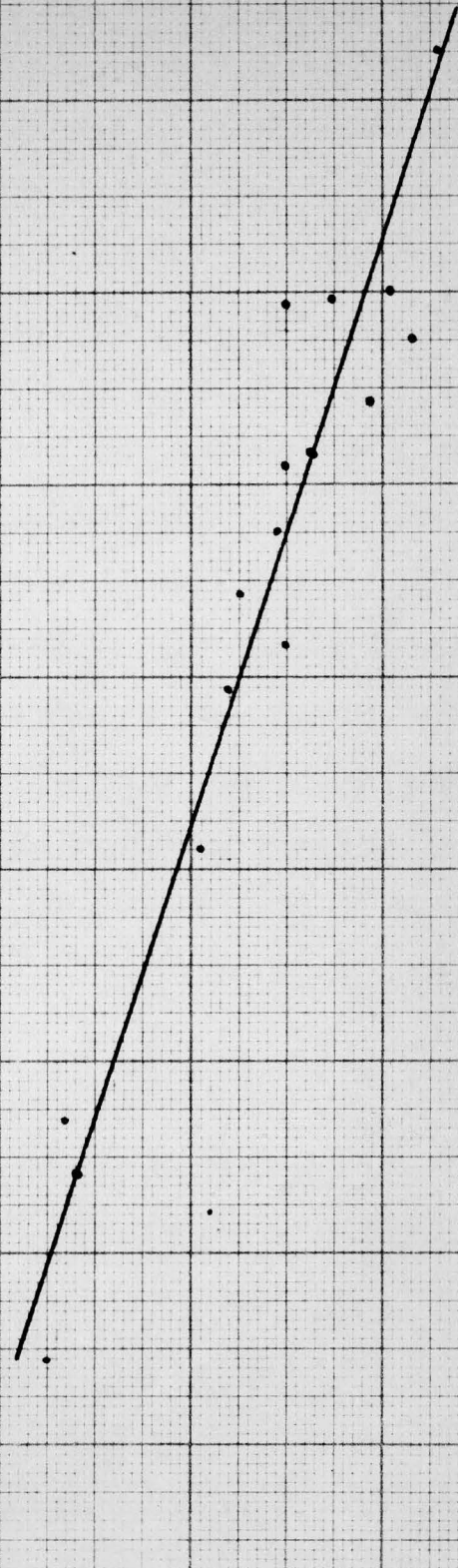
definitely that the multiplier phototube can detect variations in densities of the tissues. For the points that do not plot on the curve, the following explanation is offered. A definite source of experimental error stems from the fact that only a relatively small area of the circular tissue is swept by the light spot for phototube measurements, whereas the weight of the whole circular sample of tissue is measured in each case. It is thought that if the ring of tissue actually swept by the light beam could be separated from the surrounding tissue and weighed much better curves would be obtained.

INTERNATIONAL UNCOATED BROWN TISSUE  
WEIGHTS VERSUS PHOTOTUBE CURRENT

PHOTOTUBE CURRENT  
MICROAMPERES

620 630 640 650 660 670 680 690 700

WEIGHT OF TISSUE IN MILLIGRAMS  
FIGURE 26



The four sets of uncoated tissues tested above attenuate the light energy in different degrees. It was found that after the International greyish brown tissues from the six rolls were tested, that the intensity of the light beam had to be reduced by closing the iris diaphragm of the lamp about one-eighth of an inch so that the readings on the Kraftex tissues would not be off the scale of the microammeter. When the Brownsville and International Brown tissues were tested, the iris diaphragm had to be opened about one-sixteenth of an inch from the Kraftex opening to bring the phototube current reading up to the upper half of the microammeter scale. From the above observations it was concluded that the International greyish brown tissue from the six rolls attenuated the light energy the most, and the Kraftex tissue the least. In between these two extremes were the International brown and Brownsville tissues, each having about the same light attenuating characteristics.

##### 5. Evaluation of Data.

The static measurements of the coated tissues showed very definitely that the multiplier phototube detects variations in the thickness of the carbon ink. Also, the static measurements uncovered errors in the jolly balance measurements and a definite consistency in microammeter readings taken on the coated tissue "mates" was apparent, indicating that the two tissues in each set of "mates" had approximately the same thickness coating of ink.

In the static measurements on uncoated tissue, the results showed that a given small area ( $8\frac{1}{2}$  x 11 inches, e.g.) of uncoated tissue is very uniform. Also the graphs that were plotted from the data (Figures 11, 12, 13, and 14) indicated that the changes in light intensity as the spot was moved from area to area on the coated tissue, were a function, in the main, of the thickness of the carbon deposit. The paper did decrease the level of light intensity but it did so in a reasonably uniform manner for tissues cut from a given length of tissue on a roll. However, the density of a given type of tissue varies from roll to roll and the exact effect of this changing density on the thickness measurements indicated by the multiplier phototube is not fully known. It is believed, nevertheless, that the ink coating lessens the effects of the changing density of the paper to a considerable degree. The static measurements on uncoated tissue showed that the Kraftex tissue attenuated the light energy to a lesser degree than the Brownsville and International (brown) tissues. The Brownsville and International papers attenuated the light energy about the same amount as shown in Figure 14.

The dynamic measurements of coated tissue demonstrated that as long as the tissue surface remained normal to the light beam, the phototube current readings remained constant and gave an average reading for the area tested. Also, in these dynamic measurements of coated tissue, the marked consistency with which the "mate" values of phototube current agreed was demonstrated in Figures 17, 18, 19, and 20. This consistency of agreement of the "mate" value readings

demonstrated, it is believed, that the two tissue "mates" compared in most cases, had approximately the same thickness coating of carbon ink. Also since the "mate" tissues were cut from the same roll of tissue, it was also concluded that the effect of the varying density of the paper was at a minimum.

A source of error in the jolly balance measurements was discovered by weighing the uncoated tissues that were used by the manufacturer to determine the jolly balance values and noting the variations. From the variations in weight of these uncoated tissues it was concluded that errors in the jolly balance figures could be traced to the fact that the two uncoated tissues in a jolly balance set do not necessarily weigh the same as the other two coated tissues of the set before they were coated. Thus, when equal areas of coated and uncoated tissues from the same roll are weighed and the difference in weights obtained by subtracting the weight of the uncoated tissue from the weight of the coated tissue, this difference does not necessarily equal the weight of the ink coating. This is one explanation of why the phototube current readings versus the jolly balance values do not plot into a smooth curve.

The approximate weight of the ink coating on the Kraftex tissues was determined by using the jolly balance technique of the manufacturers. Refer to data under Dynamic Measurements of Coated Tissue. (Tables 16 and 17; Figure 21) The approximate weight of ink on the Kraftex tissues could be calculated without too much

error inasmuch as this type of tissue was the most translucent of the types tested. The curve plotted from the data (See Figure 21) shows that the phototube current variations are definitely a function of the thickness of the carbon ink deposit variations, in the main, for this type (Kraftex) of tissue.

In the dynamic measurements of uncoated tissue it was discovered that the multiplier phototube could be used to actually measure the weight per unit area of the uncoated tissues. Also, phototube measurements on the uncoated tissue showed the Kraftex and Brownsville tissue to be the most uniform, the International brown tissue to be the next most uniform and the International greyish brown tissue to be the least uniform type of tissue tested with respect to light transmission measurements.

## VII

### CONCLUSIONS

The following conclusions were made:

(1) The multiplier phototube detects variations in the thickness of the carbon ink deposit on a moving web of paper. The absolute effect of the varying density of the individual types of paper is not fully known, but it is believed to be small enough to be neglected or compensated for.

(2) An absolute determination of the effect of the varying density of the tissue on the phototube measurements can be made by weighing the paper samples before coating and then weighing

the samples after they are coated. The difference in weight obtained by subtracting the weight of the tissue before coating from the weight of the tissue after coating would be more nearly the exact weight of the carbon ink deposit. Dynamic phototube measurements could then be taken of the coated tissue and measurements could be made also on the uncoated tissue prior to coating, as well. Coating of the circular samples could be accomplished by spraying the paper with ink from a paint spray gun or some other method. It is believed an evaluation of the data obtained as above would give a much more accurate idea of the effect of the varying density of the paper on the phototube measurements of ink thickness.

(3) The density of the tissue varies from point to point on a given roll of tissue to a relatively small degree. It varies to a larger degree from one roll of the same type of tissue to another. Also, the different types of tissues made by the various paper manufacturers affect the level of the phototube readings on the coated tissue. The Kraftex paper was found to be the most translucent, the Brownville and International brown papers were found to be the next best in translucent properties (both approximately the same), and the International grayish brown paper the least translucent of the uncoated tissues tested.

(4) The multiplier phototube detects variations in the density of the uncoated tissue. This property could be used to monitor the thickness of the tissue paper during manufacture. Also, by using this property, the effects of the varying density of the

different types of tissue papers could be compensated for when using the multiplier phototube as an indicator of the thickness of the ink coating. A second multiplier phototube could be used to monitor the varying density of the paper. The output of the two phototubes could be fed into a bridge or comparison network and a differential voltage obtained that would be a function of the varying ink coating alone.

(5) Future work involving the use of filters may possibly eliminate the effect of the different translucent properties of the various tissue papers. A narrow band of wavelengths of light near or in the infrared may eliminate the tissue as a variable and the light energy transmitted through the coated tissue would be a function of the thickness of the carbon ink coating alone.

## VIII

### SUMMARY

The multiplier phototube thickness indicator developed in this research detects the varying thickness of the carbon ink coating on a moving web of paper. The absolute effect of the density variations of any of the particular types of tissue tested on these measurements has not been fully determined as yet, but it is believed that if a given type of tissue is used the density variations of the paper can be neglected or compensated for. Changing the type of tissue when coating would necessitate recalibration of the multiplier phototube thickness indicator every time a different type of tissue was used.

The multiplier phototube detects changes in density in a moving web of paper. This property can be useful in monitoring the thickness of tissue paper as it is being manufactured and in monitoring and compensating for changes in the density of the different types of tissue fed into the ink coating machine.

## IX

ACKNOWLEDGEMENTS

The author of this thesis wishes to express his indebtedness and gratitude to Professor W. Richardson for his guidance and advice rendered throughout this investigation. The writer is also indebted to the members of the Department of Physics of the Virginia Polytechnic Institute who willingly gave their time and interest in the progress of this research. The many helpful suggestions and assistance of Dr. F. I. Rebeson, Dr. H. Y. Loh, Professor H. D. Ussery, Professor J. F. Ryan, \_\_\_\_\_, c, and \_\_\_\_\_ are greatly appreciated.

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APPENDIXData on Carbon Tissues Nos. 2 - 23, Inclusive:

Static measurement using the multiplier phototube on the 216 square areas tested on Carbon Tissues Nos. 2 - 23. The figures are in microamperes.

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 2

	Columns																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	205	185	210	203	190	195	x	138	200	115	138	145	120	140	90	130	90	120
Row 2	x	195	200	203	195	200	180	160	150	140	190	160	150	120	110	95	110	160
Row 3	x	200	210	210	190	170	190	165	155	175	165	175	170	105	95	95	110	165
Row 4	x	195	210	210	190	168	190	160	170	190	165	140	115	118	100	100	115	125
Row 5	x	195	190	204	170	150	200	155	150	140	200	149	120	120	93	98	98	120
Row 6	210	180	180	195	190	162	145	170	138	110	138	102	100	100	90	75	70	92
Row 7	210	170	185	170	175	183	180	x	140	180	163	135	150	115	110	85	95	130
Row 8	x	195	185	210	x	190	167	200	155	155	160	170	135	125	102	100	105	140
Row 9	x	x	200	210	210	210	200	170	190	170	171	171	x	150	130	110	120	165
Row 10	210	210	190	205	210	x	195	170	185	180	165	133	162	150	150	120	140	125
Row 11	x	190	210	200	200	210	180	210	185	160	185	190	160	130	165	125	110	140
Row 12	x	305	210	210	182	198	200	190	162	185	205	190	165	175	135	125	115	121

Note: x means off scale reading.

Total average: 163.3  
Jolly Balance: 3.2 lbs. per resm above limits  
Type tissue: International

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 3

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	115	150	105	120	117	113	107	125	130	123	112	105	107	105	105	105	145	125
Row 2	112	125	115	123	111	141	141	140	130	118	112	130	125	100	96	98	103	120
Row 3	132	150	118	143	121	133	134	147	131	150	112	200	150	125	110	130	90	102
Row 4	120	113	107	114	140	138	130	132	151	130	112	142	140	131	102	95	99	110
Row 5	108	135	128	135	130	135	180	152	125	117	120	128	102	115	131	140	120	120
Row 6	160	120	110	140	152	175	110	141	138	145	101	110	130	155	120	96	88	113
Row 7	140	140	145	152	145	160	160	160	142	134	160	132	135	115	120	112	118	105
Row 8	118	140	130	123	125	170	152	145	150	150	135	138	160	118	120	100	105	118
Row 9	121	155	130	150	142	134	130	131	135	141	130	145	155	125	121	110	110	115
Row 10	108	125	120	115	115	130	130	143	110	108	100	125	115	115	108	118	90	85
Row 11	125	110	100	138	135	140	118	105	128	130	110	95	130	108	105	85	115	125
Row 12	110	150	135	160	110	138	130	140	118	121	130	130	112	112	107	100	100	90

Note: x means off scale reading

Total average: 124.53

Jelly Balance: 5.4 lbs. per resam, above limits

Type tissue: International

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 4

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	95	96	99	96	96	97	94	92	83	83	97	92	104	97	92	96	89	96
Row 2	102	102	111	120	104	112	106	107	102	112	99	108	113	110	106	101	96	108
Row 3	106	102	103	118	115	109	99	105	112	106	96	108	113	100	105	105	107	107
Row 4	94	99	95	106	104	100	101	100	120	92	89	98	103	96	92	93	115	110
Row 5	94	94	91	100	88	96	94	90	98	90	82	92	88	88	92	85	85	80
Row 6	103	90	110	118	93	108	115	100	104	92	99	92	92	92	92	95	98	98
Row 7	92	97	84	94	85	91	92	88	99	81	78	81	82	82	79	85	85	80
Row 8	97	85	95	91	87	95	88	97	90	90	115	82	84	95	97	98	80	87
Row 9	90	86	91	90	97	95	95	99	100	96	117	96	94	91	102	95	99	95
Row 10	78	86	89	89	102	98	82	103	100	90	99	91	93	87	98	102	89	92
Row 11	98	118	85	92	92	101	94	92	97	100	97	95	96	100	93	93	90	95
Row 12	100	102	100	102	108	98	92	105	102	100	102	105	102	98	102	110	100	95

Total Average: 96.51  
 Jelly Balance: 3.0 lbs. per ream, below limits  
 Type Tissue: Kraftex

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 5

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	30	32	31	35	41	37	34	32	40	32	33	35	33	31	33	46	43	45
Row 2	30	35	32	35	35	39	35	31	30	40	34	40	35	35	45	48	35	65
Row 3	35	35	32	40	42	35	34	31	31	32	33	35	33	35	42	37	68	40
Row 4	35	35	33	35	40	32	34	35	32	35	33	32	34	32	35	33	33	36
Row 5	33	32	35	40	35	32	35	32	32	35	33	32	35	37	35	35	33	35
Row 6	40	35	35	35	35	35	35	35	35	32	32	32	32	35	42	33	40	40
Row 7	38	35	35	35	36	31	30	32	33	33	31	30	31	32	37	34	32	37
Row 8	37	35	35	40	38	39	34	35	33	35	35	30	35	31	33	37	34	35
Row 9	35	38	34	38	40	38	39	35	34	39	37	36	40	38	40	38	35	33
Row 10	35	32	37	38	38	35	33	35	35	35	34	35	35	35	34	39	40	35
Row 11	32	30	31	34	32	34	32	30	35	33	31	30	35	35	37	33	35	38
Row 12	31	28	32	32	31	35	31	32	34	35	35	35	35	35	33	35	32	35

Total Average: 35.32  
 Jolly Balance 5.7 lbs. per room, within limits  
 Type Tissue: Kraftex

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 6

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	16	16	16	14	17	18	15	18	21	20	25	22	22	16	15	12	12	
Row 2	18	17	18	16	15	16	15	19	23	21	25	23	21	19	16	13	12	
Row 3	20	18	17	18	16	17	17	18	23	22	26	25	30	20	17	15	15	15
Row 4	19	21	20	22	17	18	19	18	23	64	28	55	27	20	18	15	19	18
Row 5	19	20	19	18	16	17	20	18	19	65	45	27	21	20	17	15	30	14
Row 6	20	19	18	17	15	18	20	19	20	42	48	25	22	25	18	17	15	15
Row 7	19	19	18	17	15	17	45	18	21	65	80	24	25	25	20	17	15	17
Row 8	20	21	20	19	16	18	19	22	33	50	68	62	55	26	19	18	18	16
Row 9	19	22	22	20	16	20	19	19	24	60	125	23	25	25	20	19	18	17
Row 10	18	22	19	18	18	18	22	22	36	70	32	32	50	35	21	20	18	19
Row 11	20	21	20	18	17	19	20	24	26	25	28	27	30	23	21	18	21	21
Row 12	21	20	16	16	17	18	22	34	22	25	23	56	23	35	19	19	20	17

Note: x means omitted from averaging.

Total Average: 19.71  
Jolly Balance: 5.1 lbs. per ream, above limits  
Type Tissue: Kraftex

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 7

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	38	35	31	29	30	31	29	31	30	28	25	25	26	30	31	25	30	26
Row 2	35	55	31	30	28	35	33	32	30	28	28	30	28	21	25	31	27	28
		x																
Row 3	30	50	38	50	33	32	30	32	28	30	26	50	22	27	28	25	30	32
		x																
Row 4	36	40	32	29	32	35	43	48	58	29	30	45	45	26	26	29	28	26
						x	x	x	x		x	x	x					
Row 5	30	28	30	28	30	24	31	30	30	30	32	25	28	23	25	30	22	28
Row 6	38	35	33	31	32	45	35	34	42	40	30	26	33	28	25	28	25	25
					x			x	x		x		x					
Row 7	35	35	30	35	53	28	26	28	30	28	25	23	29	25	24	22	30	28
					x													
Row 8	30	30	30	28	24	25	26	22	20	22	25	22	22	19	29	22	23	20
Row 9	25	27	25	27	24	20	23	25	25	22	23	20	21	23	19	20	21	23
Row 10	25	26	32	28	32	23	25	23	22	21	19	22	20	19	21	20	19	18
Row 11	28	23	28	25	23	22	21	21	22	20	18	20	21	20	20	18	18	20
Row 12	18	20	21	25	22	21	19	20	20	16	20	20	19	17	15	15	18	15

Note: x means omitted from averaging.

Total Average: 26.17  
 Jolly Balance: 3.2 lbs. per room; below limits  
 Type Tissue: International

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 8

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	42	38	40	32	41	45	51	35	30	32	32	30	37	35	32	32	45	42
Row 2	45	39	40	44	45	38	35	35	35	45	30	35	38	35	32	35	45	45
Row 3	43	45	40	40	42	37	40	38	30	35	38	35	28	30	35	35	30	28
Row 4	45	45	43	39	45	40	38	39	38	35	32	37	32	35	31	25	37	38
Row 5	47	43	42	49	45	45	39	39	40	35	41	41	35	33	35	40	28	36
Row 6	42	42	45	45	38	40	45	40	40	45	35	35	38	38	35	32	35	38
Row 7	50	42	38	45	45	42	39	39	37	35	35	35	34	38	33	38	37	38
Row 8	38	41	47	42	34	39	42	40	32	35	35	35	35	32	35	38	40	37
Row 9	50	52	42	38	39	45	35	35	39	35	32	32	35	35	37	34	40	39
Row 10	47	50	52	49	43	42	40	42	36	32	35	35	30	29	35	37	38	38
Row 11	46	47	42	44	45	46	45	45	43	41	35	35	37	38	35	33	38	39
Row 12	45	42	41	45	45	42	42	38	43	38	35	40	38	35	38	37	37	30

Note: x means omitted from averaging.

Total Average: 38.33  
 Jolly Balance: 3.8 lbs. per ream, within limits  
 Type Tissue: International

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 9

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	16	14	15	15	15	15	17	15	14	16	13	13	12	11	13	13	14	15
Row 2	12	12	12	15	13	14	13	14	12	13	11	11	10	10	10	11	12	15
Row 3	15	14	13	13	13	14	15	16	15	12	12	10	9	11	10	10	17	10
Row 4	12	12	12	13	13	13	15	19	15	11	11	10	10	10	12	10	15	12
Row 5	13	13	12	12	12	13	13	15	13	12	13	10	10	10	11	10	10	10
Row 6	11	11	10	11	11	13	12	12	13	13	12	10	10	11	11	10	10	11
Row 7	10	11	11	11	12	12	11	13	12	11	12	10	10	10	10	10	9	8
Row 8	10	10	11	11	10	10	10	11	11	10	11	10	10	10	9	8	8	8
Row 9	10	10	10	10	9	10	10	10	11	11	10	11	10	10	8	9	11	8
Row 10	10	10	10	10	10	11	9	10	9	8	8	8	8	8	8	8	9	8
Row 11	10	10	9	8	8	8	10	10	10	6	7	8	8	8	8	8	9	8
Row 12	10	10	10	10	9	11	10	11	11	9	6	10	6	9	9	9	9	8

Note: x means omitted from averaging. Total Average: 10.98  
 Jolly Balance: 5.6 lbs. per ream, above limits  
 Type Tissue: International

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 10

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	75	67	76	79	75	69	80	72	82	80	70	70	68	74	78	66	62	75
Row 2	55	55	60	57	65	57	70	70	65	62	62	52	56	56	52	50	50	60
Row 3	62	60	60	60	58	58	68	62	70	57	58	56	55	49	52	55	65	70
Row 4	67	72	62	65	62	66	67	77	69	77	70	72	61	58	56	62	70	71
Row 5	71	70	67	69	68	71	75	71	71	71	60	75	66	60	60	59	60	66
Row 6	80	72	73	53	77	72	78	74	82	73	72	72	70	72	65	55	75	76
Row 7	80	88	81	75	80	82	80	82	85	95	85	85	78	72	80	80	80	78
Row 8	78	83	80	80	82	82	80	88	90	92	92	98	88	78	80	78	77	88
Row 9	90	90	82	88	85	90	80	107	88	80	91	98	75	80	80	74	82	88
Row 10	83	90	78	82	98	90	98	100	91	80	80	85	88	80	78	82	120	104
Row 11	82	88	82	83	100	85	92	105	98	90	87	90	80	80	70	80	80	85
Row 12	75	75	68	75	75	90	98	81	89	78	90	80	72	75	72	69	68	87

Note: x means omitted from averaging.

Total Average: 74.93  
 Jelly Balance 5.3 lbs per ream, below limits  
 Type Tissue: Brownsville

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 11

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	79	80	85	82	80	78	70	88	80	78	78	85	81	72	77	81	88	82
Row 2	85	78	85	95	90	80	79	80	85	79	85	82	72	80	93	110	98	85
Row 3	89	89	90	88	95	80	73	80	78	74	77	80	100	80	89	90	110	88
Row 4	80	73	75	82	73	72	78	82	80	75	75	75	68	73	82	75	80	78
Row 5	78	78	68	74	65	72	68	80	78	72	68	71	68	69	76	69	70	70
Row 6	75	75	78	78	87	75	72	73	78	88	75	91	80	70	75	75	75	72
Row 7	72	69	75	68	68	70	65	59	65	70	68	60	58	65	65	65	67	69
Row 8	63	59	68	61	58	57	60	55	65	61	57	54	55	59	62	65	57	60
Row 9	60	63	69	61	51	51	57	50	57	70	51	48	51	50	50	55	55	56
Row 10	58	65	65	58	50	55	49	50	53	55	55	50	48	55	55	58	58	61
Row 11	62	55	55	65	53	50	55	52	58	51	55	50	55	58	55	61	55	55
Row 12	55	55	52	60	49	45	52	52	58	48	45	52	58	75	55	58	58	65

Total Average: 69.8  
 Jelly Balance: 3.5 lbs. per ream, below limits  
 Type Tissue: Brownsville

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 12

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	75	75	80	93	82	80	70	80	75	73	74	55	68	65	70	65	80	80
Row 2	75	70	69	72	71	68	68	62	55	71	68	65	58	55	58	60	58	60
Row 3	70	125	90	76	68	70	60	58	57	63	58	58	50	70	57	55	62	62
Row 4	70	85	65	62	63	64	64	58	58	61	65	53	49	50	55	50	62	56
Row 5	65	60	55	55	52	58	62	63	49	62	70	44	50	51	52	53	49	55
Row 6	55	49	59	57	65	58	55	65	70	55	47	50	42	52	48	43	44	49
Row 7	60	68	58	50	57	50	50	50	50	51	44	41	43	48	55	52	45	53
Row 8	70	65	62	57	53	60	55	55	63	54	50	48	49	50	56	58	58	75
Row 9	58	65	61	57	55	52	50	48	82	49	53	48	49	48	48	49	51	53
Row 10	55	58	62	55	59	56	48	51	52	52	45	45	44	43	42	50	41	45
Row 11	65	68	63	55	62	65	53	55	55	55	58	57	50	62	49	53	49	49
Row 12	63	50	58	65	63	58	60	58	58	56	53	55	52	57	63	50	52	48

Note: x means omitted from averaging.  
 Total Average: 57.46  
 Jelly Balance: 4.6 lbs. per ream, within limits  
 Type Tissue: Brownsville

Readings in Micrometers of the  
216 Square Areas Tested on Carbon Tissue No. 13

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	72	77	70	70	92	85	75	75	80	100	82	72	77	77	80	78	90	95
	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Row 2	62	68	62	66	65	65	68	62	68	82	126	68	65	68	72	130	80	72
									X	X	X	X	X	X	X	X	X	X
Row 3	65	70	63	67	67	68	71	60	72	68	72	68	80	72	72	75	70	68
	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Row 4	60	75	58	52	69	58	60	65	59	59	62	56	72	57	62	62	63	68
	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Row 5	60	58	58	60	62	58	58	68	56	61	58	59	59	62	58	70	62	62
																X		
Row 6	56	65	61	54	50	55	58	68	62	68	58	55	52	58	60	52	52	57
Row 7	58	55	47	51	58	55	58	50	56	82	62	55	52	49	55	60	55	61
										X								
Row 8	56	60	55	56	55	59	52	50	48	57	62	59	65	61	55	59	66	82
																		X
Row 9	58	65	54	62	58	66	63	55	55	59	59	68	58	56	52	55	65	70
																		X
Row 10	55	55	57	52	55	60	62	51	52	80	57	52	60	58	52	55	65	65
									X									
Row 11	60	62	65	62	65	70	68	62	69	68	68	58	75	70	68	70	65	72
													X	X	X	X	X	X
Row 12	60	65	60	65	69	70	55	70	72	68	62	72	78	85	80	64	70	90
											X	X	X	X	X	X	X	X

Note: X means omitted from averaging.  
 Total Average: 59.66  
 Jolly Balance: 4.6 lbs. per ream, within limits  
 Type Tissue: Brownsville

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 14

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	30	19	30	18	18	17	18	18	20	60	18	21	20	19	18	17	17	17
	x		x							x								
Row 2	15	18	18	17	18	20	18	15	14	18	20	22	18	18	17	17	15	15
Row 3	100	32	18	17	15	13	17	13	15	19	20	19	18	25	18	17	19	15
	x	x												x				
Row 4	17	19	21	16	15	15	20	15	15	18	19	19	18	20	22	18	16	15
Row 5	20	21	19	18	18	18	18	18	17	19	19	20	18	18	20	20	17	17
Row 6	23	18	18	18	18	18	78	22	57	55	15	20	18	20	21	18	15	17
	x						x		x	x								
Row 7	20	19	17	18	19	17	20	21	95	100	17	19	20	20	15	18	18	15
									x	x								
Row 8	23	19	18	18	15	18	18	20	70	93	18	25	18	18	19	16	18	18
	x								x	x								
Row 9	18	18	18	16	15	15	18	30	48	102	15	19	18	18	18	21	17	15
								x	x	x								
Row 10	17	17	17	16	16	18	18	18	30	45	15	20	18	18	20	18	20	15
									x	x								
Row 11	17	15	15	16	20	18	19	18	15	55	18	19	18	20	15	18	15	16
										x								
Row 12	15	15	16	17	17	16	16	16	15	16	15	20	18	19	18	17	15	15

Note: x means omitted from averaging.

Total Average: 17.69  
Jolly Balance: 5.6 lbs. per ream, above limits  
Type Tissue: Brownsville

125

Readings in Micromperes of the  
216 Square Areas Tested on Carbon Tissue No. 15

Columns

Row 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Row 2	14	13	15	18	18	18	15	15	40	13	15	16	13	12	19	22	13	15		
Row 3	13	16	14	15	23	18	15	15	x	15	17	13	15	13	13	15	13	17	12	
Row 4	15	13	13	18	18	18	17	13	13	15	15	13	12	13	12	13	13	15	15	13
Row 5	13	13	15	13	19	17	17	17	17	13	13	13	12	12	13	12	13	12	13	12
Row 6	15	15	15	16	17	19	17	14	19	17	16	14	15	15	15	15	15	15	15	15
Row 7	14	15	15	14	18	17	15	18	51	35	22	65	12	12	12	13	11	20		
Row 8	14	17	13	18	13	17	15	13	x	x	x	14	12	15	13	14	15	15		
Row 9	16	16	15	18	28	16	18	13	58	130	13	16	16	15	13	12	15	18		
Row 10	16	15	15	18	17	16	16	15	60	180	28	15	16	17	14	15	25	18		
Row 11	15	15	15	17	19	17	15	15	85	110	18	17	20	16	17	15	16	17		
Row 12	15	15	17	17	19	17	17	17	x	x		15	16	19	25	15	15	30		

Note: x means omitted from averaging.

Total Average: 15.57  
 Jolly Balance: 5.6 lbs. per resm, above limits  
 Type Tissue: Brownsville

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 16

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	96	92	96	115	110	96	99	99	108	112	100	105	92	106	90	88	80	
Row 2	105	108	132	100	123	115	110	103	111	101	95	88	94	110	120	102	108	148
Row 3	135	118	108	132	101	112	105	105	98	98	118	114	112	87	108	98	111	107
Row 4	104	100	100	115	110	100	122	119	108	95	111	101	125	110	122	108	92	128
Row 5	112	107	115	108	102	115	130	125	141	159	122	195	135	112	100	142	145	121
Row 6	138	130	145	160	140	135	125	128	138	132	132	190	123	140	150	200	162	135
Row 7	145	145	155	140	140	130	132	125	122	130	170	160	200	190	200	200	200	140
Row 8	151	145	120	160	138	140	134	125	140	139	148	156	144	155	136	169	185	167
Row 9	142	155	146	120	140	146	150	172	170	130	135	145	132	160	122	150	152	140
Row 10	176	150	165	136	148	157	167	160	153	130	155	138	155	135	141	152	170	159
Row 11	141	165	135	142	170	150	180	166	160	145	148	155	160	151	150	177	165	135
Row 12	167	180	161	145	169	167	150	170	148	170	156	152	142	152	138	200	131	132

Note: x means omitted from averaging.

Total Average: 130.94

Jelly Balance: 5.3 lbs per ream, below limits

Type Tissue: Brownsville

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 17

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	149	145	130	122	132	125	148	149	138	149	158	139	130	139	149	150	141	149
Row 2	150	120	165	150	125	128	145	151	140	150	107	112	120	117	129	100	145	139
Row 3	159	140	128	130	131	128	168	148	138	139	135	129	131	121	130	125	157	160
Row 4	149	148	120	165	135	135	170	149	138	127	125	108	112	135	129	125	129	137
Row 5	172	200	139	139	145	155	180	175	129	179	145	129	129	131	150	162	172	140
Row 6	145	195	140	112	140	145	129	130	130	200	145	165	170	140	195	185	145	139
Row 7	170	130	142	119	180	129	119	112	142	195	175	200	115	162	200	115	129	142
Row 8	200	115	109	145	112	123	109	107	115	152	200	150	200	119	110	135	115	130
Row 9	149	130	130	135	142	130	112	149	118	155	120	145	139	139	129	140	115	149
Row 10	129	124	121	169	159	130	139	157	137	170	165	140	151	145	145	125	129	115
Row 11	129	110	132	110	190	132	128	145	135	135	112	115	122	121	132	108	105	112
Row 12	99	75	98	149	131	125	190	117	149	112	103	112	129	115	125	105	101	101

Note: x means omitted from averaging.  
 Total Average: 131.14  
 Jolly Balance: 3.3 lbs. per rem, below limits  
 Type Tissue: Brownsville

Readings in Microscopes of the  
216 Square Areas Tested on Carbon Tissue No. 15

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	64	90	92	85	95	88	72	65	67	65	62	65	65	65	72	55	72	67
Row 2	59	68	90	75	73	75	60	65	55	57	66	58	65	61	60	60	62	61
Row 3	62	79	70	71	70	82	62	68	57	55	65	57	58	70	62	57	62	68
Row 4	61	64	70	64	65	65	68	65	56	58	57	58	55	65	58	49	59	55
Row 5	68	62	68	65	68	58	61	68	65	70	73	55	56	65	68	61	56	58
Row 6	68	62	67	65	73	66	67	80	99	65	58	56	60	74	109	70	61	68
Row 7	63	65	60	58	58	65	58	69	59	51	52	51	57	68	62	59	53	57
Row 8	66	60	60	57	53	58	68	66	69	52	52	66	59	63	59	57	58	64
Row 9	72	58	55	61	55	49	57	58	65	52	53	56	52	58	55	59	52	61
Row 10	62	58	58	58	56	58	55	61	52	60	55	55	69	58	62	72	55	58
Row 11	66	66	65	66	76	65	67	65	55	57	65	54	75	75	72	54	55	60
Row 12	65	59	57	65	75	65	62	59	58	61	56	49	57	65	95	52	55	55

Note: x means omitted from averaging.

Total Average: 62.25  
 Jelly Balance: 4.2 lbs. per ream, within limits  
 Type Tissue: Brownsville

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 19

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	67	68	67	65	69	70	68	68	74	65	61	69	69	72	72	85	72	92
Row 2	68	64	62	60	78	65	63	68	66	65	61	68	65	71	78	72	107	97
Row 3	71	65	63	64	69	63	65	73	67	65	65	58	61	67	68	70	96	65
Row 4	77	78	71	70	65	68	67	65	71	78	70	67	68	58	71	65	65	60
Row 5	65	59	58	62	61	63	58	55	69	85	69	68	65	72	63	62	69	66
Row 6	69	59	62	59	67	59	65	62	60	69	79	63	67	61	63	58	68	63
Row 7	65	63	58	56	61	58	58	57	58	70	68	63	63	61	63	59	61	69
Row 8	75	69	60	72	65	62	65	55	60	76	55	62	58	59	58	61	63	68
Row 9	80	73	75	70	65	79	63	53	59	65	55	55	62	52	53	62	60	61
Row 10	X	60	55	56	61	67	58	60	66	62	55	62	62	55	58	60	57	59
Row 11	120	62	115	85	68	60	62	72	62	73	67	58	62	64	60	60	65	75
Row 12	X	85	138	90	72	71	68	70	68	70	68	63	68	68	65	72	68	70
	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Note: X means omitted from averaging.

Total Average: 65.85  
 Jolly Balance: 4.2 lbs. per room, within limits  
 Type Tissue: Brownsville

Readings in Micrometers of the  
216 Square Areas Tested on Carbon Tissue No. 20

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	112	85	109	98	101	99	107	108	94	127	130	125	125	126	143	117	125	110
Row 2	81	84	84	89	98	115	98	101	119	135	152	131	118	138	155	139	109	107
Row 3	97	99	89	91	105	112	125	101	115	131	115	130	125	148	178	149	118	115
Row 4	92	105	105	91	101	112	94	100	112	108	120	115	130	125	118	138	116	126
Row 5	99	105	102	92	107	98	120	112	150	137	145	132	120	112	122	121	136	128
Row 6	98	102	105	97	92	119	121	109	121	160	145	139	118	116	132	120	140	128
Row 7	130	105	100	97	93	129	125	115	150	153	149	132	130	131	139	129	149	145
Row 8	106	107	102	110	111	163	112	200	200	147	143	147	118	147	120	125	139	135
Row 9	90	99	101	121	125	120	116	200	145	160	180	130	132	140	118	145	150	117
Row 10	88	160	114	107	108	142	132	149	155	165	151	152	142	135	158	137	123	131
Row 11	94	97	119	88	112	129	111	125	230	197	150	155	129	132	140	120	115	136
Row 12	98	132	121	125	133	130	180	200	200	200	192	180	152	190	151	155	149	137

Note: x means omitted from averaging.

Total Average: 122.02  
Jolly Balance: 5.5 lbs. per ream, below limits  
Type Tissue: Brownsville

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 21

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	115	122	122	129	149	149	156	110	124	134	121	125	116	92	106	105	111	110
Row 2	118	135	136	151	159	142	130	137	122	130	117	117	116	113	115	111	115	110
Row 3	149	145	130	150	149	125	170	140	132	145	121	115	120	119	110	105	109	102
Row 4	139	132	140	130	127	122	128	116	103	115	114	117	117	107	110	109	101	128
Row 5	150	123	120	119	122	120	126	125	107	113	125	129	110	102	102	95	112	95
Row 6	159	140	130	145	132	130	120	132	173	145	122	112	107	92	95	99	95	94
Row 7	155	150	139	159	160	142	138	133	175	159	200	109	119	62	92	108	123	105
Row 8	159	149	150	150	126	145	170	149	175	125	138	116	132	93	99	93	95	112
Row 9	152	129	155	155	133	140	141	172	131	200	200	200	95	105	99	95	99	92
Row 10	140	135	115	115	161	149	140	135	130	200	140	130	102	95	132	93	155	90
Row 11	155	145	128	130	160	140	145	192	190	200	129	109	122	97	99	118	120	98
Row 12	160	139	149	139	139	156	135	179	142	200	200	150	130	124	104	180	115	69

Note: x means omitted from averaging.

Total Average: 123.61  
Jolly Balance: 3.3 lbs. per rem., below limits  
Type tissue: Brownsville

Readings in Microamperes of the  
216 Square Areas Tested on Carbon Tissue No. 22

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	125	143	107	103	92	91	97	102	109	139	135	112	118	118	133	130	112	105
Row 2	68	100	108	99	105	94	95	110	108	101	150	110	165	165	101	186	135	150
Row 3	81	175	105	95	110	122	113	99	115	112	132	129	153	159	165	165	185	182
Row 4	112	108	107	107	103	95	94	95	100	95	119	130	124	135	145	130	130	145
Row 5	102	115	92	99	109	125	99	116	129	125	116	115	118	145	145	112	165	160
Row 6	143	118	115	112	105	101	110	102	132	155	102	105	108	118	118	125	120	118
Row 7	160	135	119	99	110	115	102	115	125	135	115	107	108	122	135	112	109	102
Row 8	130	125	112	103	102	110	150	110	145	115	130	140	97	100	105	130	122	115
Row 9	125	128	185	105	101	110	118	100	115	132	115	119	102	98	105	105	118	113
Row 10	102	109	110	135	114	95	121	110	102	130	107	93	95	99	115	102	102	102
Row 11	108	90	122	105	139	105	100	105	102	112	112	108	99	99	120	99	109	109
Row 12	108	102	135	112	112	122	112	102	102	115	145	108	125	110	142	100	118	108

Note: x means omitted from averaging.  
 Total Average: 114.19  
 Jolly Balance: 4.4 lbs. per room, within limits  
 Type Tissue: Brownsville

Readings in Micrometers of the  
216 Square Areas Tested on Carbon Tissue No. 23

Columns

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Row 1	42	55	170	40	56	75	118	105	89	95	59	52	60	45	75	140	92	82
Row 2	45	55	48	42	55	62	72	110	79	105	59	58	80	62	88	88	85	115
Row 3	70	125	94	67	68	53	62	72	76	87	90	65	76	65	70	75	110	95
Row 4	78	60	58	112	125	63	74	92	70	68	69	55	62	65	72	110	82	85
Row 5	69	80	55	122	130	72	75	101	90	80	82	75	70	75	90	82	83	108
Row 6	67	60	62	85	80	76	78	82	82	110	105	82	85	100	82	85	95	132
Row 7	63	62	58	68	72	80	80	82	65	80	125	70	75	56	72	88	105	150
Row 8	82	65	75	70	65	75	90	88	90	100	90	82	82	80	80	90	105	105
Row 9	70	72	72	80	78	75	75	90	112	115	88	75	95	75	75	100	97	105
Row 10	85	72	71	88	65	70	98	72	85	88	85	78	80	75	115	85	95	170
Row 11	68	70	80	86	82	80	80	92	85	100	105	85	95	98	82	88	85	100
Row 12	68	64	74	70	72	84	75	78	92	97	85	72	90	75	70	62	80	82

Note: x means omitted from averaging.

Total Average: 76.69  
Jelly Balance: 4.4 lbs. per ream, within limits  
Type Tissue: Brownsville