THE EFFECT OF AGE AND TRAFFIC DEPOSITION ON THE SPECTRAL TRANSMISSION OF GREENHOUSE GLASS

A Major Thesis

Submitted by

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INTRODUCTION

For several years Mr. A. G. Smith, of Fallon the Florist, in Roanoke, Virginia, has been attempting to correct the abnormal growth of plants in the older greenhouses. Plants in these houses grow to almost twice their normal height, but their stems are spindling, and their foliage and blossoms do not have normal development. Fig. 1, from a photograph, shows a chrysanthemum plant as it grew in an older greenhouse. The stem should normally be about four feet high. Mr. Smith has made every attempt to correct all mal-conditions of the soil, but the plants inthe older houses still continue their abnormal growth. The present problem is to determine the effect of aging and traffic film* on the spectral transmission of the glass from these older greenhouses; and to determine the relative intensity of the light which is transmitted through the glass of various ages, in the hope that this information may lead to the solution of the florists' difficulty.

* a layer of oil, dust, and cleaning compound that has been acquired over a long period.

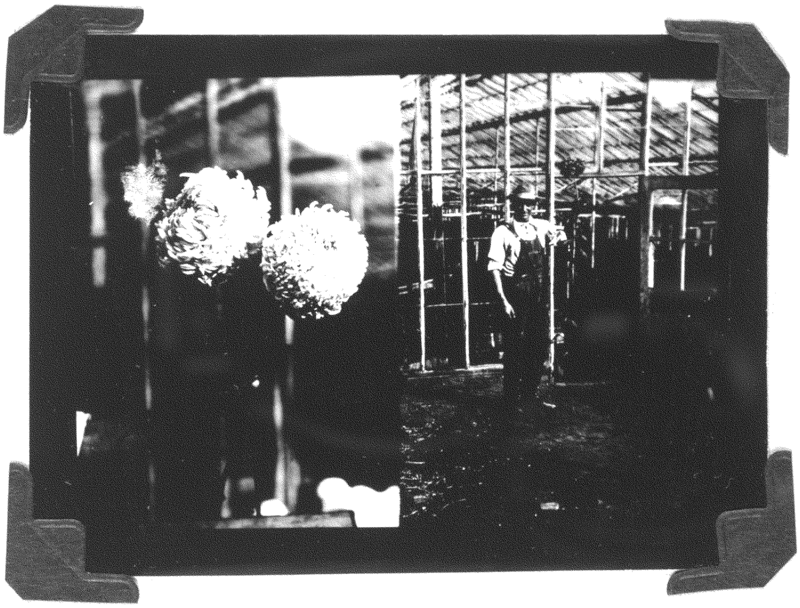

Fig. 1. A plant growing under
the old glass.

ACKNOWLEDGEMENTS

The writer is greatly indebted to Dr. F. L. Robeson for assistance in planning this investigation and for his willing and helpful advice in connection with it.

She also wishes to thank Dr. S. A. Wingard for the photograph used as Fig. 1 in this text; and Mr. A. G. Smith of Fallon the Florist, for information concerning the glass and the growth of the plants under it.

REVIEW OF LITERATURE

No record has been found of work which has been done on this particular problem. Upon inquiry at the Bureau of Standards, Washington, D. C., we find that there are data on the ultra-violet transparancy of various kinds of glass and organic substitutes for window glass (Vita-glass, Sunlit, Helioglass, etc.) which show effects of solarization on these glasses. A foot note in the letter received in response to above mentioned inquiry states that greenhouse glass, which is ordinary window glass, does not age in sunlight. We have no data which will substantiate the above statement.

A study of Chapters I, II, IV and V of Baly (1) gives a theoretical and working knowledge of the spectroscope. Chapters I and II are a historical review of all the important work which has been done in spectroscopy. Chapters IV and V contain a description of the construction and calibration of the principle types of spectroscopes.

An article by Withrow and Benedict (2) describes an experiment to determine the growth-promoting effect of the region from 2900 to 3100 Ångstroms. However, this is a region entirely cut off by ordinary greenhouse glass and the results of their experiments cannot be applied in this case.

Two statements made by Pfeffer (6) :

"Within certain limits, a decrease in the illumination produces an accelerated rate of growth in a phototonic plant, ..." and "......behind a solution of potassium bichromate, which allows the red and yellow rays to pass, but cuts off the blue and ultra-violet ones, flowering plants turn green, but otherwise grow as though in darkness or in very feeble light."

The above statements, although quite general, show that the abnormal growth of the plants might be due either to lessened intensity of all light or to actual selective filtering of the ultra-violet.

DESCRIPTION OF GLASS

Four different specimens of greenhouse glass were presented. They are tabulated as follows:

"A"- This specimen is new glass which has not been used in the greenhouse. It is the hardest of the four and is quite brittle. It has a greenish tinge.

"B"- This specimen has been used in the greenhouse about three years. It has a light film on the outer surface. It also has a greenish tinge.

"C"- This specimen has been used about fifteen years. It is rather heavily coated with dirt and traffic film, and the color is almost white.

"D"- This specimen has been used at least twenty years, and has a heavy, smoky film. The texture of this glass is quite soft, and it has a pinkish tinge. This glass has been scrubbed several times on the outer surface during the time it was in the greenhouse, and the surface is somewhat scratched.

All four of these specimens are of approximately the same thickness.

DESCRIPTION OF APPARATUS

A Gaertner spectograph was used in making the measurements of the spectral transmission. This instrument is designed to photograph the emission and absorption spectra in the visible and ultra-violet regions from 8,000 to 1,800 Ångstroms. Collimator and camera lenses are made of quartz, twenty-five millimeters aperture. The prism is of the Cornu type (built up of two thirty-degree prisms of left and right handed quartz, with faces in optical contact). Its faces are twenty millimeters high and thirty millimeters long. The plate holder, the slide, and the camera box are made of metal throughout. The plate holder takes a standard size plate, $3\frac{1}{4}$ x $4\frac{1}{4}$ inches, and may be readily shifted vertically by rack and pinion motion for the successive exposures. A millimeter scale is attached to the slide serving to indicate the position of the plate.

The plates which were used for making photographs of the spectra were Wratten and Wainwright Process Panchromatic Plates.

The source of light which was used was a Cooper-Hewitt Lab-Arc. The tube in which the arc was formed was made of fused quartz which gives a transmission into the ultra-violet of 2225 Ångstroms, and in the visible up to 5769-90 Ångstroms. These are the yellow lines of mercury.

The spectrograms were measured on the dividing engine of Max Kohl, Chemuntz, Germany, capable of reading to 0.001 mm.

Relative intensity measurements of the light transmitted by the different specimens of the glass were made by means of a Bunsen Photometer. The photometer head was of the Lummer-Brohun intensity and contrast type, made by A.Krüss, Hamburg. Two ordinary tungsten lamps maintained at constant operating conditions were used as light sources.

METHOD OF PROCEDURE

Calibration of Spectrograph Using Lab-Arc As Light Source

In order to determine the wavelengths transmitted by the glass, it was necessary to make a photograph of the entire spectrum, and identify the lines by means of tables of standard lines of the mercury arc.

The Lab-Arc was placed about a foot from the slit of the spectrograph. The flourescent screen provided for the purpose was used in the plăte holder while adjustments were made to focus the lenses. These adjustments remain the same throughout all the experiments.

In order to give an easy identification of two of the lines, a filter of a saturated solution of potassium bichromate was placed just in front of the slit and an exposure was made. This filter transmits only 5461 Å and 5769-5790 Å. From these it was possible to identify the other lines, as shown in Table I.

By means of the dividing engine, the spectrogram, Fig. 4 was measured and the readings recorded in Table I. In order to check, the measurements were first taken from left to right without changing the direction of the screw. Then the telescope was moved a little away fromthe last measured lines, the directio of the screw reversed, and the telescope moved back to focus on the last line. The readings were taken in reverse order, again without changing the direction of the screw. The average differences of these readings was taken. Line (1) as shown in Fig. 4 was taken as zero, and the distance to each successive line read in millimeters.

Determination of the Extent of Spectral Transmission of the Different Specimens of Glass

Visible and Ultra-Violet Spectra: Samples, approximately three inches square, were cut from the different specimens of glass, and lettered as indicated above; i.e., "A", "B", etc. Each sample was marked with a piece of carborundum into small squares. Three lines were drawn parallel to each face, and the squares numbered, 1, 2, 3, -----9. Special care was taken to avoid scratching any of the film or dirt from the surfaces of the old glass before the first determinations were made.

It was necessary at first to make several trials to determine the time required to give a fairly equal exposure of the plates through the different kinds of glass. The oldest glass cuts down the transmission about 50 per cent. (This determination was made by photometer, and not by ratio of necessary time exposures). The "A" glass required eight seconds for good exposure; the light source was placed about a foot from the slit of the spectrograph and the glass screen was as close as possible to the slit. (Fig. 2). Using the same arrangement

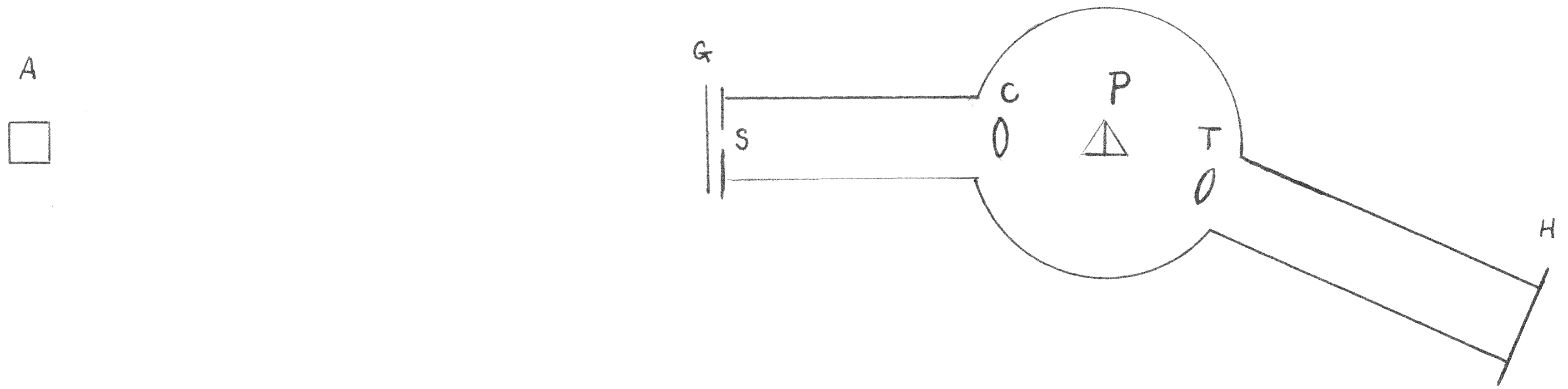

Fig. 2. A cross section of arrangement used in making spectrograms. A is the mercury arc; G is the glass screen, S is the slit, C, the collimator lens, P, the Cornu prism, T the telescope lens and H the plate holder.

for exposure, the "B" glass required an exposure of twelve seconds; the "C" glass, sixteen seconds; and the "D" glass, twenty-five seconds. A stop watch was used in measuring the times of exposure.

After the correct exposures had been determined, four plates, one using each kind of glass for a screen, were made. Each plate contained one exposure through each marked square on the sample, making nine exposures for each plate. In this way, an average spectrum was obtained for each sample of the glass and the possibility of error in the exposure was minimized.

Samples "B", "C" and "D" which had been used in the houses, and were aged and film-coated, were then cleaned with Bon Ami. Only half of each sample was cleaned, and the other left as it was, for control purposes. Another set of three plates were made. This time, each plate contained four exposure Three of these were made, using each of three squares of the clean glass as a screen, and one exposure was made through the glass as it was originally. In this way a close comparison between the spectrum transmitted by the old, <u>clean</u> glass and the old, <u>dirty</u> glass was obtained. In making these exposures it was necessary to expose the plate only eight seconds when the clean glass was used as a screen. The exposures made through the dirty glass were of the same length as given above.

Measurement of Intensity of Light Transmitted Through Various Specimens of Glass

By Photometer. The photometer was set up as shown by sketch in Fig. 3. The screen was placed on one side of the photometer head as close to the opening as possible. The head was moved up and down on the scale until an intensity match was secured, and the lengths L_1 and L_2 recorded. The following relations were used in working out the percentage of light cut out by the different specimens of glass.

The law for the photometer is :*

$$\frac{I_1}{I_2} = \frac{L_1^2}{L_2^2} \qquad (1)$$

where I_1 and I_2 are intensities without any screen, and L_1 and L_2 are their respective lengths from the photometer head when intensity match is obtained.

From equation (1) we have that:

$$I_2 = \frac{L_2^2}{L_1^2} I_1$$

When a screen is used on the I_2 side of the photometer head it is equivalent to changing the intensity of I_2. If "A" screen is used and the equivalent intensity obtained is called I_A, we have the relation:

* Watson---A Text-Book of Physics (Longman), p.498

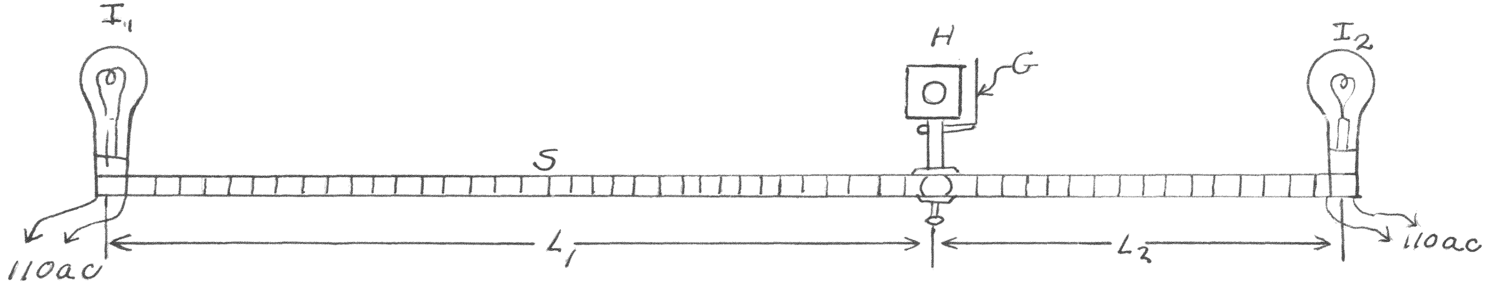

Fig. 3. Sketch showing photometer arrangement. G is the glass screen, H is the movable photometer head, and S is the scale.

$$I_A = \frac{L_{A_2}^2}{L_{A_1}^2} \quad I_1$$

In which L_{A_1} is the distance of the photometer head from I_1 and L_{A_2} is distance from I_A. I_1 is the same in each case.

Then the ratio of the intensity of light using screen "A" to the intensity of I_2 is :

$$\frac{I_A}{I_2} = \frac{I_1 \left(\frac{L_{A_2}}{L_{A_1}}\right)^2}{I_1 \left(\frac{L_2}{L_1}\right)^2}$$

If we multiply this value of $\frac{I_A}{I_2}$ by 100, and call it T_A, we have the percentage of total light which is transmitted by screen "A".

Similarly:

$$T_B = \frac{\left(\frac{L_{B_2}}{L_{B_1}}\right)^2}{\left(\frac{L_2}{L_1}\right)^2} \times 100$$

$$T_C = \frac{\left(\frac{L_{C_2}}{L_{C_1}}\right)^2}{\left(\frac{L_2}{L_1}\right)^2} \times 100$$

$$T_D = \frac{\left(\frac{L_{D_2}}{L_{D_1}}\right)^2}{\left(\frac{L_1}{L_2}\right)^2} \times 100$$

In the present case it is also desirable to obtain the ratio of the intensity of light transmitted by screens "B", "C", and "D" to the light transmitted by screen "A". To do this we use relations similar to those above:

$$\frac{I_B}{I_A} = \frac{\left(\frac{L_{B_2}}{L_{B_1}}\right)^2}{\left(\frac{L_{A_2}}{L_{A_1}}\right)^2}$$

And from this we can obtain the light transmitted by "B" in terms of the percentage of the light transmitted by "A".

We can also obtain similar relations for "C" and "D" screens.

Measurements were made for each one of the samples. An intensity match was obtained by moving the photometer head first from right to left. Then it was moved from left to right, and an arithmetic mean of these readings for L_1 and L_2 computed. The photometer head was reversed and, keeping the screen always on the I_2 side, the same process was repeated several times. An arithmetic mean was computed for all readings of L_1 and L_2 taken.*

It must be understood, however, that a photometer match is a matter of visual judgment and will differ with different observers. But since the transmissions are ratios, this personal error will tend to be eliminated.

*Not theoretically correct, but sufficiently exact for most purposes, provided the differences between the readings are small.

RESULTS AND OBSERVATIONS

<u>Calibration of Spectograph Using Lab-Arc As Light Source</u>. Fig. 4 is the photograph of the entire spectrum using the apparatus as described above. The lines which are numbered are those which were identified. Table I contains the data which were used in making this identification. Fig. 5 is the dispersion curve which was plotted using wavelengths as ordinates and distances between lines as abscissas.

Although the relation between the wavelength and the distance is not quite a straight line one, if enough lines are measured and identified when plotting the curve it is possible to determine quite accurately the wavelength of any unknown line by interpolation.

<u>Determination of Extent of Spectral Transmission Through the Different Specimens of Glass</u>.

<u>Visible and Ultra-Violet Spectrum</u>. Figs. 6, 7, 8 and 9 are photographs of the spectrum which were taken as described above. Fig. 6 is the photograph of the spectrum as transmitted by the "A" glass. The nine different exposures were made through the nine different divisions of the glass. In comparing any one of these spectra with the standard as shown in Fig. 4, we find that the "A" glass transmits from 3131 Å in the ultra-violet to 5769-90Å.

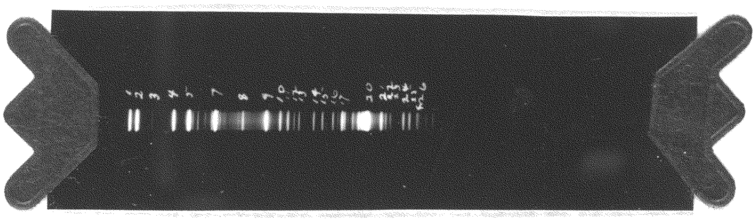

Fig. 4. Calibration spectrogram

Table # I *

Line No.	Reading in cm.	Scale in mm.	Scale in mm.	reverse direction reading in cm.	average scale in mm.	wavelength in Angstroms
1	80.9895	0.000	0.000	80.9878		5769 - 90
2	81.0827	.932	.944	81.0822	.938	5461
3	81.2820	2.925	2.927	81.2805	2.926	4960
4	81.5654	5.759	5.762	81.5640	5.760	4358
5	81.7724	7.829	7.822	81.7700	7.825	4046
6	81.8821	8.926	8.928	81.8806	8.927	
7	82.1090	11.195	11.181	82.1059	11.188	3650
8	82.4697	14.802	14.789	82.4667	14.795	3342
9	82.7773	17.878	17.861	82.7739	17.869	3131
10	82.9574	19.679	19.676	82.9554	19.677	3022
11	83.0579	20.684	20.688	83.0566	20.686	2967
12	83.1397	21.502	21.501	83.1379	21.501	2925
13	83.2038	22.143	22.136	83.2014	22.139	2894
14	83.3958	24.063	24.057	83.3935	24.060	2804
15	83.5153	25.258	25.245	83.5123	25.251	2753 - 60
16	83.6469	26.574	26.565	83.6443	26.569	2700
17	83.7652	27.757	27.752	83.7630	27.754	2654
18	83.9065	29.170	29.155	83.9033	29.162	
19	83.9797	29.902	29.891	83.9769	29.896	
20	84.1015	31.120	31.100	84.0978	31.110	2535
21	84.2741	32.846	32.837	84.2715	32.842	2482
22	84.3378	33.483	33.682	84.3560	33.582	2462
23	84.3965	34.070	34.054	84.3932	34.062	2446
24	84.5679	35.784	35.744	84.5622	35.764	2412
25	84.6442	36.547	36.540	84.6418	36.543	2378
26	84.7445	37.550	37.557	84.7435	37.553	2345

*<u>International</u> <u>Critical</u> <u>Tables.</u> and Lab-Arc-Bulletin 104-A-
Engineering Dept.- Cooper Hewitt Electric Co. Hoboken, N. J.

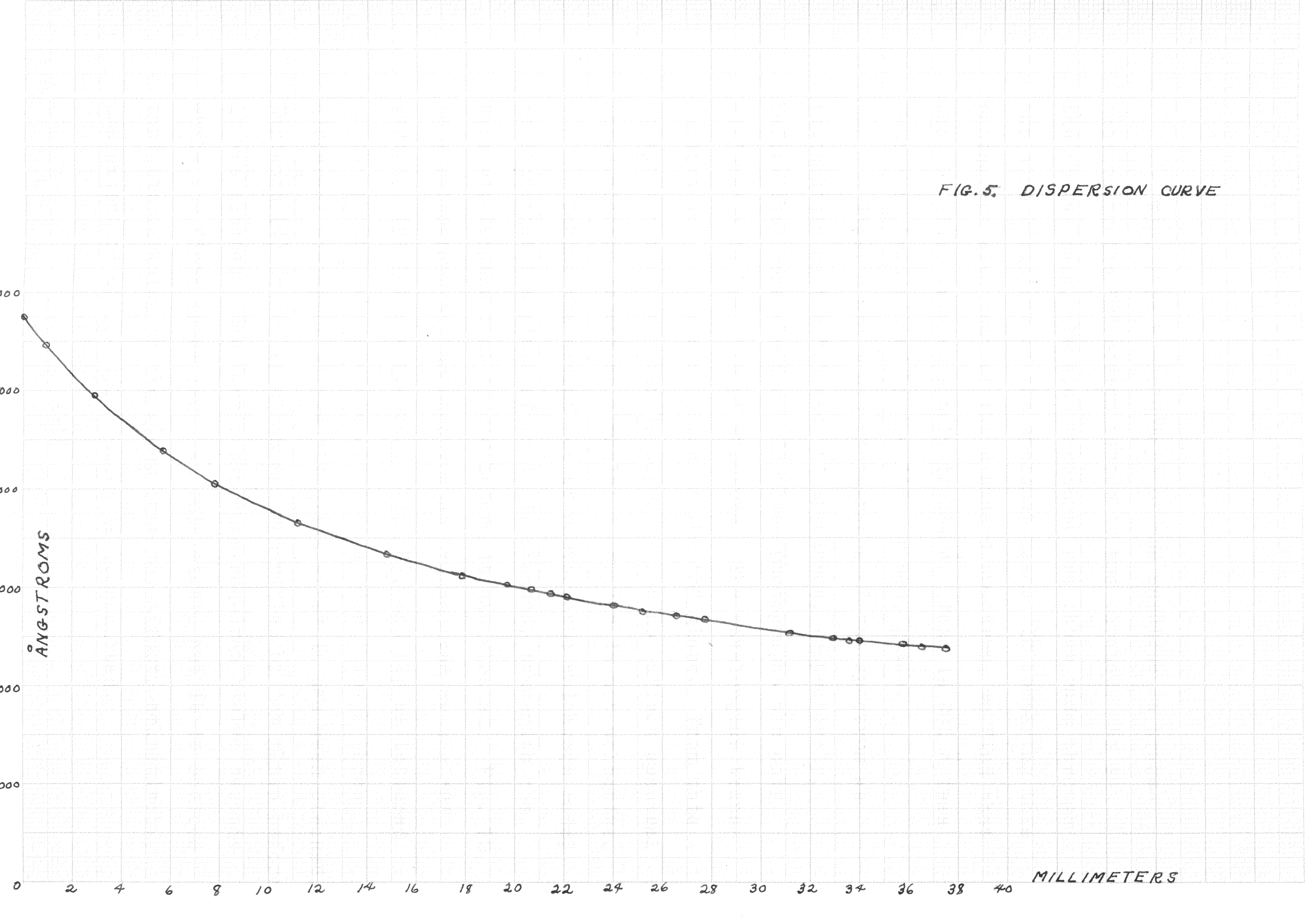

FIG. 5. DISPERSION CURVE

Fig. 7 is a photograph of the spectrum as transmitted by the "B" screen before it was cleaned. As in the former case, the nine exposures are those made through the nine divisions of the specimen used. In comparing this photograph with that of the standard spectrum, we find that the "B" glass transmits only to 3342Å. This is 221 Å less than were transmitted by the "A", or new, glass.

Figs. 8 and 9 are photographs of the spectrum as transmitted by the "C" and "D" specimens, respectively, before they were cleaned. In these photographs the only difference is the time of exposure. The wavelengths transmitted are the same as those of the "B" glass. From this it appears that the traffic deposit does not affect spectral transmission except as a whole; i. e., it is not selective.

Taking the second set of photographs whichwere made, we find that the glass after it is cleaned, transmits the same wavelengths that it did before it was cleaned. Fig. 10 is a photograph of the spectrum as transmitted by the "B" screen. The three exposures, (1), (2), and (3) as lettered on the photographs are the spectra as seen through three different divisions of the "B" glass after it had been cleaned. Exposure (4) is the spectrum as transmitted by the glass before it was cleaned. The fourth exposure required twelve seconds while the first three required only eight, but it is obvious that the cleaning of the glass does not affect, selectively, the extent of ultra-violet which is transmitted.

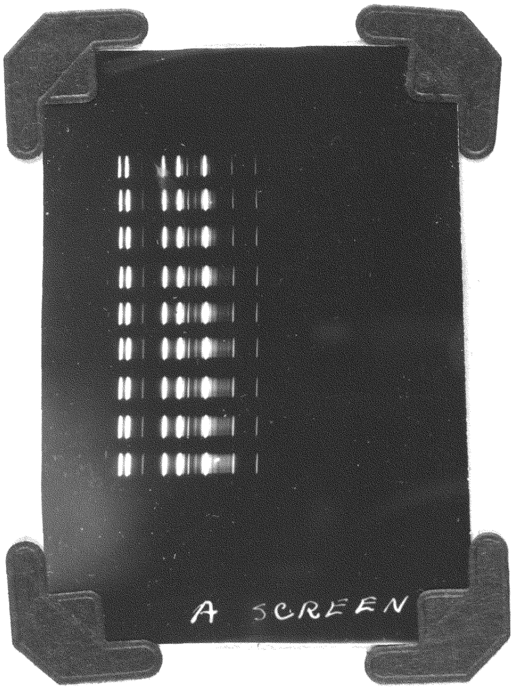

Fig. 6.

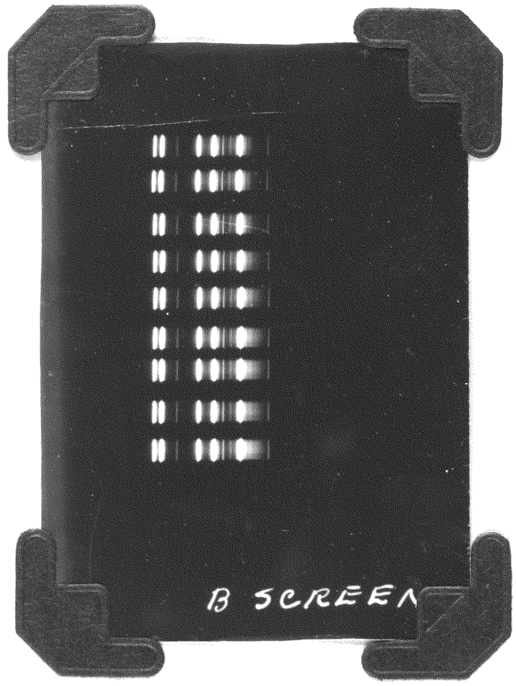

Fig. 7.

Fig. 8.

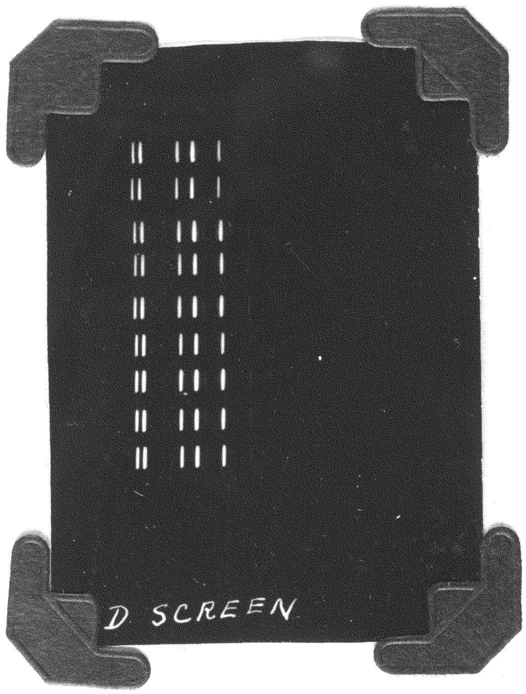

Fig. 9.

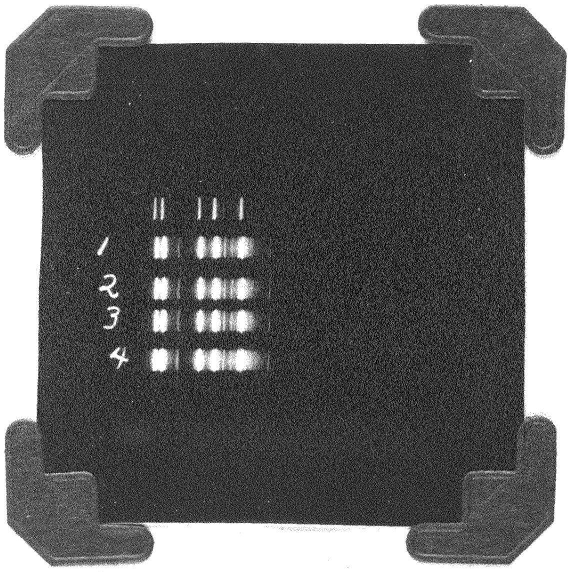

Fig. 10. "B" Screen

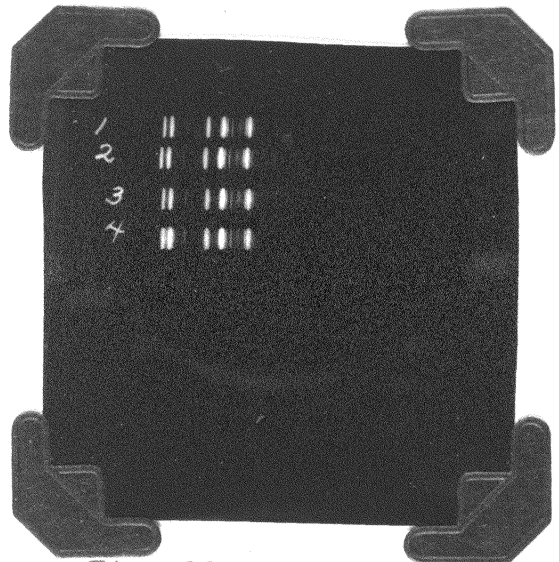

Fig. 11. "C" Screen

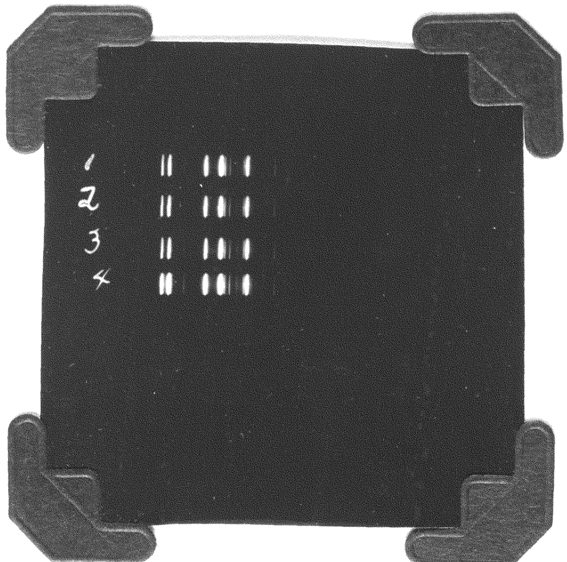

Fig. 12. "D" Screen

Figs. 11 and 12 are those corresponding to Fig. 10. They represent the spectral transmissions through "C" and "D" screens after they have been cleaned. In each photograph, exposures (1), (2) and (3) are through different sections of the cleaned glass. Exposure (4) was made through the dirty glass. In these photographs as in Figs. 7, 8, and 9 it can be seen that all of the old glass cuts off 221 Å more than the new glass.

Measurement of Intensity of Light Transmitted Through the Various Specimens of Glass

By Photometer. Table II gives the data which were obtained in determining the relative intensity of the light transmitted by the different specimens.

It will be seen from this table that the film and dirt on the old glass cuts down the intensity of the light which was transmitted very noticeably.

TABLE II

Screen	Left	right	reversed head left	reversed head right	L_2 average	L_1 $180-L_2$	% I_2	I_A
	98.5	99.0	96.5	97				
None	98.5	99.0	96.7	96.5	97.7	82.3	100	
A	96.1	96.0	94.3	94.4				
	96.3	96.0	94.1	94.3	95.2	84.8	89.3	100
	94.5	94.3	92.8	93.0				
B	94.6	94.5	93.3	92.5				
	94.7	94.3	92.1	92.4	93.0	87.0	80.8	90.5
C	89.8	89.8	88.1	88.4				
	89.6	89.7	88.3	88.4	88.9	91.1	67.5	75.5
	81.4	80.8	83.0	83.0				
D	80.8	81.3	83.0	83.0				
	80.8	81.0			82.0	98.0	49.7	55.6

DISCUSSION

From the foregoing experiment we have found that the old greenhouse glass cuts off about 200 Å in the ultra-violet which is transmitted by the new glass; and that although the dirt and traffic film deposited on the old glass cuts down the intensity of the light transmitted to as much as 50% it is not selective toward ultra-violet light.

It cannot be said at present that the difference in spectral transmission of the old and new glass is due to aging in sunlight, because it is possible that the specimen of new glass which was submitted is not of the same composition as the three specimens of old glass. It is pointed out, however, that all of the three old specimens which were tested transmitted the same wavelengths, and it is not probable that they were of exactly the same composition when new. It is probable, therefore, that this difference in selective transparancy to ultra-violet of the old and new specimens is due to aging in sunlight.

It is not possible to say that the abnormal growth of the plants is caused, either by the actual cutting off of certain portions of the spectrum or by the lessened intensity transmission, but from the statement by Pfeffer, (6) it might possibly be due to either or both of these effects.

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