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REPORT ON AN EXAMINATION OF THE SPECTRAL ENERGY DISTRIBUTION IN THE NASA CLEVELAND SOLAR SIMULATORS

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Prepared for

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Cleveland 35, Ohio

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(S. O. 9002)

1. INTRODUCTION

This report summarizes the results obtained during the visit of the undersigned to the NASA Cleveland (Lewis Center) facility, 24-26 June 1963. The spectral distribution of radiant energy, at the test location, was measured in three different solar simulators designated LPRB, IRL and LRB. In the case of the LPRB simulator, measurements were made in vacuum and with cold walls as well as in air at normal ambient temperature; in the other two cases, the program was confined to exposure in air. Each simulator is powered by an open carbon arc.

A series of four laboratory-type thermopile detectors was employed. Three of these were water-cooled; the fourth one incorporated temperature compensation of instrument sensitivity. Three series of calibrated filters were available for the test program, viz. (a) 12 narrow bandpass type specially constructed for the isolation of carbon-arc spectra, (b) 5 narrow bandpass type intended originally for the isolation of high-pressure xenon-arc spectra (but equally applicable in the present investigation with revised calibration) and (c) 5 broad bandpass type (including thermopile windows of crystal quartz pyrex and Schott KG 7 glass).

Prefix to report on "An Examination of the Spectral Energy Distribution in the NASA Cleveland Solar Simulators"

In connection with the attached report by the Eppley Laboratory, Inc., as submitted to NASA Lewis Research Center at Cleveland, Ohio, the following pertinent points are noted which affect analysis of the final reported results.

1. The spectral distribution of the carbon electrode chosen by Eppley Laboratory as the assumed source reference distribution was not the one produced by the actual conditions of operation. The IRB solar simulator uses a 13.6mm hi-intensity positive electrode burning at 200 amperes, while the EPRB* and the IRL simulators employ Ultrex positive electrodes operating at a current density of 2 amperes/cm^2.

2. The spectral distribution plotted in the report (Figure 2) is actually a composite in which the final results for each of the three simulators are averaged together.

3. The measurements were made over a period of several days under less than ideal conditions. (However, a duplicate set of the instruments used by Eppley Laboratory has been purchased and is expected shortly. This center will then have the capability of repeating these measurements under more controlled conditions, and comparing the results obtained with simultaneous measurements using dispersion-type instruments.)

Kenneth Yass
Physicist

* Reference: "Carbon Arc Solar Simulator by O. W. Uguccini and J. L. Black. ASME publication, No. 62-WA-241, presented at meeting in New York City, Nov. 25, 1962.

All thermopiles were calibrated before and after the program, at Newport, over the range of intensity involved and in vacuum as well as in air. The transmission of the filters was checked on return to Newport. The calibration of the thermopile readout instrumentation employed (viz. Leeds and Northrup D.C. indicating thermocouple amplifier model 9835, L. and N. recording millivolt potentiometer model H with variable scale and Rubicon portable potentiometer) was verified during the measurement period.

One of the two filter wheel assemblies (series (a) filters) was provided with means for automatic selection of the filters through remote control; in this way, it was possible to repeat the most significant portion of the filter examination at reduced pressures.

As an additional check of the constancy of radiant flux density, at the measurement location, in the large EPRB simulator, as operated both in air and evacuated, a hermetically sealed selenium barrier-layer photoelectric cell, fitted with a band-pass filter (isolating a narrow spectral region around 650 mμ), was incorporated into the radiation sensing equipment.

2. THERMOPILE CONSTANTS

		Sensitivity (20-25°C): mv per mw cm^{-2}		
			Spectral flux	
		Total flux	Broad band	Narrow band
(a) L. 5556	air	0.260	-	0.257
(Circular, 16-junction bismuth-silver, lamp-black receiver, water-jacketed)	vacuum	0.690	-	0.780

		Sensitivity (20-25°C): mv per mw cm^{-2}		
		Total flux	Spectral flux Broad band	Spectral flux Narrow band
(b) E. 5150	air	0.168	0.166	0.160
(Circular, 8-junction bismuth-silver, lampblack receiver, water-jacketed)	vacuum	-	-	-
(c) E. 4616	air	0.079	0.074	0.071
(Circular, 12-junction copper-constantan, lampblack receiver, water-jacketed)	vacuum	-	-	0.147
(d) E. 5384	air	0.088	0.087	0.085
(Circular, 8-junction bismuth-silver, lampblack receiver, temperature compensated)	vacuum	-	0.245	-

N.B. Although the filters designated UG 11 and 300+ are essentially of the broad band type, isolating practically the whole of the UV emission from a carbon-arc source (see next section), the transmitted energies are so low that the narrow band thermopile sensitivities are the appropriate ones.

All calibrations were made with a crystal quartz window in position as this was the manner of operation.

3. THERMOPILE WINDOWS

AND BROAD BANDPASS FILTERS

A(1) crystal quartz: uniform transmittance 250-3000 mμ

(2) pyrex glass: center of lower cutoff 295 mμ, transmission in general similar to quartz

(3) Schott WG 7 glass: center of lower cutoff 300 mμ, transmission in general similar to quartz and pyrex to 2700 mμ

		Sensitivity (20-25°C): mv per mw cm^{-2}		
			Spectral flux	
		Total flux	Broad band	Narrow band
(b) E. 3150	air	0.168	0.166	0.160
(Circular, 8-junction bismuth-silver, lampblack receiver, water-jacketed)	vacuum	-	-	-
(c) E. 4816	air	0.079	0.074	0.071
(Circular, 12-junction copper-constantan, lampblack receiver, water-jacketed)	vacuum	-	-	0.147
(d) E. 5384	air	0.088	0.087	0.085
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(4) Schott UG 11 glass: bandpass 270-380 mμ, maximum transmittance (0.68) at 335 mμ, filter factor 2.30

(5) Metallic 300+: bandpass 300-380 mμ, maximum transmittance at 340 and 370 mμ, filter factor 5.00

(6) Schott OG 1 glass: center of lower cutoff 535 mμ, filter factor 1.10

(7) Schott RG 8 glass: center of lower cutoff 700 mμ, filter factor 1.10

(8) Metallic 780+: bandpass 780-2700 mμ, average maximum transmittance (0.75) 800-2000 mμ, filter factor 1.40

4. NARROW BANDPASS FILTERS

	Wavelength limits (mμ)	Reference wavelength (mμ)	Filter factor
B(1)	260- 330	290	9.90
(2)	280- 370	320	8.80
(3)	335- 385	360	6.05
(4)	375- 430	400	3.70
(5)	420- 520	460	2.80
(6)	500- 610	545	2.40
(7)	585- 690	645	3.65
(8)	680- 820	740	4.00
(9)	770-1000	900	3.90
(10)	1050-1300	1160	4.60
(11)	1250-1850	1550	3.05
(12)	1750-2500	2100	3.75

	Wavelength limits (mμ)	Reference wavelength (mμ)	Filter factor
(1)	315- 360	340	10.0
(2)	325- 385	355	3.65
(3)	350- 420	385	3.60
(4)	405- 515	450	2.60
(5)	505- 620	550	2.35
(6)	600- 710	650	2.50
(7)	1350-1750	1550	2.55
(8)	1800-2200	2000	3.25

The narrow bandpass filters were mounted in filter wheels; the thermopile windows and the broad bandpass filters were mounted, individually, in slides.

5. FILTER DEFINITIONS

As is indicated above two types of filter were employed in the investigation, viz. broad and narrow bandpass specimens. The respective wavelength regions isolated by the various filters are tabulated. In the case of the narrow bandpass filters, the limits given for the particular "bandpass" refer to the wavelengths at which the transmittance is about 1-2 per cent; thus the bandpass or bandwidth is the wavelength interval over which the filter transmittance exceeds this threshold figure, with the condition that there is no significant (i.e. exceeding about 1 per cent in general) secondary transmission within the spectral region of the source (in this instance 250-3000 mμ). For reasons of designation of the filter bandpass, an entry "reference wave-

length" has been included in the narrow bandpass filter tables. This value is approximately the center of the band and would be exactly so if the filter transmission was always symmetrical about the position of maximum transmittance; in point of fact, the value adopted here for the reference wavelength is the center of gravity of the band.

With regard to the broad bandpass filters, three types were employed, viz. (a) filters isolating regions approximating the total ultra-violet spectrum as emitted by a carbon-arc source (actually 270-380 mμ and 300-380 mμ), (b) a filter isolating a region approximating the total infra-red spectrum as emitted by the arc (actually 780-2700 mμ) and (c) filters with lower sharp cutoff at 535 and 700 mμ (these wavelengths indicate the position where the transmission is half that of the main band).

Three thermopile windows, viz. quartz, pyrex and WG 7 glass, were included primarily for the purpose of assessing UV radiation below about 300 mμ and infra-red radiation above about 3000 mμ.

The transmission properties of the filters and window materials are reproduced in the appended spectrophotometric charts. Inspection of these records will clarify such terms as bandpass, filter limits, center of lower cutoff, average maximum transmittance and reference wavelength (formerly designated central transmission).

As is stated above, the transmission of all the filters used was re-determined, at Newport; no significant changes were observed.

6. FILTER FACTORS

A filter factor may be defined as that coefficient by which a filter-spectroradiometer output must be multiplied in order to obtain that value which would have been obtained, for a specific spectral region of the incident radiation, if that region could have been tested without using a filter. This corresponds to the reciprocal of the filter factor as defined by Forsythe (Ed. by W. E. Forsythe, "Measurement of Radiant Energy". McGraw-Hill Book Company, 1937, pp. 100-103).

The desired figure is evaluated through consideration of the spectral curves of the source, filter and detector. The observed detector value, O_m, is given by

$$O_m = \int_{\lambda 1}^{\lambda 2} J(\lambda)\,\tau(\lambda)\,S(\lambda)\,d\lambda \qquad (1)$$

where $J(\lambda)$ is the spectral irradiance at the measurement plane,

$\tau(\lambda)$ is the transmittance of the filter, and

$S(\lambda)$ is the spectral sensitivity of the detector.

The "true" reading, viz. that representative of the radiation intensity at the front surface of the filter, would obviously be

$$O_t = \int_{\lambda 1}^{\lambda 2} J(\lambda)\,S(\lambda)\,d\lambda . \qquad (2)$$

As Eppley radiometers (well blackened thermopile detectors) essentially exhibit uniform response, with regard to the wavelength of the incident energy, over the solar spectral emission region (i.e. the spectral region involved in solar simulating systems),

$S(\lambda)$ is a constant in this instance and may be removed from the integral. The filter factor, FF, as derived at the Eppley Laboratory, for filter measurements with these instruments is then

$$FF = \frac{O_t}{O_m} = \frac{\int_{\lambda 1}^{\lambda 2} J(\lambda)d\lambda}{\int_{\lambda 1}^{\lambda 2} J(\lambda)\tau(\lambda)d\lambda} . \qquad (3)$$

The total energy contained in the particular band is the product of the detector reading, converted (through its sensitivity constant) to radiant flux density, and this filter factor.

It will be seen that the simplest case is the one for which $\tau(\lambda)$ is constant or practically so (as occurs in the main transmission region of lower sharp cutoff filters). Here, the filter factor is merely the reciprocal of the (average) transmittance.

Examination of equation (3) shows that in order to obtain the filter factor, in instances excepting the above-mentioned simple case, some knowledge is necessary of the spectral emission curve of the source. Hence, in such evaluations, an assumed curve based upon the known emission characteristics of the type of source under investigation has to be adopted. The two methods commonly employed to evaluate the more complex type of filter factor are (a) planimeter graphical integration or numerical integration utilizing a computer and (b) point-by-point analysis. In the second method, an approximation sufficiently good for all practical purposes can be obtained if both source and filter curves are reasonably smooth. Choosing a number of wavelengths (usually

10 to 12 is sufficient for the filters issued by the Eppley Laboratory for such spectral studies) within the region of the filter transmittance band

$$FF = \frac{J_{\lambda 1} + J_{\lambda 2} + J_{\lambda 3} + \ldots}{J_{\lambda 1}\,\tau_{\lambda 1} + J_{\lambda 2}\,\tau_{\lambda 2} + J_{\lambda 3}\,\tau_{\lambda 3} + \ldots} = \frac{\sum_n J_{\lambda n}}{\sum_n J_{\lambda n}\,\tau_{\lambda n}} . \qquad (4)$$

In this method the source curve is generally normalized to the highest value in each filter region, in turn.

Should the spectral characteristics of the measured source differ substantially from those adopted as the basis on which to evaluate the filter factors (e.g. through marked modification by a complex intervening optical system) it may be desirable to repeat the filter factor evaluation procedure several times, each time starting with the previously derived source curve. This successive approximation technique is applicable to both FF methods discussed above.

In the Cleveland study, which is the subject of this Report, the second FF method was employed and one series of operations only were carried out, since it was judged that the measured sources were sufficiently close in their spectral characteristics to the assumed source reference (viz. National Carbon Company 13.6 mm carbon arc at 160 amperes - see Genarco leaflet 310D) to permit filter factor evaluations to be made reliably within the experimental limitations of the general filter radiometric approach to such source investigations.

7. ARCS

Open carbon arc, operated at the following average power levels:

(a) LPRB 83.5 v 390 a, i.e. 32.5 KVA

(b) IRL 70 v 155 a, i.e. 11 KVA

(c) LRS 76 v 190 a, i.e. 15 KVA

Throughout each radiation measurement series, attempts were made to regulate the arc input power for best constancy of radiation output.

8. RESULTS (DETAILED)

(1) LPRB Simulator

Three thermopile detectors were employed simultaneously, viz. E. 5556, 5150 and 4816 in the measurement series (1.1) and E. 5556, 5364 and 4816 in the series (1.2, 1.3 and 1.4). The location of these thermopiles is indicated in Fig. 1; the receivers were positioned 6.5 inches above the base plate of the instrument test platform. Control measurements of total flux were made at the start and finish of each series; the values given below are means. In computing the percentage of the total for any filter bandpass, from the microvolt figures, account has been taken of the difference in thermopile sensitivity for total and filtered exposure.

(1.1) Initial test in air outside of simulator chamber but with same pathlength (45 feet) and optics

		mw cm^{-2}
Total flux	E. 5556	138-136
	5150	132-128
	4816	135-131
	Mean	135-132 (arc power 32 KVA)

TABLE I Spectral energy distribution in defined bands

Broad A

	(4)	(5)	(6)	(7)	(8)	E. 5150 Total
mv	1.23	1.16	15.0	11.5	10.0	20.3 (power low)
%	6.5	6.0	74.0	56.6	49.2	

Narrow B

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	E. 5556 Total
mv	0.89	1.92	1.01	3.75	6.40	6.67	7.08	6.30	6.69	4.42	5.66	3.80	35.8
%	2.5	5.4	5.1	10.5	17.9	18.6	19.8	17.6	19.2	12.3	15.9	10.6	

Narrow C

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	E. 5150 Total
mv	1.35	1.07	2.45	3.98	3.57	3.30	2.35	1.13	22.1
%	6.3	5.1	11.6	18.9	17.0	15.7	11.2	5.4	

N.B. In the first series of measurements replacement of the quartz window by ones of pyrex and WG 7 glass, in turn, indicated that, at wavelengths below 295-300 mμ, there was about 1 per cent of the total emission.

(1.2) Repeat in air inside simulator chamber

Total flux E. 5556 145 mw cm^{-2}

TABLE II Spectral energy distribution in defined bands

Broad A (mean of two series)

	E. 4816 (5)	E. 5304 (7)
mw cm^{-2}	8.5	82
%	5.9	56.5

Narrow B (mean of two series)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	E. 5556 Total
mv	1.05	2.07	1.87	3.87	6.79	7.00	7.34	6.61	7.19	4.93	6.56	3.81	37.7
%	2.8	5.5	5.0	10.3	18.0	18.6	19.5	17.5	19.0	13.1	17.4	10.1	

Photocell readout: 16.5±0.5 mv

(1.3) Repeat in vacuum (top 10^{-4}, bottom 10^{-5} torr) - walls at normal ambient temperature

Total flux E.5556 144 mw cm^{-2}

TABLE III Spectral energy distribution in defined bands

Broad A

	E. 4816 (5)	E. 5384 (7)
mw cm^{-2}	9.1	77.5
%	6.3	53.8

Photocell readout: 16.5±0.5 mv

(1.4) Repeat in vacuum (top 10^{-4}, bottom 10^{-7} torr) - walls at 81° K (-313°F)

Total flux E. 5556 145 mw cm^{-2}

TABLE IV Spectral energy distribution in defined bands

Broad A (mean of three series)

	E. 4816 (5)	E. 5384 (7)
mw cm^{-2}	8.8	80.5
%	6.1	55.5

Narrow B

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	E. 5556 Total
mv	2.78	5.82	5.37	11.5	19.9	21.0	22.2	20.0	22.5	15.9	21.9	12.0	100.1
%	2.5	5.2	4.7	10.2	17.6	18.6	19.6	17.7	19.9	14.0	19.4	10.6	

Photocell readout: 16.5±0.5 mv

(2) IRL Simulator (air ambient)

One thermopile detector (viz. E. 5384) and three series of filters were employed.

Total flux E. 5384 114 mw cm^{-2} (this value was found to be about 5 per cent lower than that typical of the normal exposure plane of this simulator where the corresponding figure would be 120 mw cm^{-2} for the source input power setting of this measurement)

TABLE V Spectral energy distribution in defined bands

Broad A

	(4)	(6)	(7)	E. 5384
mv	0.585	7.45	5.65	10.0
%	6.1	74.5	56.5	

Narrow B

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	E.5384 Total
mv	0.198	0.457	0.509	1.19	1.62	1.51	1.57	1.62	1.93	1.51	2.05	1.18	10.0
%	2.1	4.7	5.3	12.3	16.8	15.6	16.3	16.8	20.0	15.6	21.2	12.2	

Narrow C

	(2)	(3)	(7)	E. 5384 Total
mv	0.437	1.03	1.44	10.0
%	4.5	10.7	14.9	

N.B. A check with a pyrex window indicated that 1 per cent of the total emission was at wavelengths below 295 mμ. This simulator has an arc source the output power of which is automatically regulated by a photocell sensor providing the means for adjust-

ing the position of the condenser lens system, with respect to the exposure plane. The opportunity was therefore taken to test for the possible introduction of significant chromatic aberration effects by this arrangement. A simple experiment decided upon was that of comparing the ratio of UV to IR radiation, in a fixed exposure plane, with the condenser lens varied over the whole of its normal movement. The results of this test are as follows:

(a) Lens near arc $\frac{.655}{7.98} = .082$

(b) Lens in middle $\frac{.577}{7.28} = .079$

(c) Lens away from arc $\frac{.512}{6.44} = .080$

Mean .080±1 %

The variation shown is within the uncontrolled arc stability figure (±2 to 3 per cent).

(3) LRB Simulator (air ambient)

One thermopile detector (viz. E. 4816) and three series of filters were employed.

Total flux E. 4816 131 mw cm^{-2}

TABLE VI Spectral energy distribution in defined bands

Broad A	(4)	(5)	(6)	(7)	E. 4816 Total
mv	0.652	0.570	7.69	5.60	10.3
%	7.1	6.2	74.7	57.1	

Narrow B	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)*	(11)	(12)	E. 4816 Total
mv	0.218	0.555	0.594	1.12	1.69	1.49	1.31	1.39	1.64	-	1.95	1.03	10.2
%	2.4	6.1	6.5	12.2	18.4	16.3	14.3	15.2	17.9	-	21.3	11.2	

* Filter damaged on removal from Simulator EPRB.

Narrow C	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	E. 4816 Total
mv	0.640	0.570	1.37	1.89	1.67	1.21	1.22	0.565	10.2
%	7.0	6.2	15.0	20.6	18.2	13.2	13.3	6.2	

N.B. A check with a pyrex window indicated that there was no measurable radiation at wavelengths below 300 mμ.

9. RESULTS (SUMMARIZED)

TABLE VII Spectral energy distribution in defined broad bands (A)

	Series No.	Percentage (4) 270–380 mμ	(5) 300–380	(6) >535	(7) >700	(8) >780	Total mw cm^{-2}
EPRB	1.1	6.5	6.0	74.0	56.6	49.2	121
	1.2	-	5.9	-	56.5	-	145
	1.3	-	6.3	-	53.8	-	144
	1.4	-	6.1	-	55.5	-	145
	Mean	6.5	6.1	74.0	55.6	49.2	139
IRL	2	6.1	-	74.5	56.5	-	114
ERB	3	7.1	6.2	74.7	57.1	-	131

TABLE VIII Spectral energy distribution in defined narrow bands (B)

Percentage

Series No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	Total
	200	280	335	375	420	500	585	680	770	1050	1250	1750	
mμ	330	370	385	430	520	610	690	820	1000	1300	1850	2500	mw cm^{-2}
PRB 1.1	2.5	5.4	5.1	10.5	17.9	18.6	19.8	17.6	19.2	12.3	15.9	10.6	138
1.2	2.8	5.5	5.0	10.3	18.0	18.6	19.5	17.5	19.0	13.1	17.4	10.1	145
1.4	2.5	5.2	4.7	10.2	17.6	18.6	19.6	17.7	19.9	14.0	19.4	10.6	145
Mean	2.6	5.4	4.9	10.3	17.8	18.6	19.6	17.6	19.4	13.1	17.6	10.4	143
RL 2	2.1	4.7	5.3	12.3	16.8	15.6	16.3	16.8	20.0	15.6	21.2	12.2	114
RB 3	2.4	6.1	6.5	12.2	18.4	16.3	14.3	15.2	17.9	-	21.3	11.2	130

TABLE IX Spectral energy distribution in defined narrow bands (C)

Percentage

Series No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Total
	315	325	350	405	505	600	1350	1800	
mμ	360	385	420	515	620	710	1750	2200	mw cm^{-2}
EPRB 1.1	6.3	5.1	11.6	18.9	17.0	15.7	11.2	5.4	132
IRL 2	-	4.5	10.7	-	-	-	14.9	-	114
ERB 3	7.0	6.2	15.0	20.6	18.2	13.2	13.3	6.2	130

10. MEAN EXTRATERRESTRIAL RADIATION OF THE SUN (SOLAR CONSTANT)

In Table X are tabulated the percentage energy distributions spectrally, of the extraterrestrial sun, according to Johnson and also to Nicolet. The bandwidth is standard at 0.01 μ (i.e. 10 mμ) centered at the indicated wavelengths.

The limits employed to designate ultra-violet, visible and infra-red radiation, in the summary at the foot of the table, were selected by consultation of the appropriate curve for photopic vision standardized by the International Commission for Illumination.

TABLE X MEAN EXTRATERRESTRIAL RADIATION OF THE SUN (SOLAR CONSTANT)

Percentage in spectral regions. ($\Delta\lambda$=0.01 μ) according to Johnson (J)* and Nicolet (N)**

μ)	J	N	Mean	$\lambda(\mu)$	J	N	Mean	$\lambda(\mu)$	J	N	Mean	$\lambda(\mu)$	J	N	Mean
22	0.02	0.01	0.02	0.44	1.45	1.38	1.41	0.66	1.14	1.19	1.17	1.80	0.11	0.12	0.11
23	04	03	03	45	58	52	55	67	11	16	14	1.90	09	10	10
24	04	03	04	46	55	56	56	68	08	13	11	2.00	08	08	08
25	05	04	05	47	56	57	56	69	06	11	08	10	07	07	07
26	09	10	09	48	55	57	56	70	03	07	05	20	06	06	06
27	18	12	15	49	43	46	45	71	1.01	05	03	30	05	05	05
28	17	11	14	50	42	50	46	72	0.98	02	1.00	40	04	04	04
29	37	26	32	51	41	50	46	73	96	1.00	0.98	50	04	03	04
30	44	30	37	52	34	40	38	74	93	0.96	95	60	03	03	03
31	54	45	49	53	40	46	43	75	91	94	92	70	03	03	03
32	61	52	57	54	42	46	44	80	81	83	82	80	02	02	02
33	82	64	73	55	40	39	40	85	72	75	73	2.90	02	02	02
34	80	63	71	56	36	45	40	90	64	68	66	3.00	02	02	02
35	85	66	75	57	34	43	39	0.95	58	61	60	10	02	02	02
36	83	68	76	58	34	43	38	1.00	52	55	54	20	02	02	02
37	95	68	81	59	32	38	35	10	43	44	43	30	01	01	01
38	88	67	78	60	30	37	33	20	36	36	36	40	01	01	01
39	80	0.72	0.76	61	27	33	30	30	29	31	30	50	01	01	01
40	1.10	1.12	1.11	62	25	30	28	40	24	26	25	60	01	01	01
41	39	27	33	63	22	27	24	50	19	22	21	70	01	01	01
42	38	27	32	64	19	24	21	60	16	19	17	80	01	01	01
.43	1.28	1.19	1.24	0.65	1.16	1.21	1.19	1.70	0.13	0.15	0.14	3.90	0.01	0.01	0.01

SUMMARY	Ultra-violet (λ<0.38μ)			Visible (λ0.38-0.75μ)			Infra-red (λ>0.75μ)		
%	7.2(J)	5.6(N)	6.4(M)	46.4(J)	47.2(N)	46.8(M)	46.4 (J)	47.2 (N)	46.8 (M)

* J. Meteor., 11, 431, 1954 ** Archiv. Meteor., Geoph., Biokl., A. 3, 209, 1951

11. COMPARISON OF CARBON-ARC SPECTRAL EMISSION DATA WITH THE EXTRA-TERRESTRIAL SUN

For this purpose, the solar reference adopted is that arrived at by taking the average, in 50-mμ bands, of the Johnson and the Nicolet extraterrestrial data as tabulated in Table X.

With regard to the carbon-arc emission data, the divergence between the different sets of values comprising series 1 (i.e. simulator EPRB) was considered to be so slight that the values could be averaged, in each of the three (filter type) instances - see Tables VII, VIII and IX, which also contain the respective data for simulators IRL and ERB.

In the case of the two sets of narrow band filter figures, each of the 20 values (expressed as percentage of the total emission) was then normalized to yield the proportionate energy contained in a standard 50-mμ band centered at the reference wavelengths tabulated in Section 4 of this Report. This was effected through simple multiplication of the originally derived percentages by the factor 50/total bandwidth in mμ. Here, however, for the value of the appropriate filter bandwidth it is necessary to consider the full bandpass as defined through the limiting wavelengths λ_0 and λ_1 each equal to zero transmittance. These limits are somewhat different from the figures given in Section 4 for the wavelength limits over which the filter factors were computed; in the latter instance, λ_0 and λ_1 correspond to wavelengths where the filter transmittance is about 2 per cent or so since extension of the point-by-point method of deriving the filter factor to

zero values of transmittance at λ_0 and λ_1 would significantly overweight the filter factor in favor of the limiting values of the particular bandpass. The bandwidths adopted to contain filter transmission between λ_0 and λ_1 each equal to zero transmittance are as follows:

Filter	Bandwidth (mμ)	Filter	Bandwidth (mμ)
B1	90	C1	75
2	110	2	70
3	65	3	90
4	65	4	125
5	110	5	135
6	135	6	125
7	125	7	550
8	160	8	550
9	240		
10	300		
11	800		
12	900		

The results of the carbon-arc:sun comparison, as represented by the narrow band filter investigation, are given in Table XI. With regard to the carbon-arc data, a column is included to represent the mean of the three carbon-arc series.

TABLE XI Narrow band (B and C) filter and solar data normalized to a 50-mμ band width (i.e. approximate width of narrowest filters used) centered at reference wavelengths

Reference wavelength mμ	Carbon arc energy % of Total					Solar energy % of Total	
	Series 1	2	3	Mean			
290(B)	7.4	1.2	1.3	1.3		1.5	
320(B)	2.5	2.2	2.8	2.5		2.9	
340(C)	(4.2	-	4.6	4.4)*		3.5	
355(C)	3.6	3.2	4.4	3.7	3.9	3.8	3.8
360(B)	3.8	4.1	4.6	4.2		3.8	
385(C)	6.4	6.0	8.3	6.9		4.5	
400(B)	7.9	9.4	9.4	8.9		5.3	
450(C)	7.6	-	8.2	7.9	7.9	7.3	7.5
460(B)	8.1	7.6	8.4	8.0		7.6	
545(B)	6.9	5.8	6.1	6.3	6.4	7.1	7.0
550(C)	6.3	-	6.7	6.5		7.0	
645(B)	7.8	6.5	5.7	6.7	6.3	6.0	6.0
650(C)	6.3	-	5.3	5.8		5.9	
740(B)	5.5	5.3	4.8	5.2		4.7	
900(B)	4.0	4.2	3.7	4.0		3.3	
1160(B)	2.2	2.6	-	2.4		2.0	
1550(B)	1.1	1.3	1.3	1.2	1.2	0.9	0.9
1550(C)	1.0	1.4	1.2	1.2		0.9	
2000(C)	0.5	-	0.6	0.6	0.6	0.4	0.4
2100(B)	0.6	0.7	0.6	0.6		0.3	

* Poor filter - low transmission

Fig. 2 was constructed by first normalizing the mean carbon-arc and the solar emission data presented in Table XI (the figures 8.9 and 7.6 per cent, respectively, being designated 100) and then plotting the derived figures against the corresponding reference wavelengths. As filter 3400 (i.e. C1) is clearly a very poor filter, the relevant data were not included in Fig. 2. The closeness of the two envelopes is rather remarkable, that of the carbon arc (mean) therefore representing a good approximation to the distribution, by wavelength, of the extraterrestrial solar radiation.

The mutual consistency of the measurements made with the narrow band and the broad band filters is demonstrated in the table contained in Fig. 2 and also reproduced below (as Table XII).

TABLE XII Comparison between filtered carbon-arc data (narrow band versus broad band) and the extraterrestrial solar emission

	Percentage of total emission			
	Filtered carbon arc			
λ (mμ)	Narrow band	Broad band	Mean	Sun
270-300	0.6	0.4	0.5	0.7
300-380	4.5	6.1	5.3	5.5
380-535	21.7	20.2	21.0	21.4
535-700	18.3	17.7	18.0	21.3
700-780	7.3	7.1	7.2	7.7
780-2700	47.6	48.5	48.0	43.4

In this table the broad band values were obtained by subtraction of one filter figure from another, with the exception of the 300-350 mμ and the 700-2700 mμ figures which were directly measured. The corresponding narrow band data were derived, from Fig. 2, through graphical integration. The solar data are numerical integrations from Table X upon which the dashed curve of Fig. 2 is based. For the sake of consistency, "total emission" is defined as the energy contained between the wavelength limits 270 and 2700 mμ, the latter being representative, essentially, of the upper cutoff of the broad band control filters OG 1, RG 8 and 700+ employed in this study.

Extension of the curves of Fig. 2 to wavelength limits of 220 and 4000 mμ, with the aid of the data contained in Table X and by extrapolation of the curves themselves, yielded the following information:

TABLE XIII Distribution of energy in the three principal spectral regions of the carbon arc simulators as compared with the extraterrestrial sun

Spectral region*	Percentage of total (220-4000 mμ) Carbon arc	Sun
Ultra-violet (< 380 mμ)	5.9	6.4
Visible (380-750 mμ)	43.0	46.8
Infra-red (> 750 mμ)	51.1	46.8

* For an explanation of the assignment of these wavelength intervals reference should be made to Section 10 above.

A. J. Drummond

Chief Research Physicist

J. J. Roche

J. J. Roche, Physicist

5 November 1963

THE EPPLEY LABORATORY, INC.
SCIENTIFIC INSTRUMENTS
NEWPORT, R.I.
U.S.A.

REPORT ON AN EXAMINATION OF THE SPECTRAL ENERGY [illegible]

APPENDIX I EXAMPLE OF DATA REDUCTION

1. [illegible] simulator: Initial test in air outside of simulator chamber but with same pathlength (45 feet) and optics - designated series 1.1 in Report.

2. [illegible]

	Before Commencement of Spectral Series			After Termination of Spectral Series		
Thermopiles	N. 5556	5150	4616	N. 5556	5150	4616
Millivolts	36.0	22.2	10.7	35.2	21.5	10.4
Sensitivity (mv/mw cm^{-2})	0.260	0.166	0.079	ditto (pages 2-3)		
Flux Density (mw cm^{-2})	136	132	135	136	128	131
Mean Flux Density (mw cm^{-2})		135			132	

3. [illegible]

Series A :	thermopile	N. 5150;	filters	broad band	A	4-6
B :	"	5556	"	narrow "	B	1-12
C :	"	5150	"	" "	C	1-6

These series were made as follows: A and C, position 3; B, position 1 (see Fig. 1).

Series A (Power Low)

	Millivolts	x →	Corrected Millivolts	x1/S →	Microwatts cm^{-2}	Spectral Energy Distribution %
Reference Total Flux	20.5	-	20.5	1/0.167	122(121)	100.0
Filter 4	0.534) 0.535) 0.534	2.30	1.23	1/0.160	7.7	6.4(6.5)
5	0.234) 0.232) 0.233	5.00	1.16	1/0.160	7.3	6.0
6	13.6) 13.6) 13.6	1.10	15.0	1/0.167	69.7	74.0
7	10.4) 10.4) 10.4	1.10	11.5	1/0.167	68.5	56.6
8	7.13) 7.13) 7.13	1.40	10.0	1/0.167	59.0	49.2
Reference Total Flux	20.2	-	20.2	1/0.167	121(121)	100.0
Reference Mean Total Flux	20.3	-	20.3		121	

F = Filter Factor (pages 3-5)

S = Thermocouple Sensitivity (pages 2-3) - note for measurements of total flux and with filters nos. 6-8, a mean sensitivity value of 0.167 (0.166 and 0.166) mv per mw cm^{-2} was employed; for measurements with filters nos. [illegible] 5, the narrow band filter value of 0.160 mv per mw cm^{-2} was employed on account of the low transmitted energies.

[illegible]

	Millivolts	[illegible]	Corrected Millivolts	[illegible]	Microwatts [illegible]	Spectral Energy Distribution
[illegible] Total Flux	36.0	-	36.0	1/0.259	139(136)	100.0
	Two series - see below					
Filter 1	0.090	[illegible]	[illegible]	"	[illegible]	[illegible]
2	[illegible]	[illegible]	1.92	"	7.41	[illegible]
3	0.300	[illegible]	[illegible]	"	6.99	[illegible]
[illegible]	[illegible]	3.70	3.75	"	14.5	10.5
[illegible]	[illegible]	[illegible]	[illegible]	"	24.7	17.9
6	[illegible]	[illegible]	[illegible]	"	25.7	18.6
[illegible]	[illegible]	3.65	7.08	"	27.3	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	"	[illegible]	[illegible]
9	1.765	3.90	[illegible]	"	[illegible]	19.2
10	[illegible]	[illegible]	[illegible]	"	17.0	12.3
[illegible]	[illegible]	[illegible]	[illegible]	"	21.9	15.9
12	[illegible]	3.75	[illegible]	"	14.7	10.6
[illegible]	[illegible]	-	[illegible]	[illegible]	137(13[illegible])	100.0
[illegible]	[illegible]	-	[illegible]		13[illegible]	

[illegible] above the same designation as above -

[illegible] value for [illegible] 0.2[illegible] (0.2[illegible] and 0.257) mv per

[illegible] cm^{-2} was employed throughout.

[illegible]

	Millivolts	x[illegible] →	Corrected Millivolts	x1/S →	Microwatts cm^{-2}	Spectral Energy Distribution %
[illegible]ence Total Flux	22.1	-	22.1	1/0.168	132	100.0
Two series - see below						
Filter 1	0.135	10.[illegible]	1.35	1/0.160	8.43	6.4(6.3)
2	0.292	3.65	1.07	"	6.68	5.1
3	0.660	3.60	2.45	"	15.3	11.6
4	1.530	2.60	3.90	"	24.9	18.9
5	1.520	2.35	3.57	"	22.4	17.0
6	1.320	2.50	3.30	"	20.6	15.7
7	0.920	2.55	2.35	"	14.7	11.2(11.1)
8	0.346	3.25	1.13	"	7.08	5.4
[illegible]ence Total Flux	22.1	-		1/0.168	132	100.0
[illegible]ference Mean Total Flux	22.1	-	22.1		132	

[illegible] have the same designation as above.

[illegible]

	Amplifier or Recorder Divisions									Amplifier Input or Recorder Input	Microvolts
	d_1	[illegible]	d_2	[illegible]	d_1	[illegible]	d_2	[illegible]	[illegible]	[illegible]	
Liver 1*	27.6	35.9	23.[illegible]	[illegible]	[illegible]	37.5	23.5	[illegible]	[illegible]	10	90
[illegible] 2*	[illegible]	2[illegible].5	14.6	10.9	14.6	25.5	14.6	10.9	10.9	20	218
3*	14.6	29.0	14.6	14.6	14.6	29.0	15.0	15.0	15.0	20	300
4**	[illegible]	33.3	7.7	25.4	7.7	33.0	7.5	25.4	25.4	40	1015
5***	[illegible]	52.9	6.6	45.3	6.6	53.0	6.9	46.1	45.7	50	2285
6***	6.9	62.5	6.6	55.6	6.6	62.5	6.9	55.6	55.6	50	2780
7***	[illegible]	45.5	6.9	38.6	6.9	46.0	6.9	39.1	38.6	50	1940
8***	7.0	38.5	7.0	31.5	7.0	38.5	7.0	31.5	31.5	50	1575
9***	7.0	42.5	6.9	35.5	6.9	42.0	7.0	35.1	35.3	50	1765
10**	[illegible]	32.0	6.0	24.0	6.0	32.0	6.0	24.0	24.0	40	960
11***	7.0	44.2	7.0	37.2	7.0	44.2	7.0	37.2	37.2	50	1860
12***	[illegible]	27.2	7.1	20.2	7.1	27.5	7.0	20.4	20.3	50	1015
Kidney 1*	30.0	50.5	37.0	13.6	37.0	50.5	37.1	13.4	13.5	10	135
[illegible] 2*	[illegible]	34.2	19.4	14.8	19.4	33.0	19.3	14.[illegible]	14.6	20	292
3*	7.5	24.5	9.5	17.0	9.5	24.5	9.5	17.0	17.0	40	680
4*	9.2	37.3	[illegible]	[illegible]	[illegible]	[illegible]	9.4	[illegible].3	34.2	[illegible]	1530
5*	9.5	47.5	9.5	[illegible]	9.5	47.5	9.5	38.0	38.0	40	1520
6*	9.5	42.5	9.5	33.0	9.5	42.5	9.5	33.0	33.0	40	1320
7*	10.0	33.1	9.[illegible]	23.2	9.[illegible]	32.6	9.[illegible]	22.[illegible]	23.0	40	920
8*	20.[illegible]	37.[illegible]	17.[illegible]	17.5	19.0	37.0	19.0	17.2	17.3	20	346

* [illegible] (Ch. [illegible] Kymographic type)

** [illegible] (Ch. [illegible] Electric Stimulator)

E_1 and E_2 = zero reading (i.e. thermopile shielded from radiation)

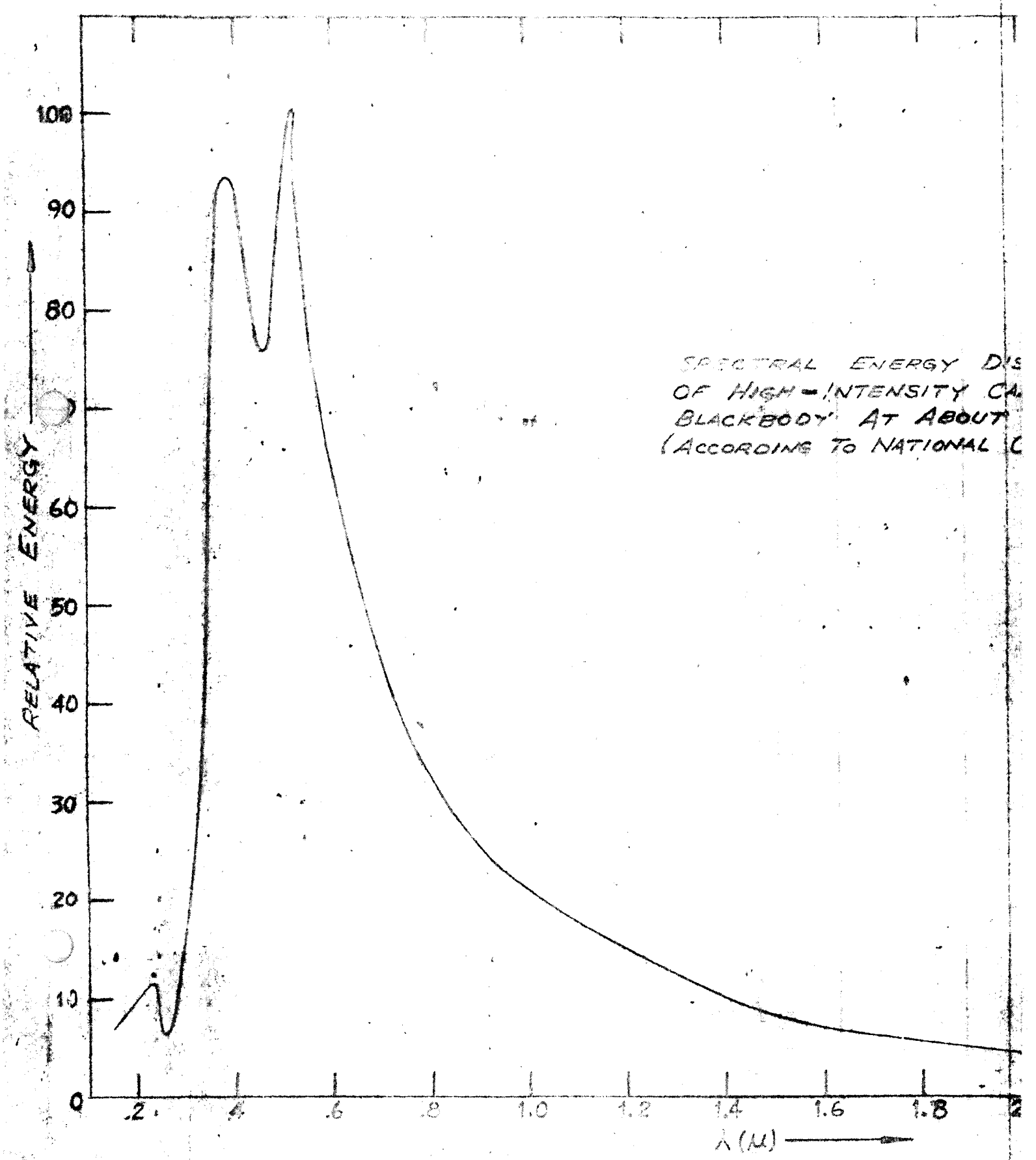
E = exposed reading (i.e. thermopile exposed to radiation)

$$E = E - \left(\frac{E_1 + E_2}{2}\right)$$

Computation of Filter Factors (two specimen narrow bandpass type)

	λ(mμ)	Filter Transmittance A	Source Emission Relative B	Normalized C	AxC	C/(AxC)
Filter 2B	280	.01	.105	.112	.001	
	290	.03	.15	.160	.005	
	300	.0[illegible]	.24	.2[illegible]	.021	
	310	.22	.30	.321	.071	
	320	.30	.375	.401	.120	
	330	.2[illegible]	.[illegible]	.[illegible]2	.121	
	340	.18	.625	.6[illegible]	.120	
	350	.10	.77	.[illegible]	.082	
	360	.0[illegible]	.91	.97[illegible]	.039	
	370	.01	.935	1.000	.010	
			Total	5.19[illegible]	0.590	$C.S_C$ = F.F.

		Filter	Source Emission		
	[illegible]	[illegible]	Relative	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	.90	.90	.090
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	.407
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	.420
	[illegible]	[illegible]	[illegible]	[illegible]	.443
	[illegible]	[illegible]	.76	[illegible]	[illegible]
	475	.52	.81	.81	.421
	[illegible]	[illegible]	.90	.90	.432
	495	.31	.96	[illegible]	.298
	[illegible]	.27	.99	.99	.267
	[illegible]	[illegible]	1.00	1.00	.030
			Total	10.31	4.019 2.6[illegible] = F.F. (2.7[illegible])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1.0
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1.4
1.6
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λ (μ)

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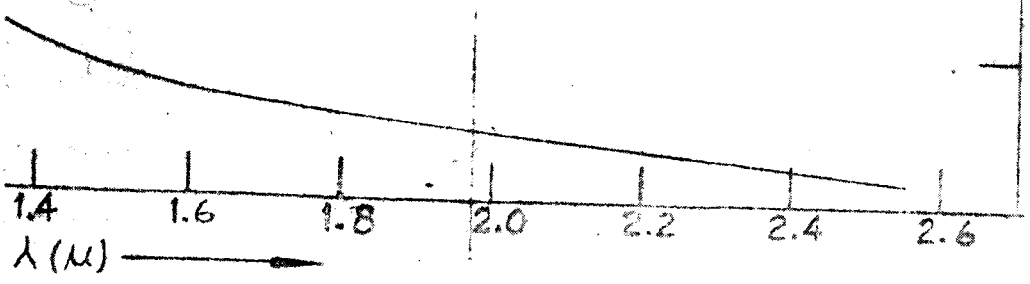


(1) — E 5556

(2) — E 4815

(3) — E 5150 or E 5384

(4) — Photocell-filter unit

(L) — Collimated illuminated lamp (for alignment of system

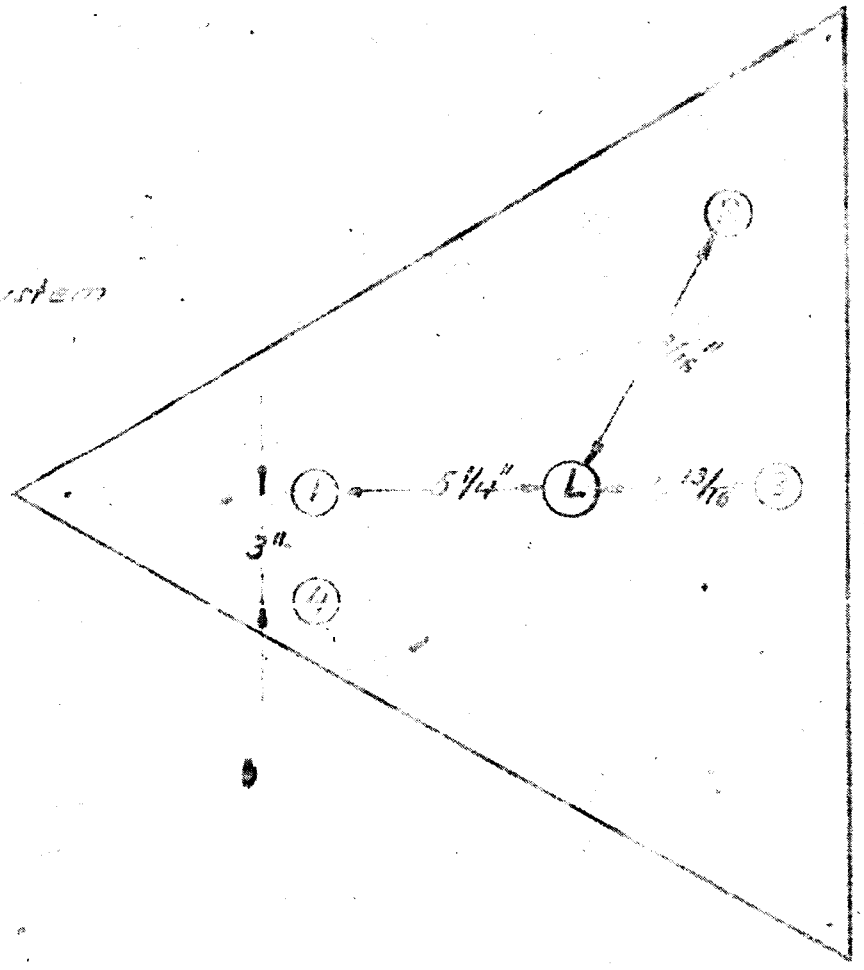
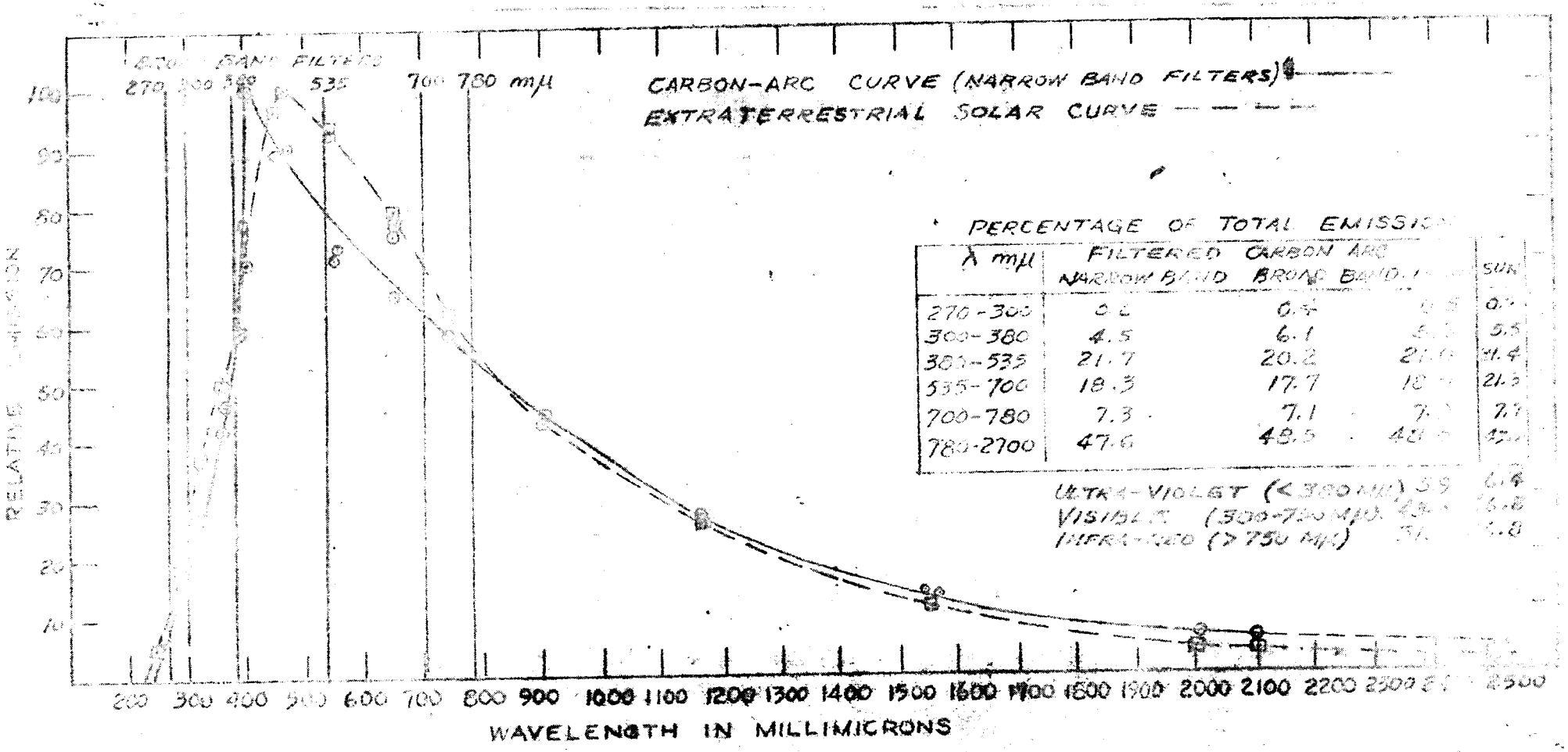


FIG. 1

PLAN VIEW OF BASE PLATE AND DETECTORS



PERCENTAGE OF TOTAL EMISSION

λ mμ	FILTERED CARBON ARC NARROW BAND	BROAD BAND	[illegible]	SUN
270-300	0.6	0.4	0.5	0.[illegible]
300-380	4.5	6.1	[illegible]	5.5
380-535	21.7	20.2	21.[illegible]	21.4
535-700	18.3	17.7	18.[illegible]	21.3
700-780	7.3	7.1	7.[illegible]	7.7
780-2700	47.6	48.5	48.[illegible]	[illegible]

ULTRA-VIOLET (< 380 mμ) 5.9 6.4
VISIBLE (380-750 mμ) [illegible] 6.8
INFRA-RED (> 750 mμ) 31.[illegible] [illegible].8

FIG-2

COMPARISON BETWEEN N.A.S.A. CLEVELAND CARBON-ARC SOURCES AND THE EXTRATERRESTRIAL SUN

SAMPLE _____

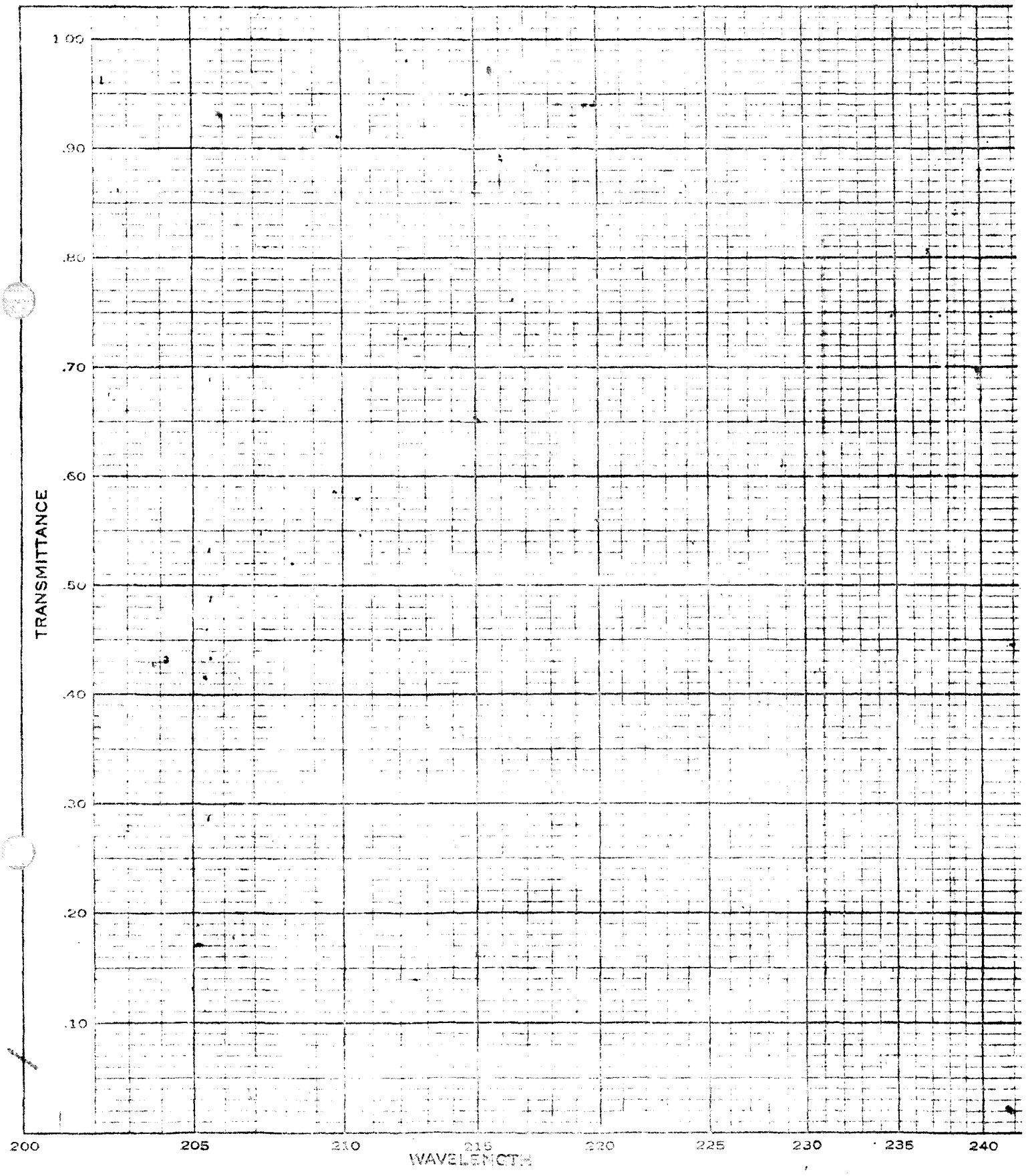
SOLVENT _____

CONC. _____

CELL _____

SPECTRACORD

THE PERKIN-ELMER CO



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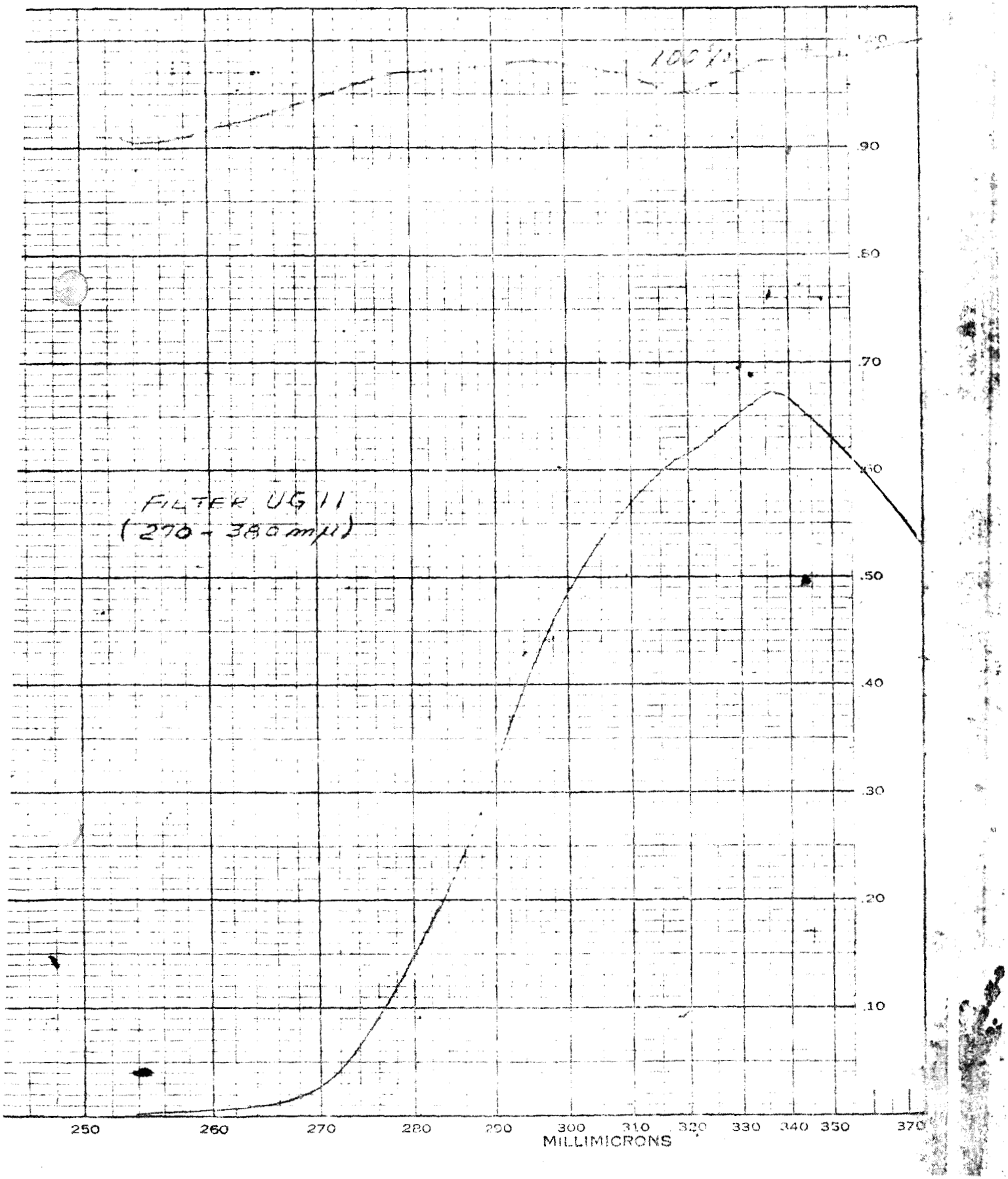

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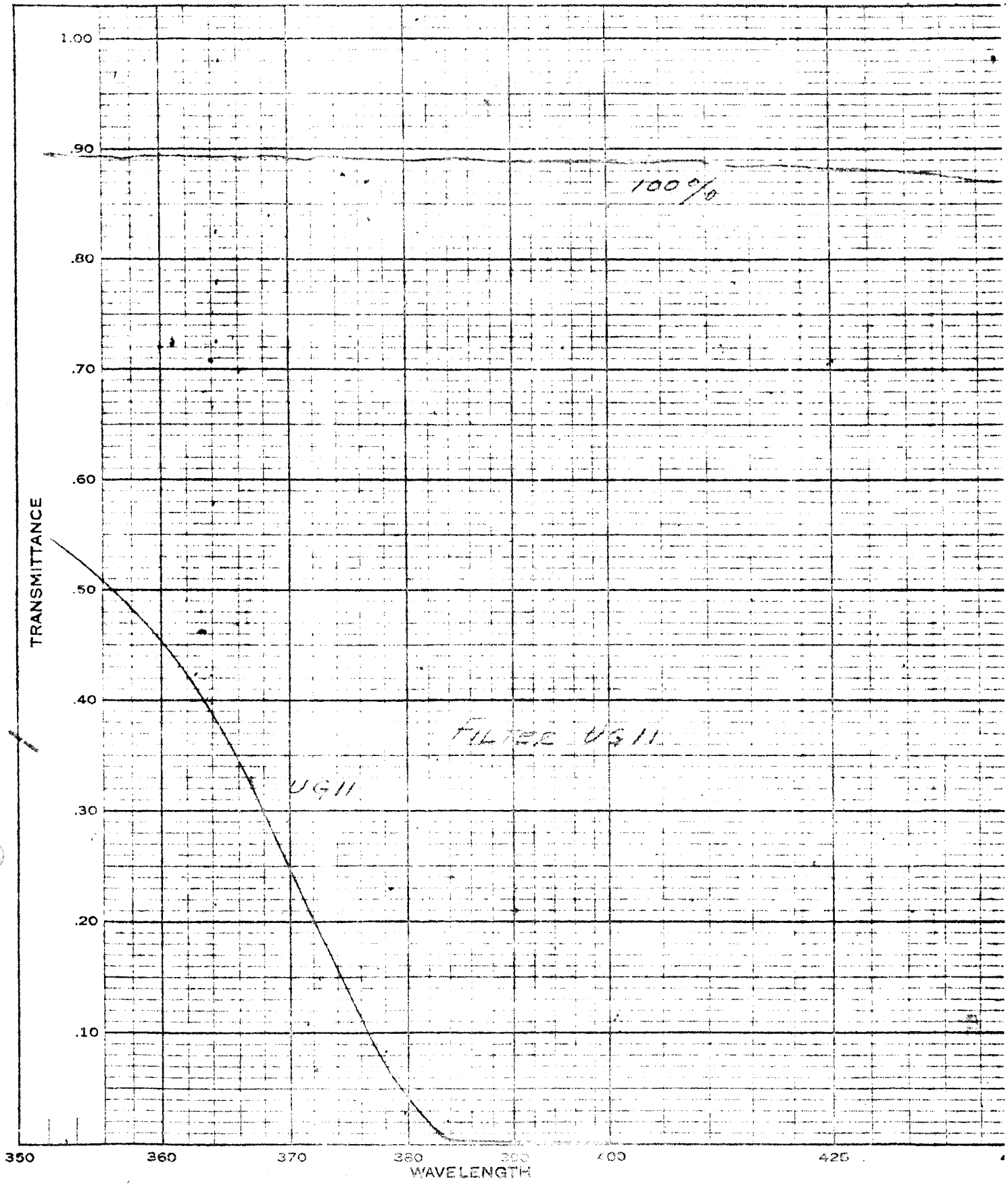

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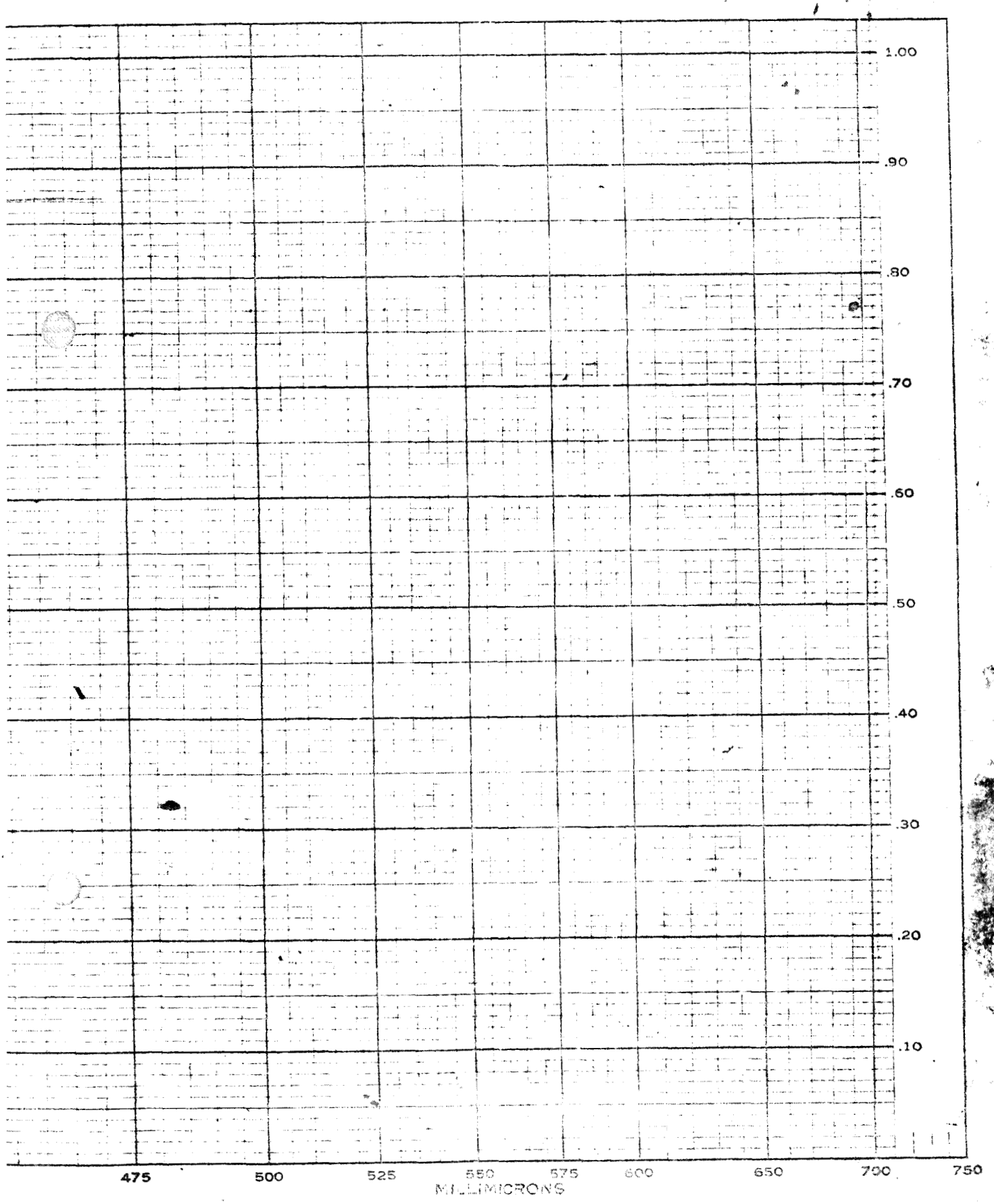

SAMPLE

SOLVENT

CONC.

CELL

SPECTRACORD

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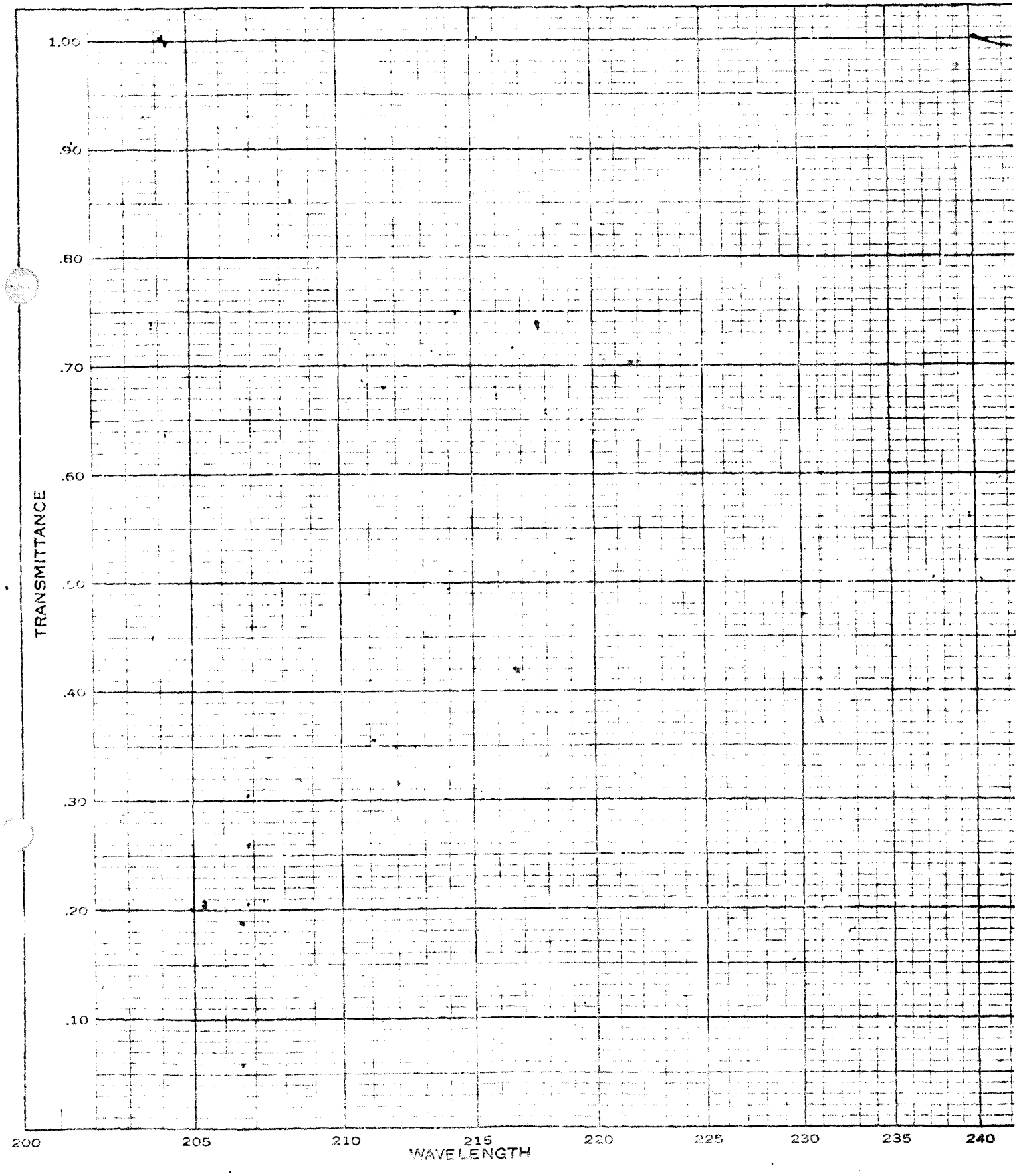

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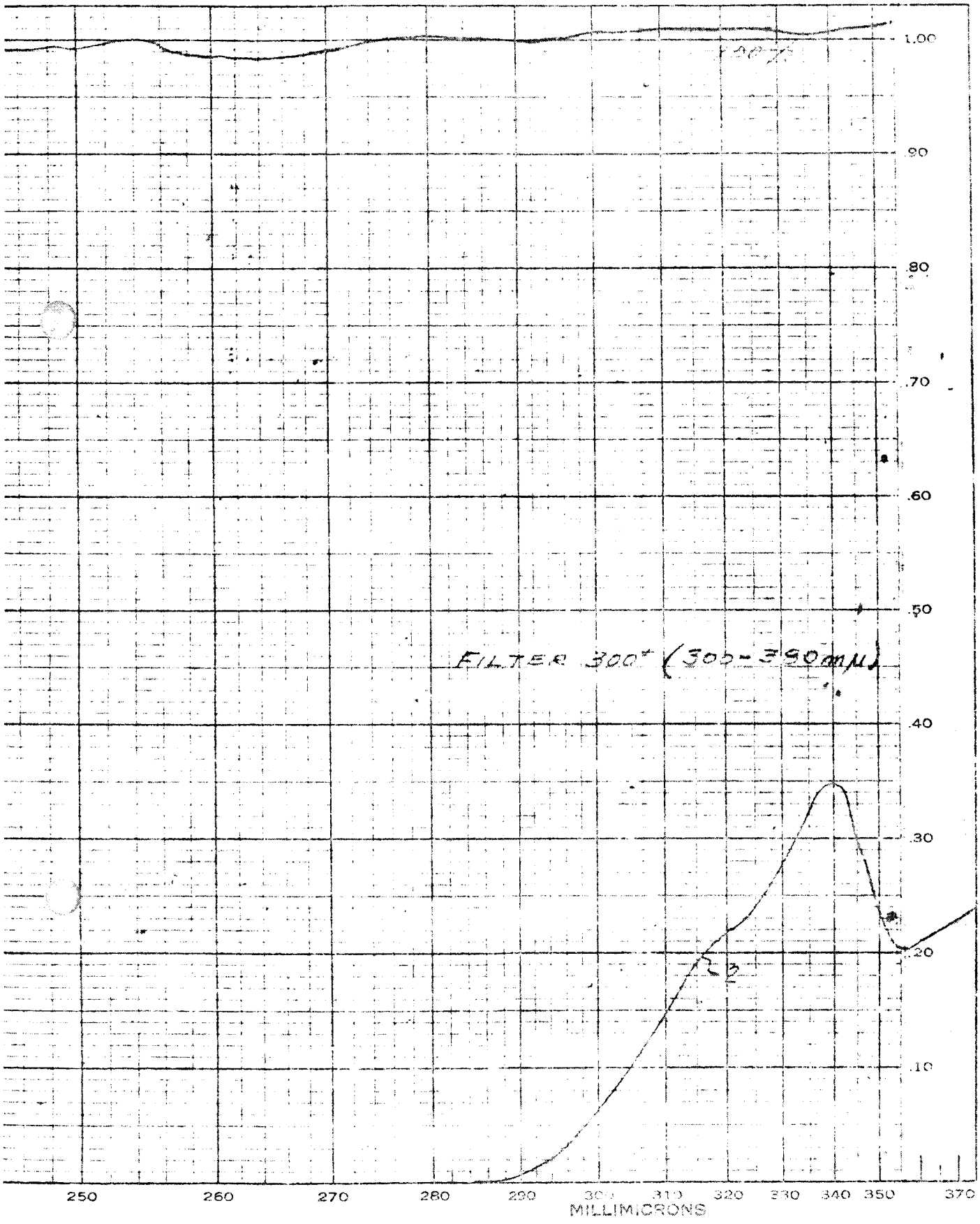

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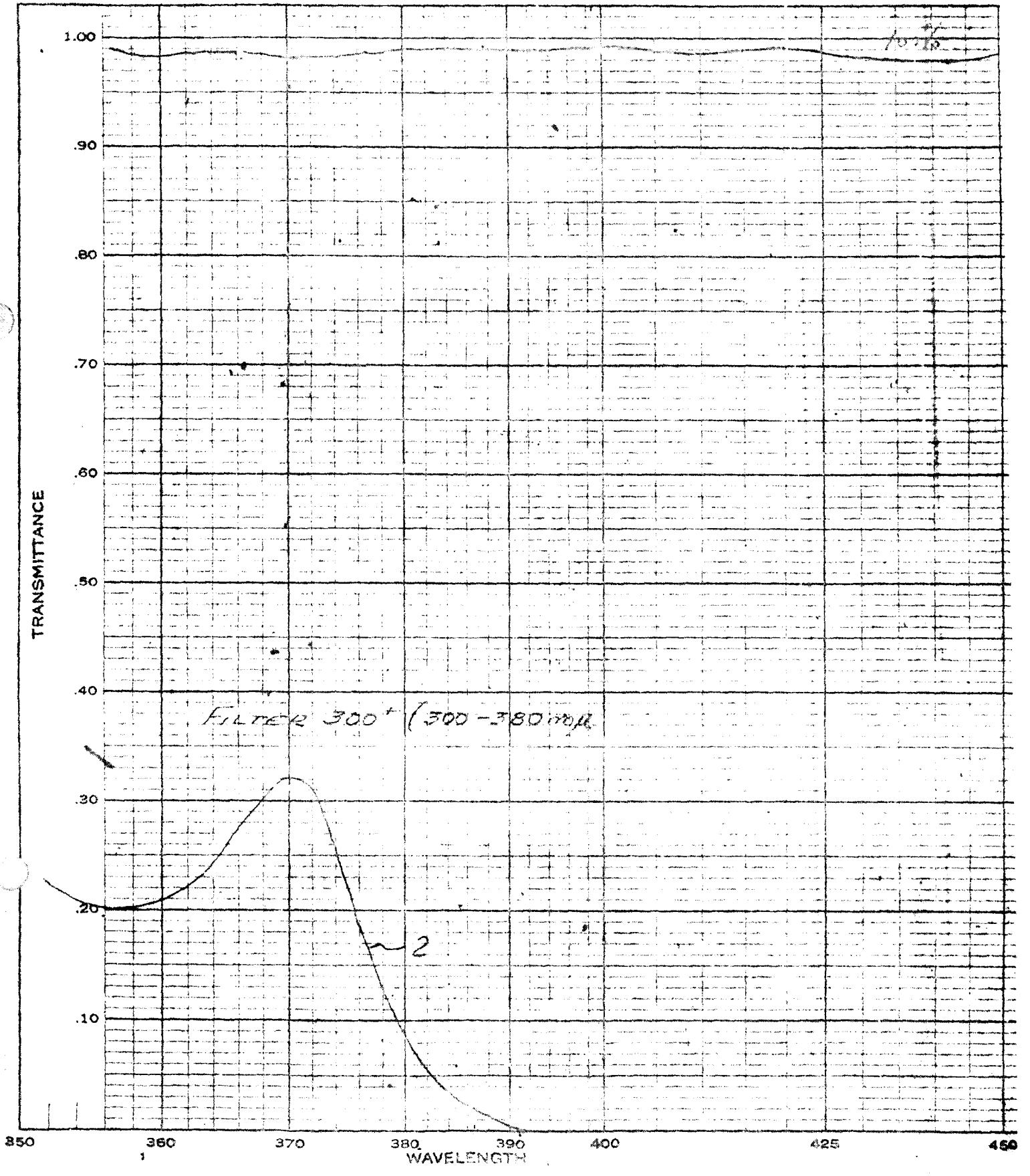

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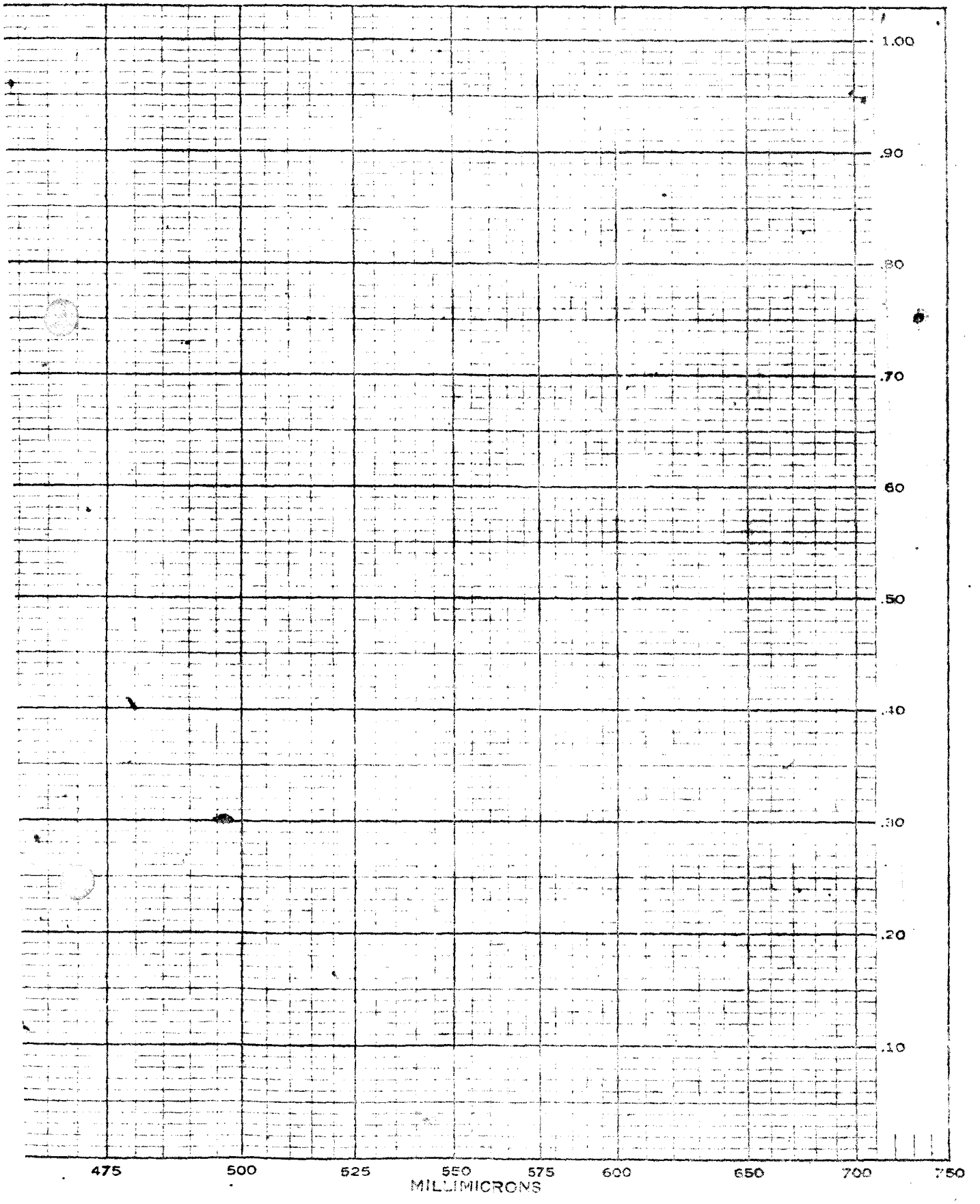

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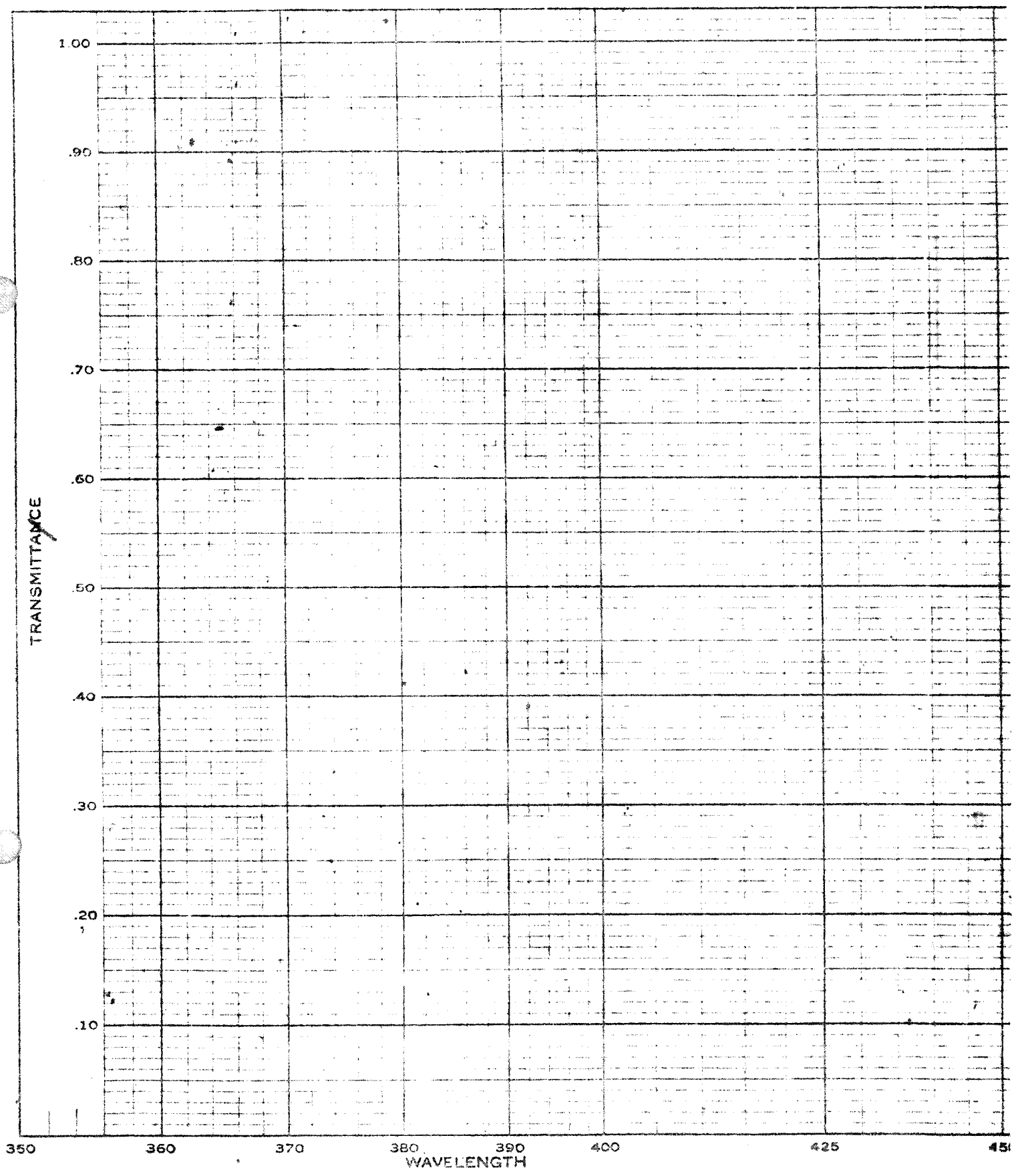

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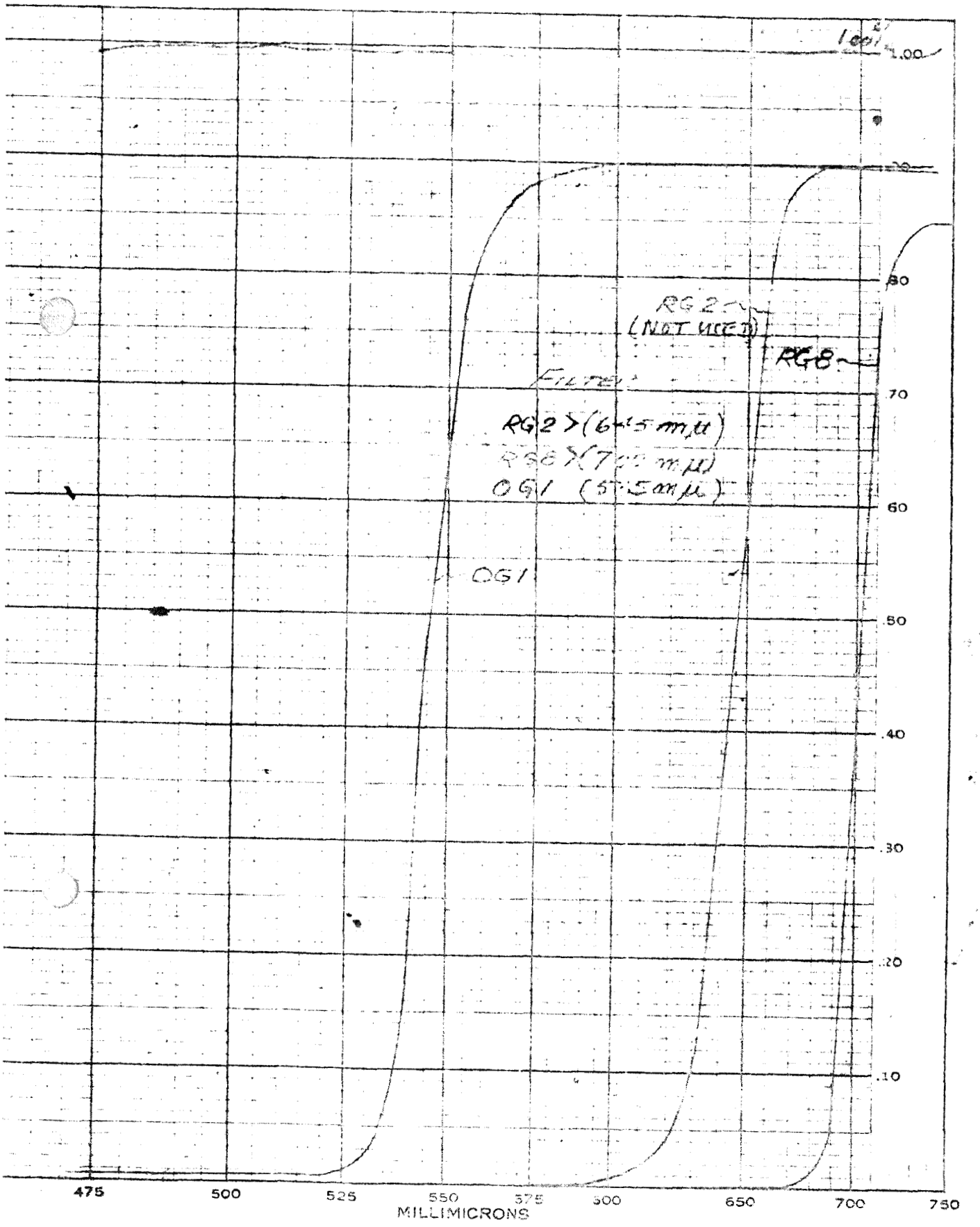

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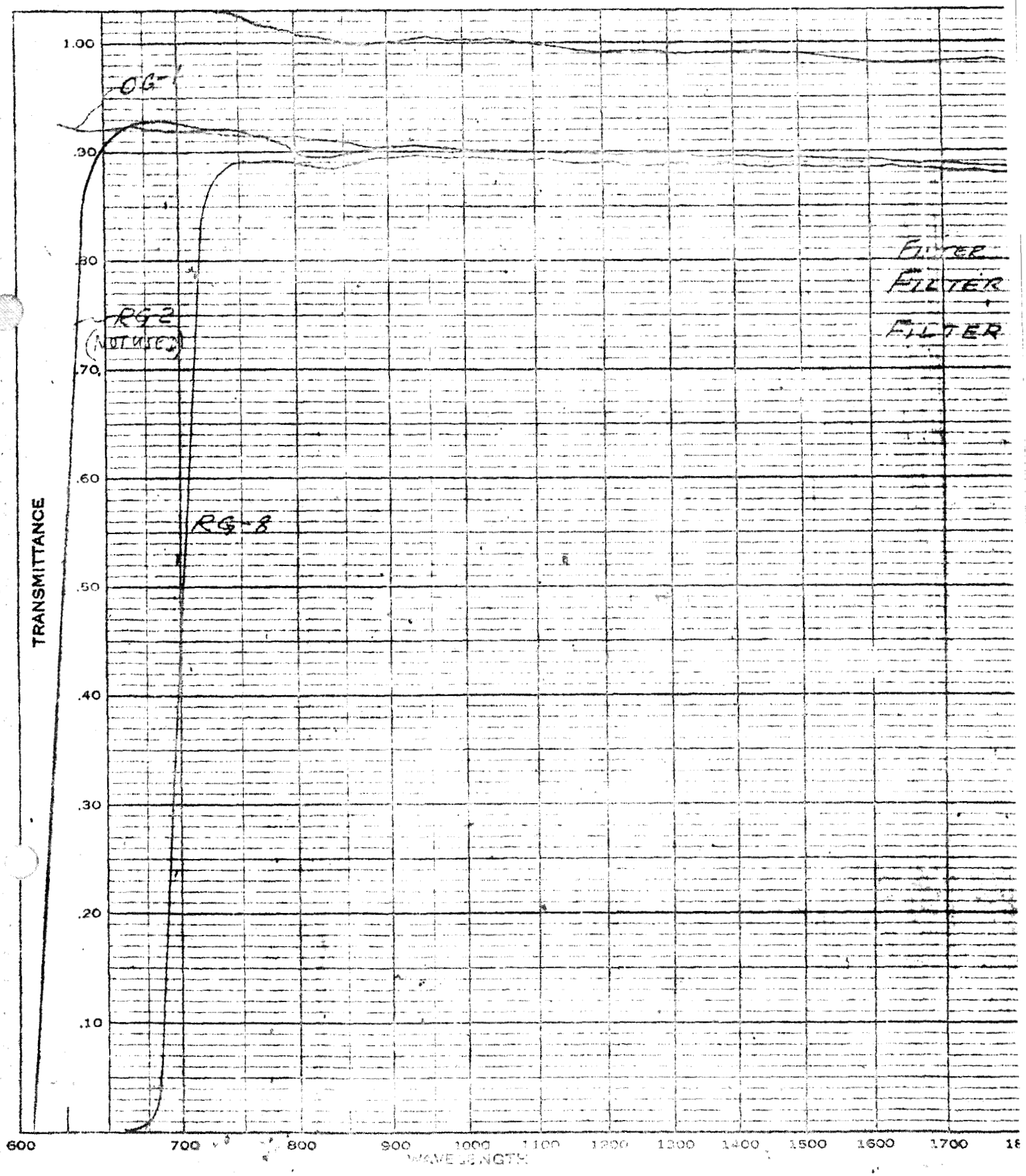

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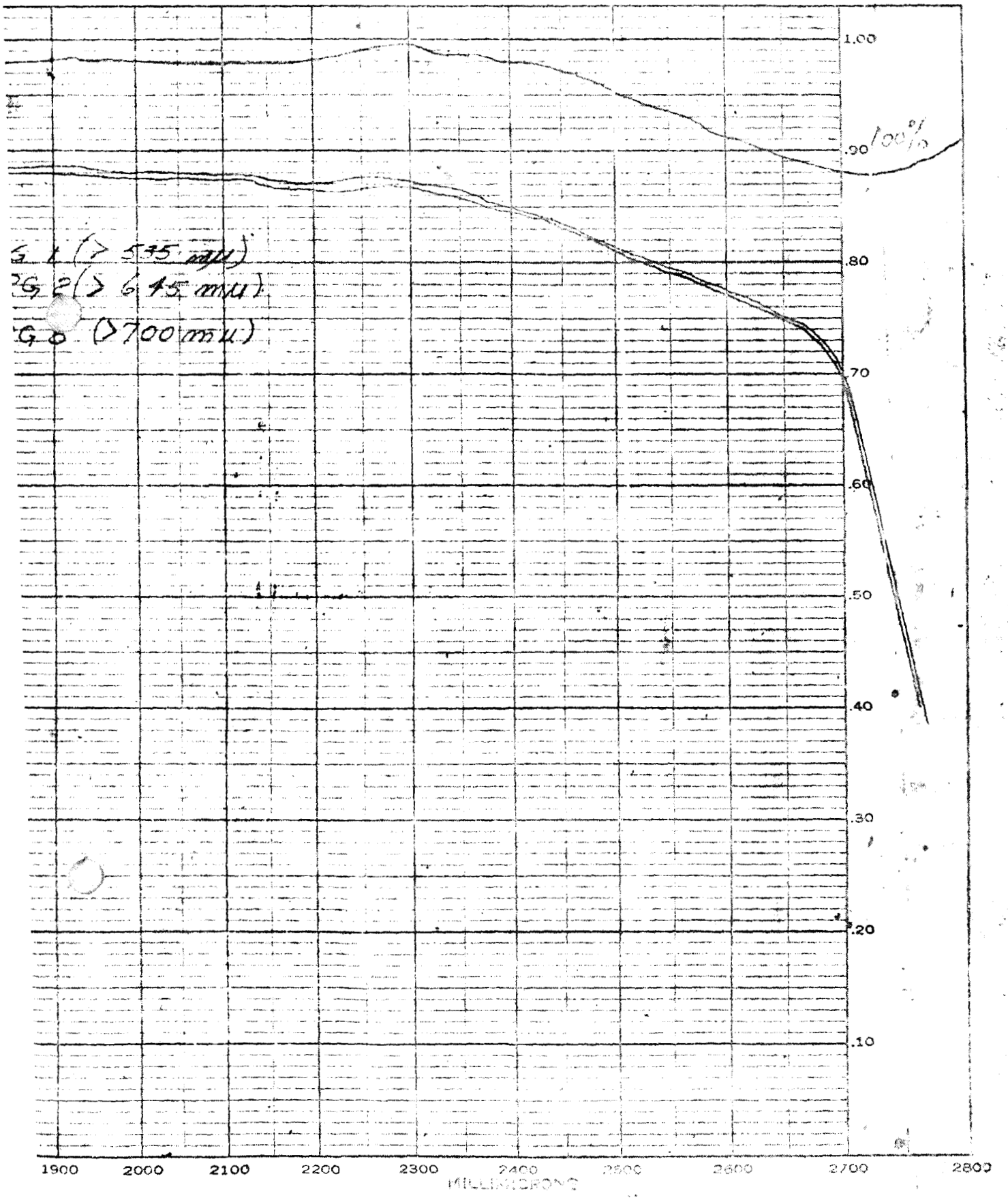

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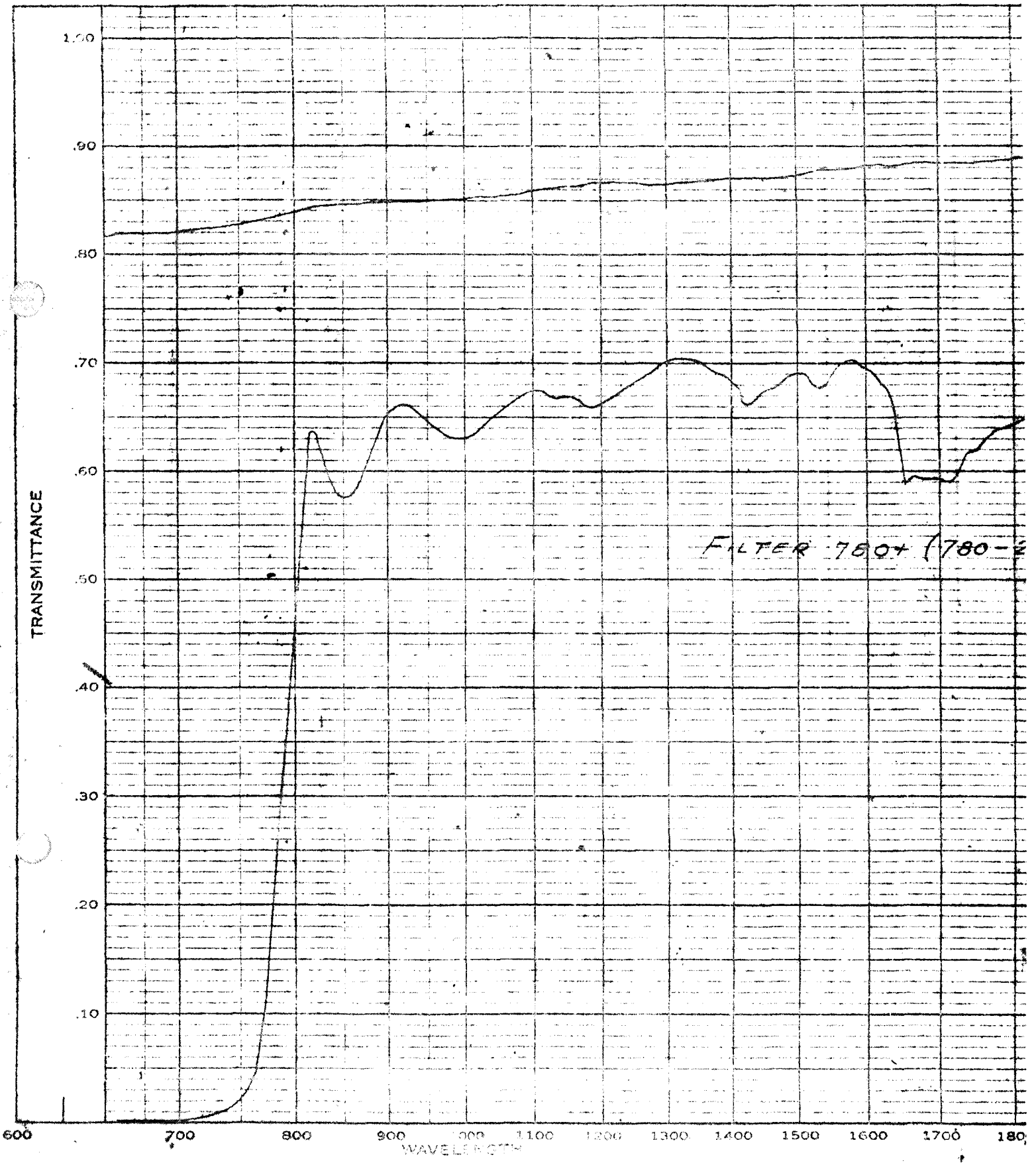

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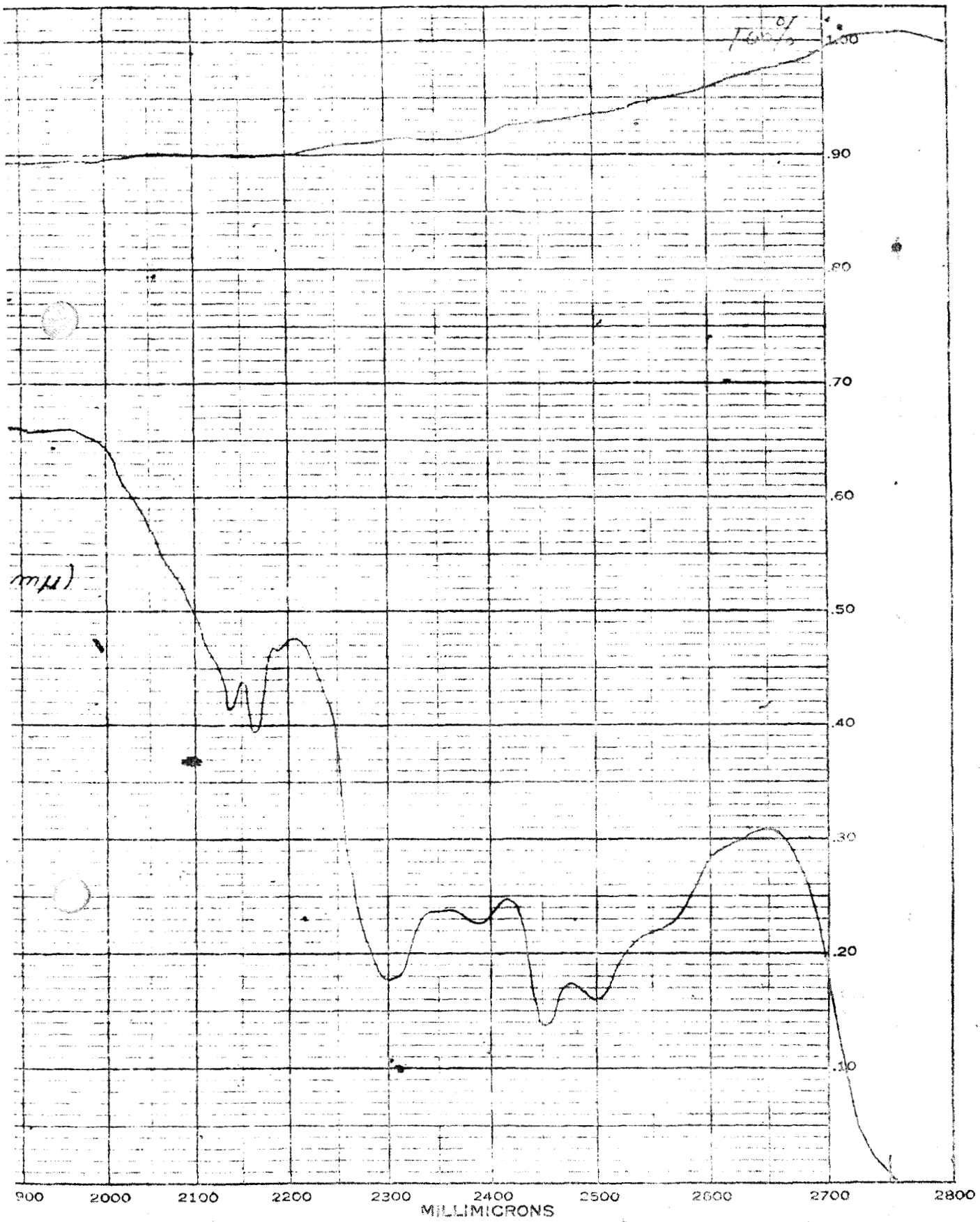

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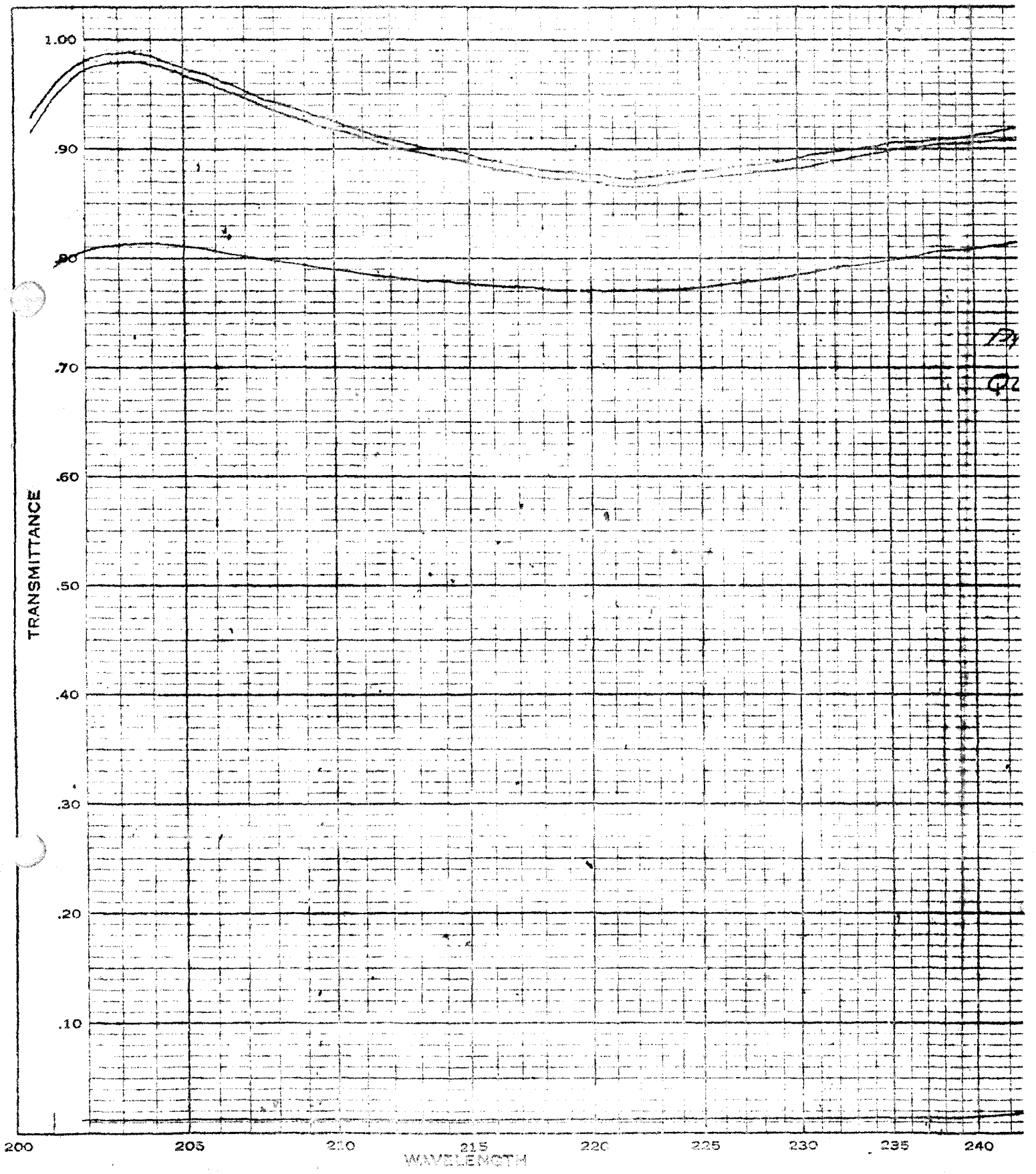

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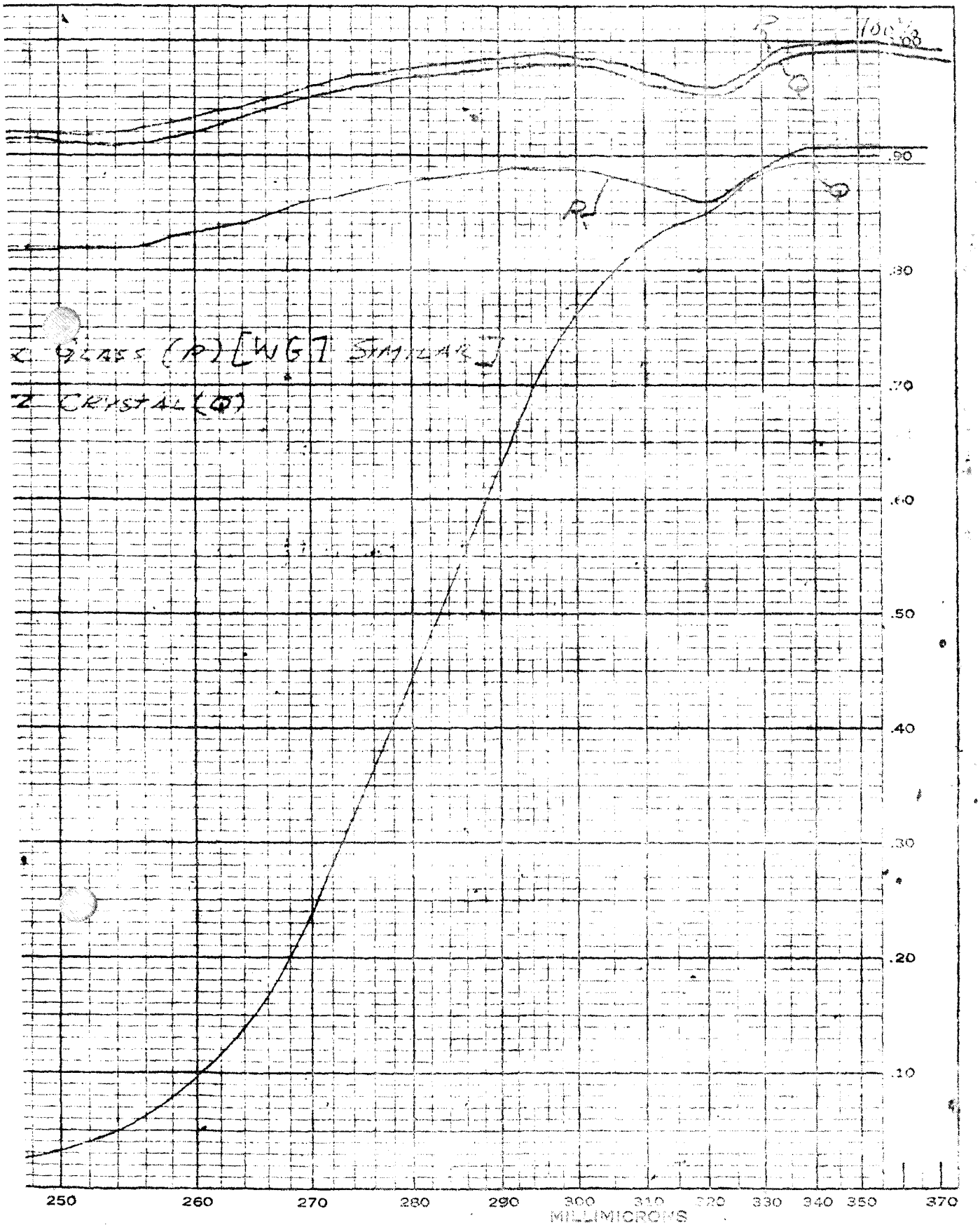

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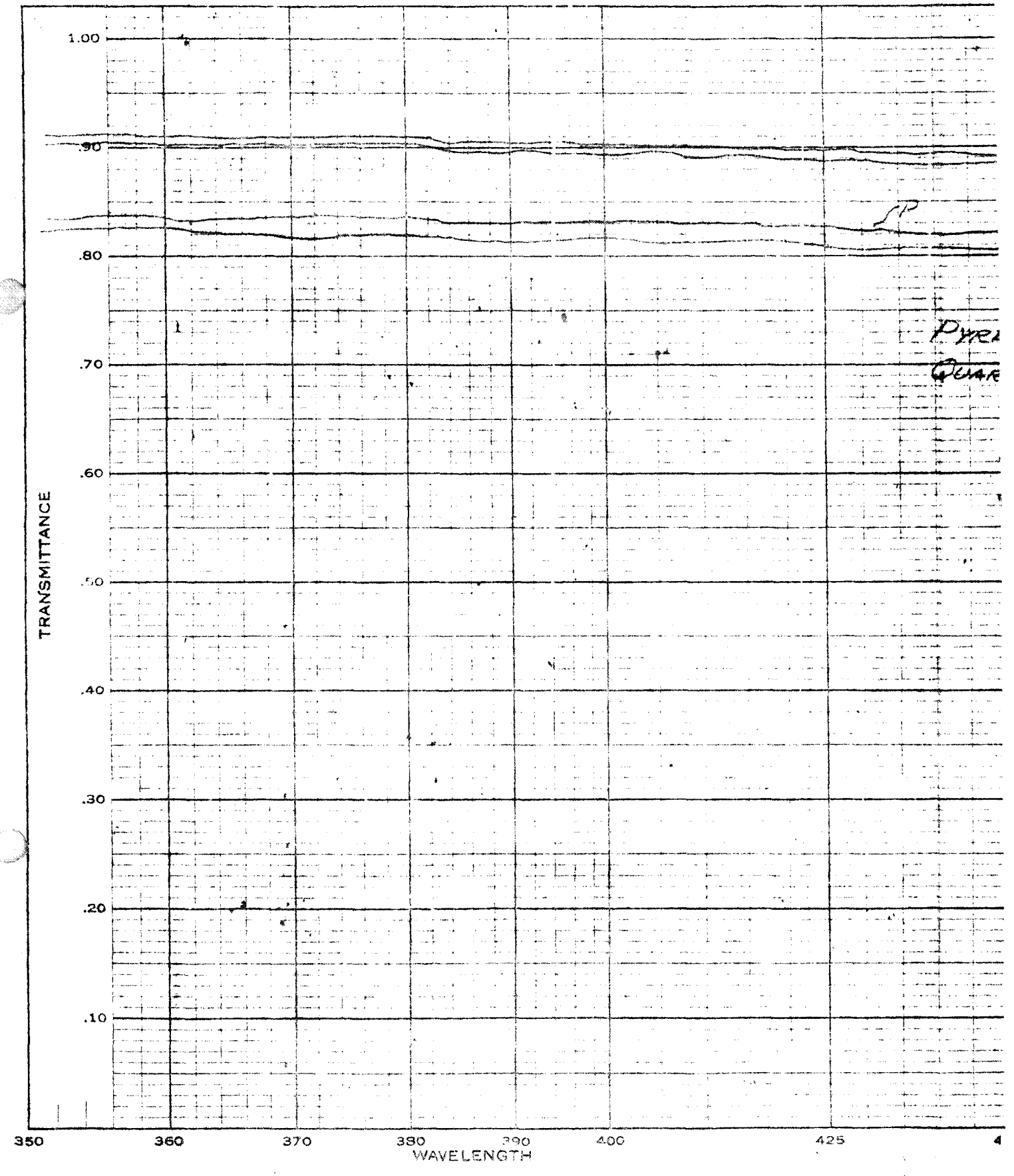

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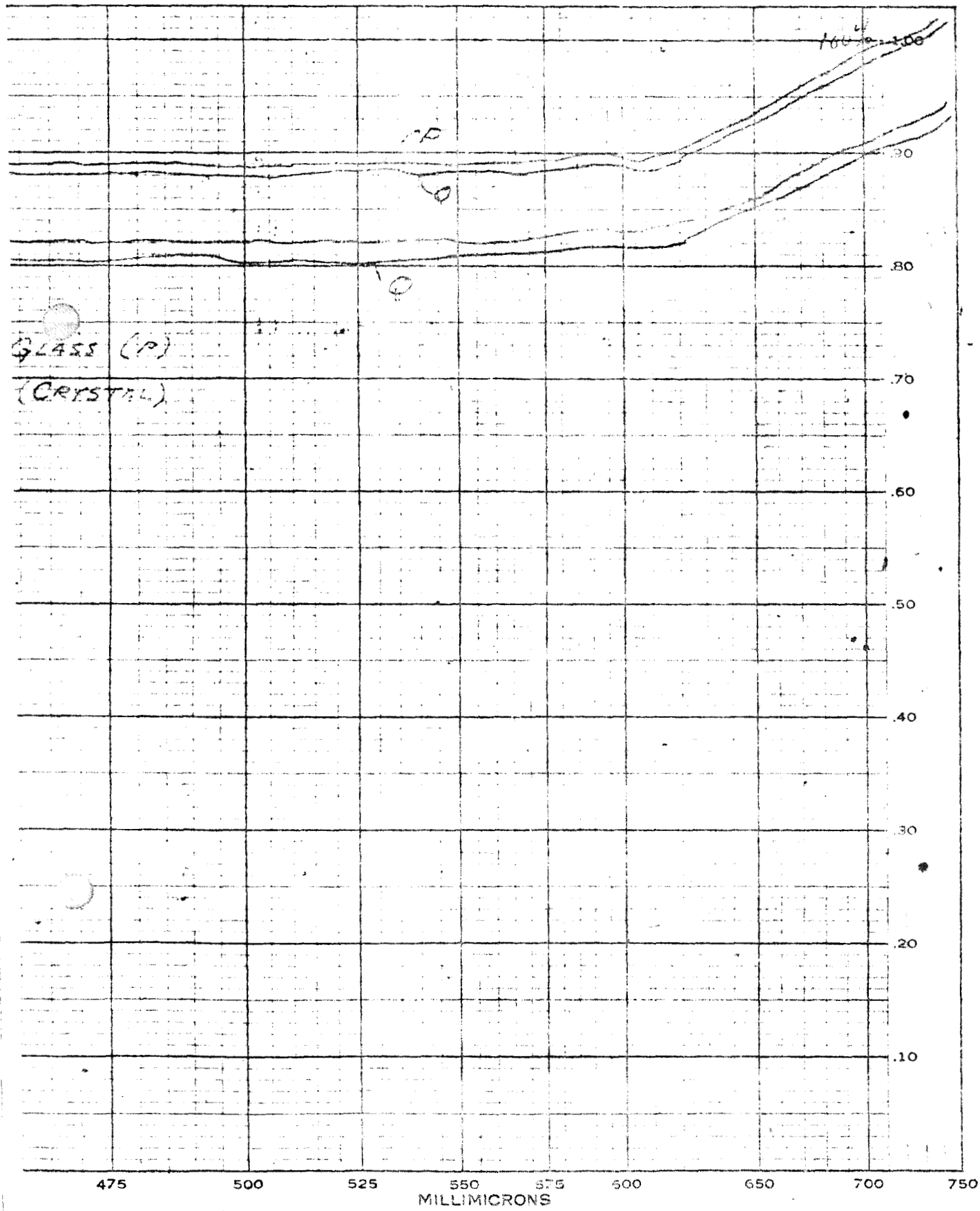

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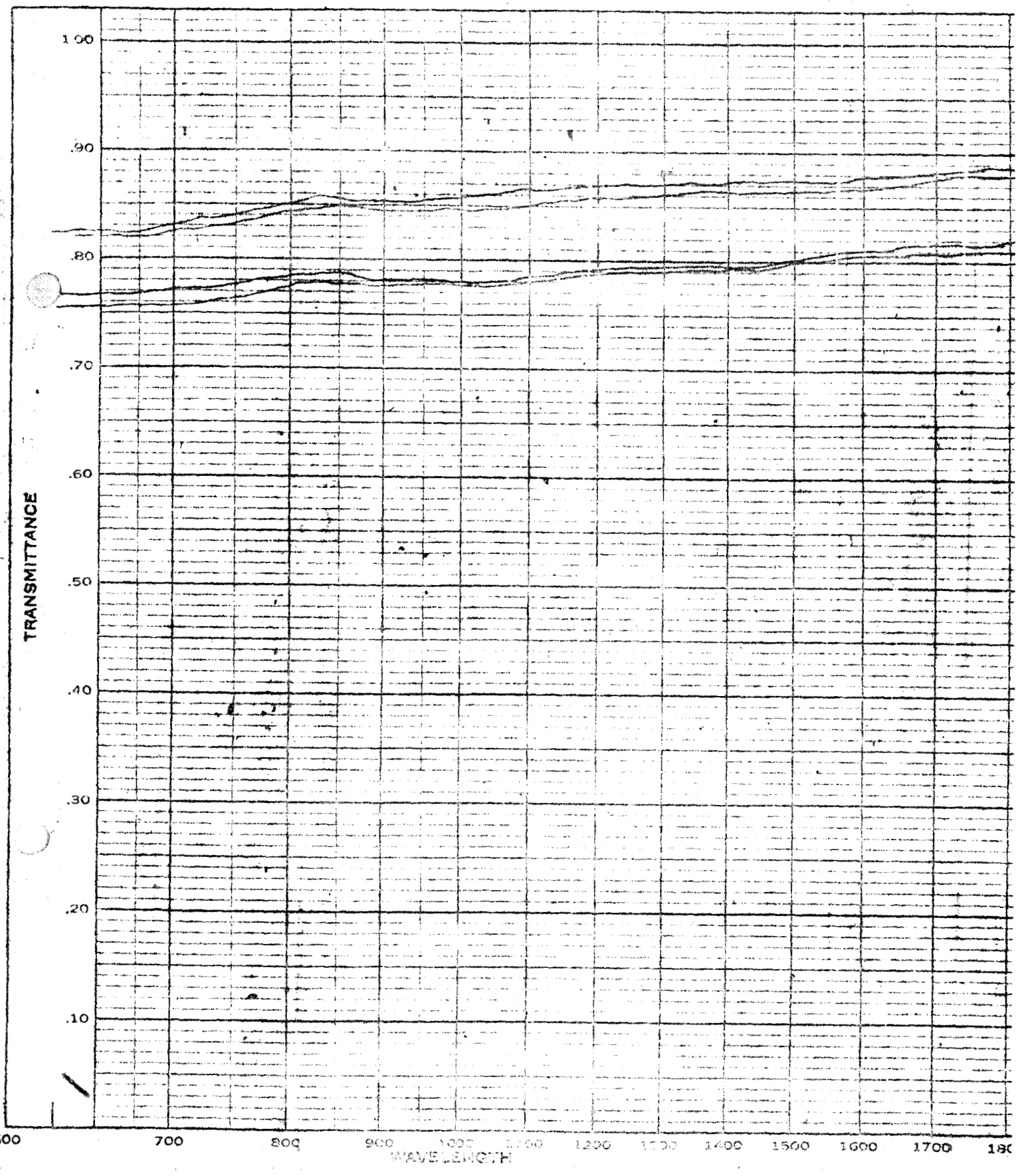

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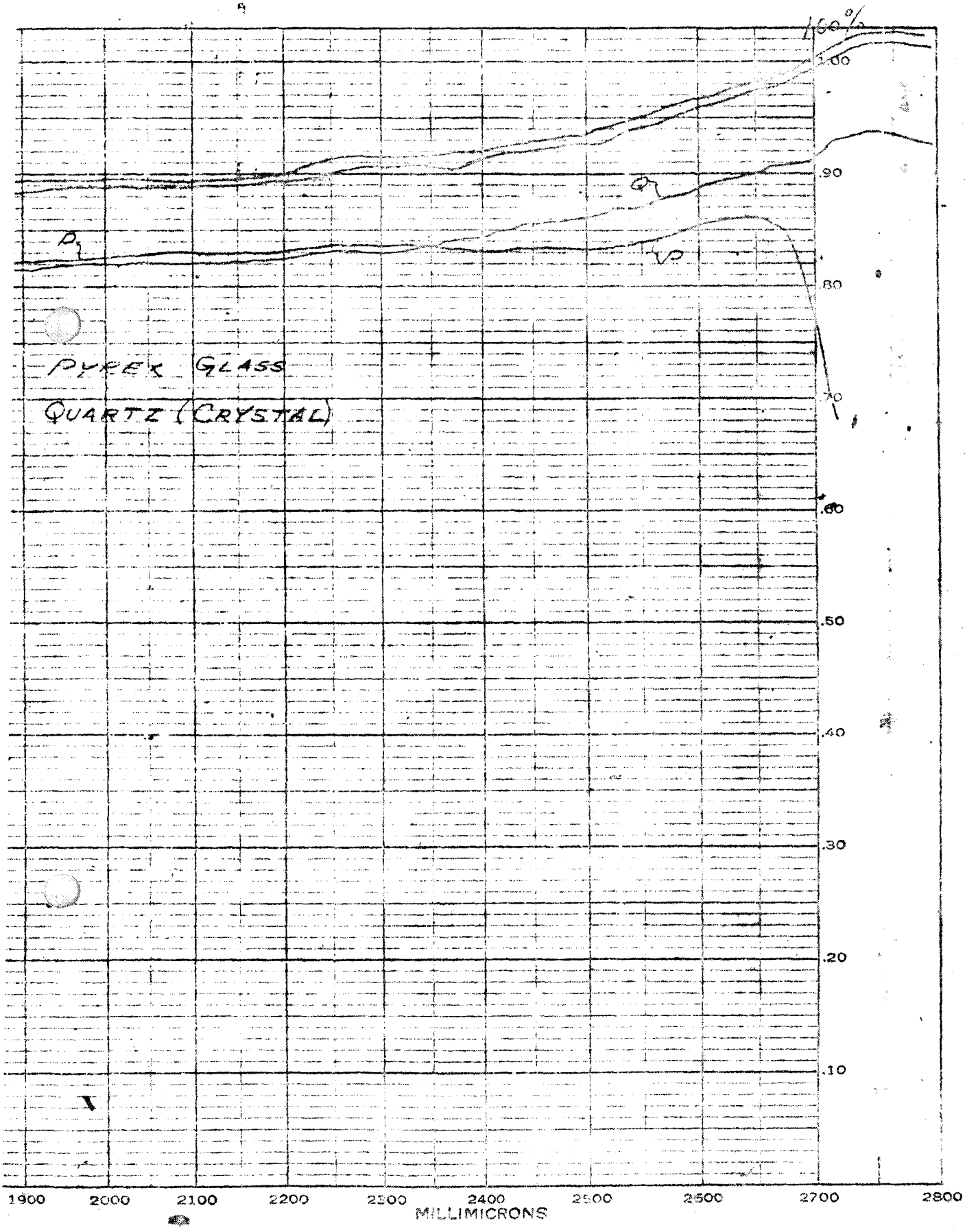

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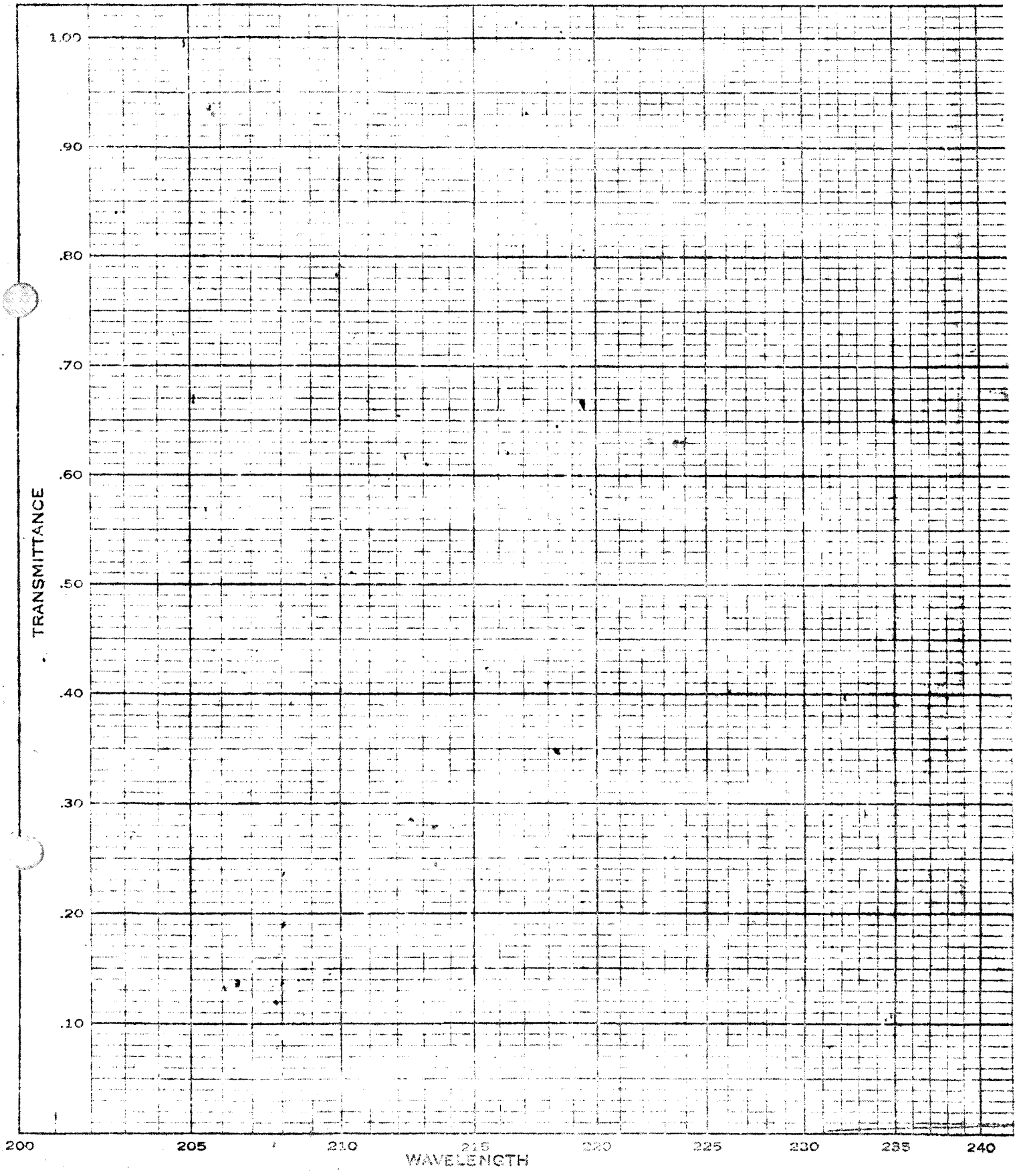

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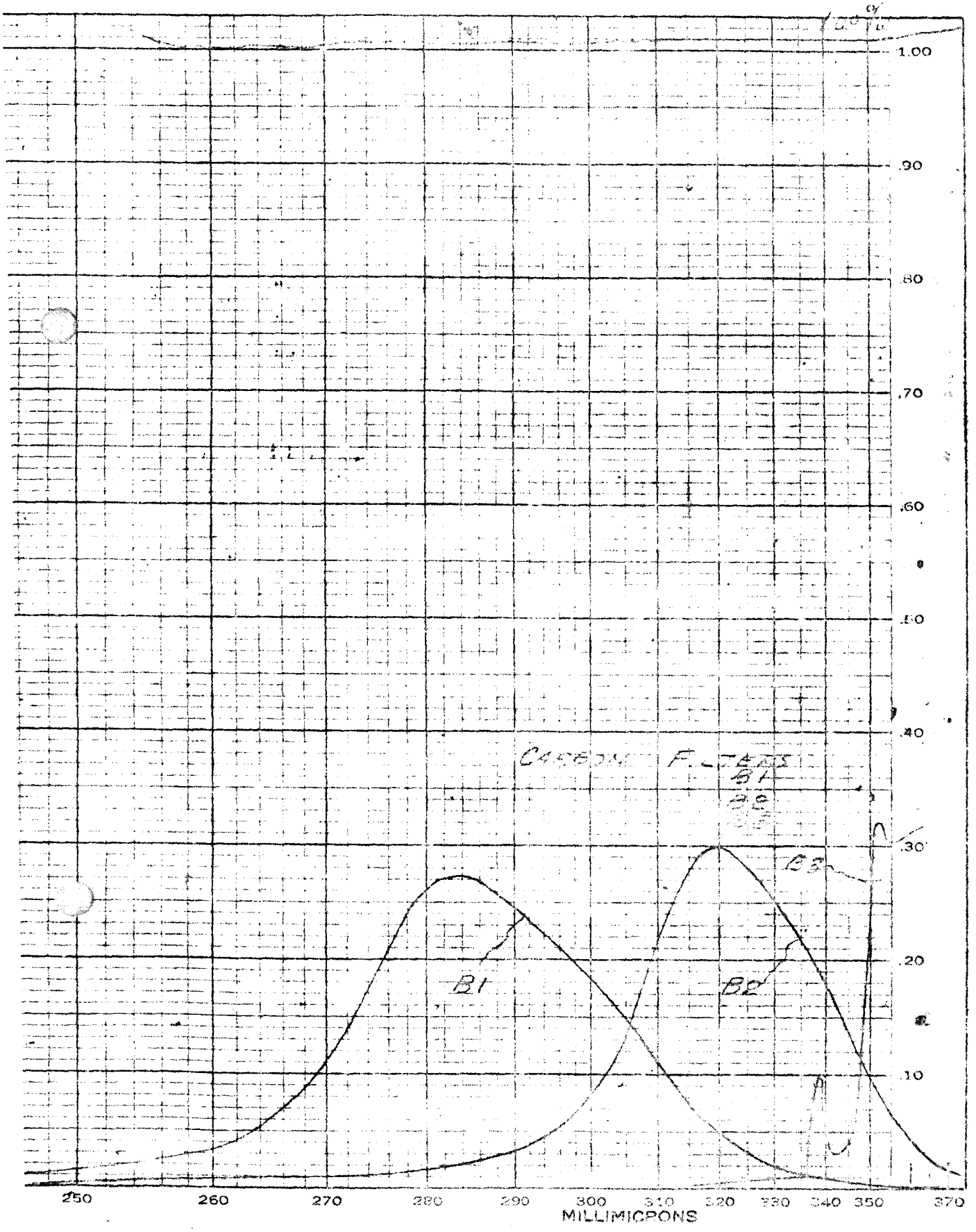

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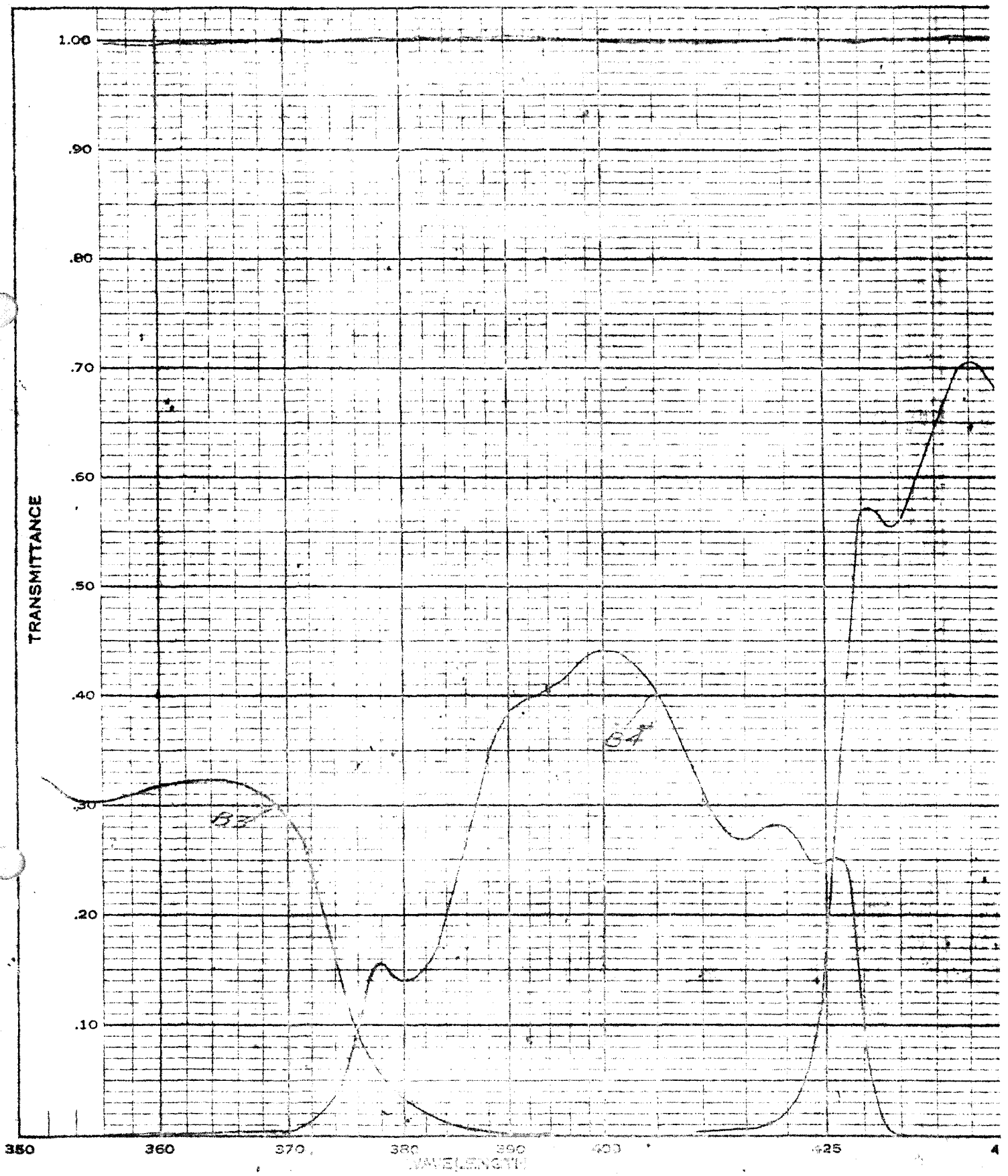

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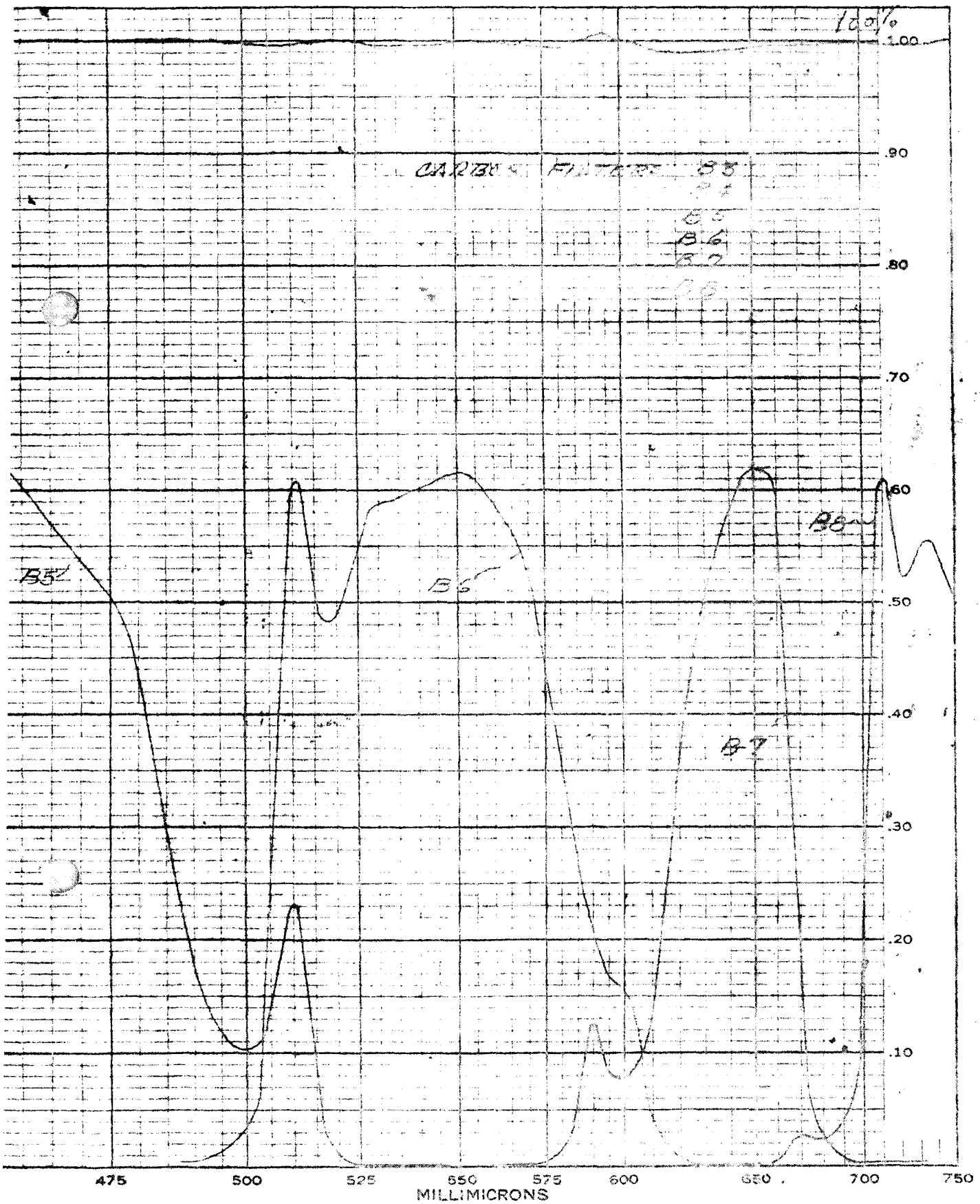

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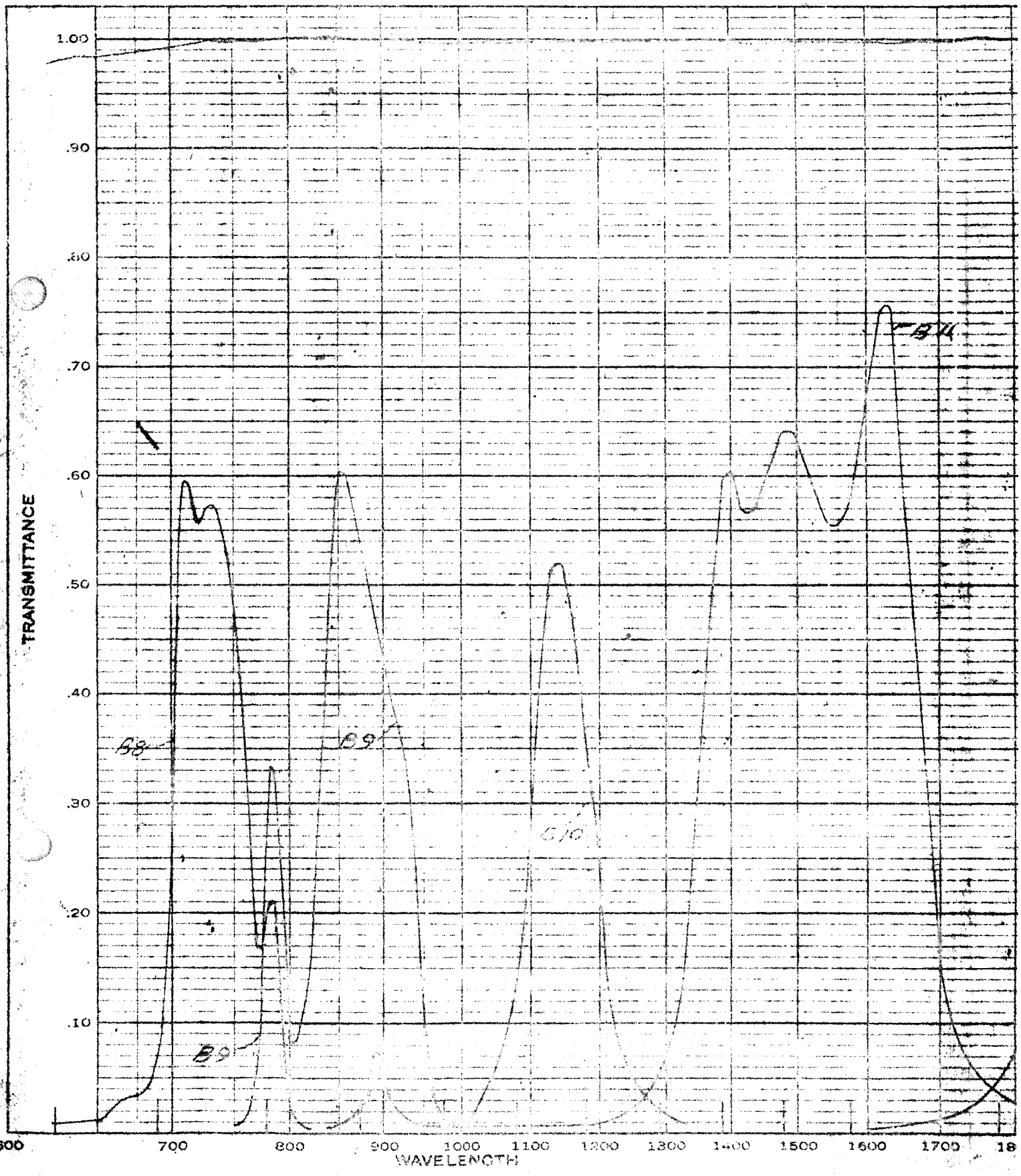

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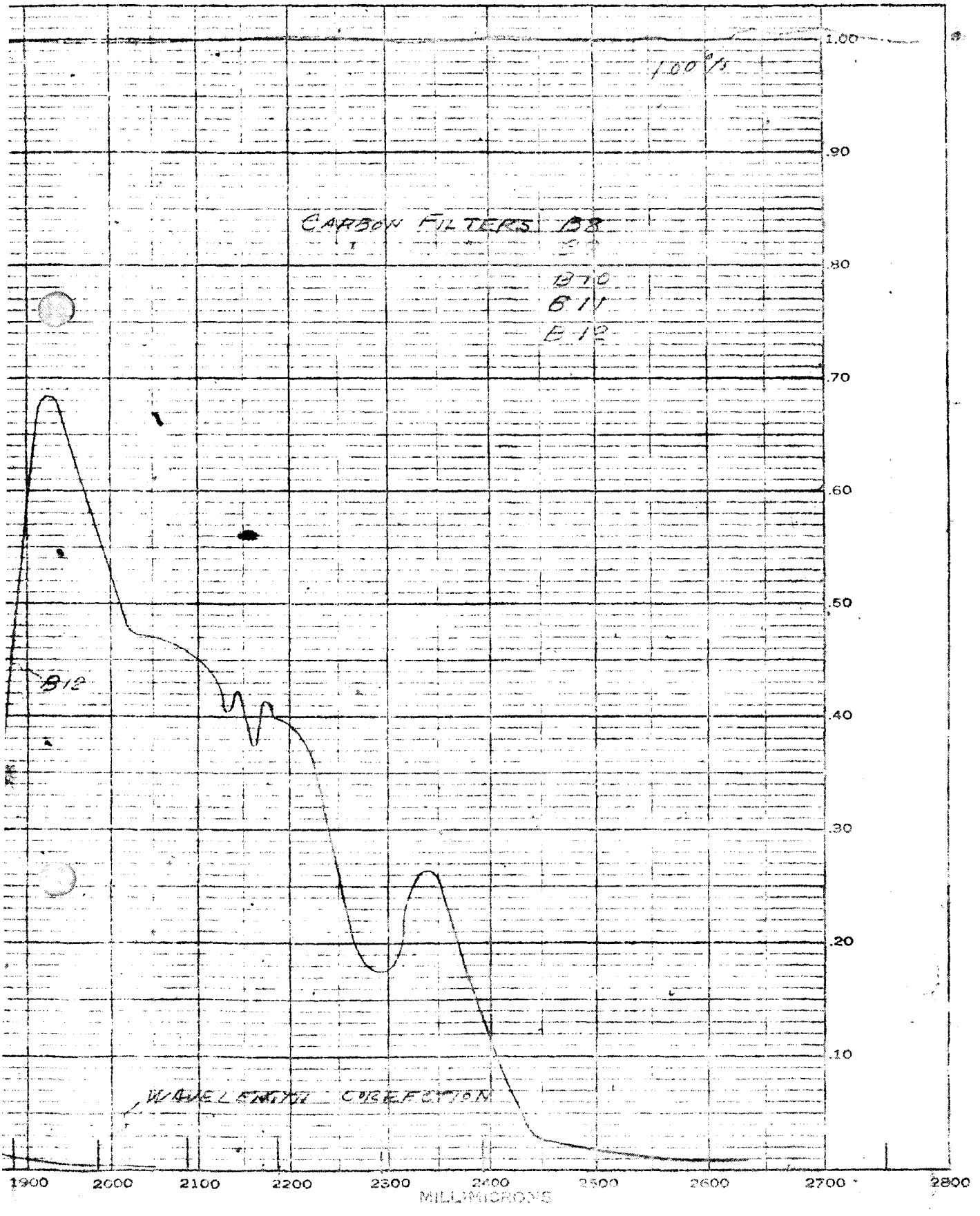

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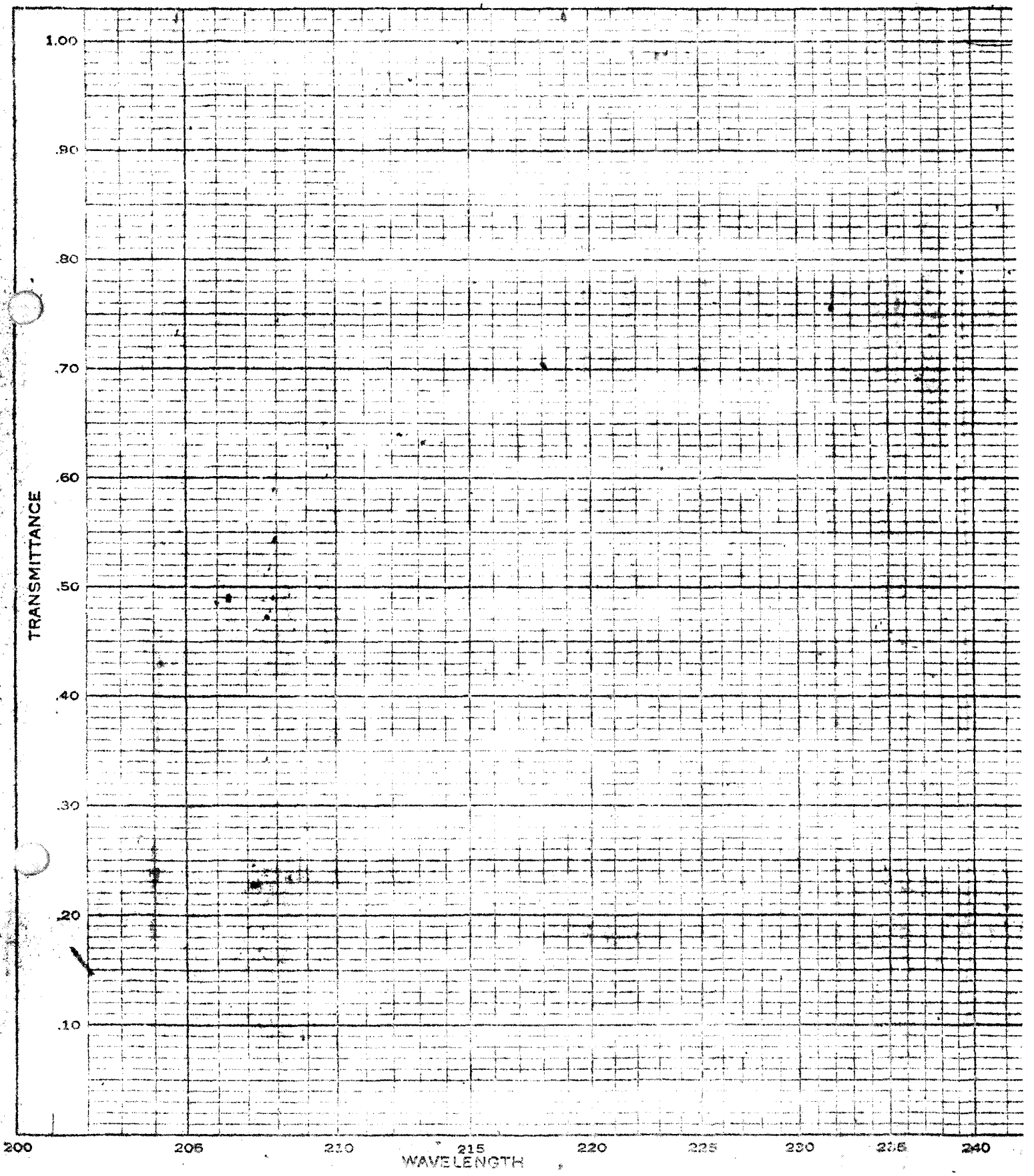

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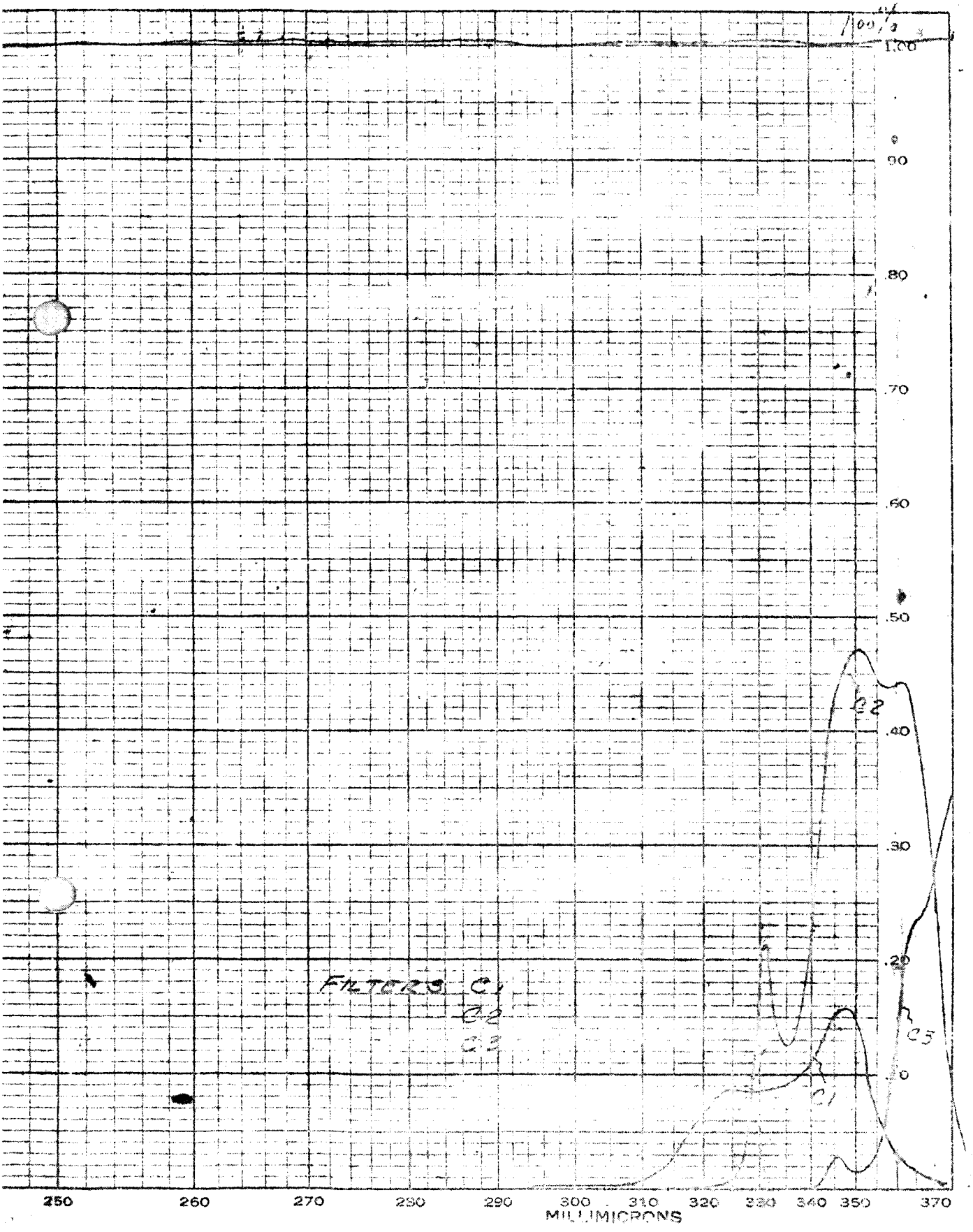

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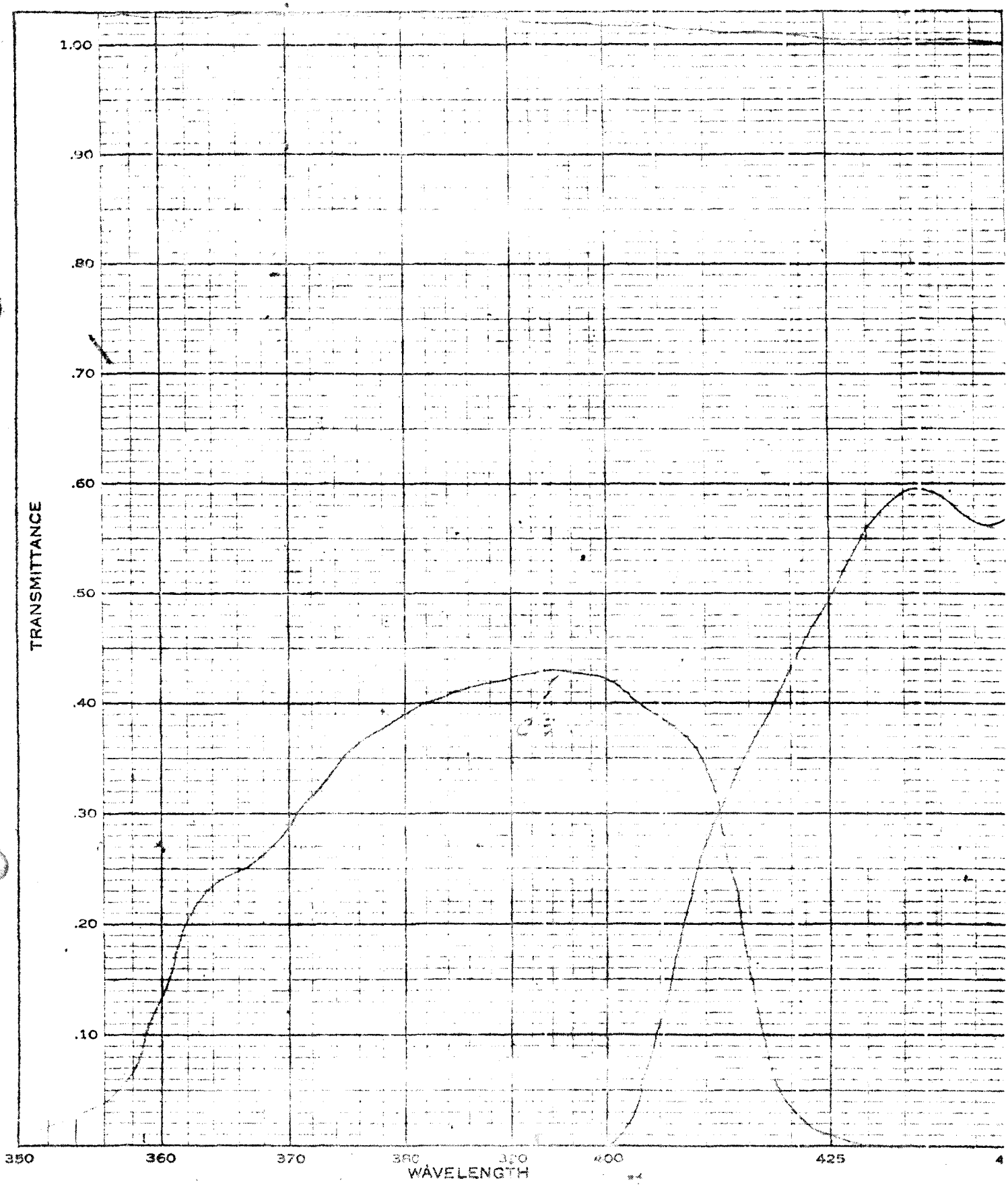

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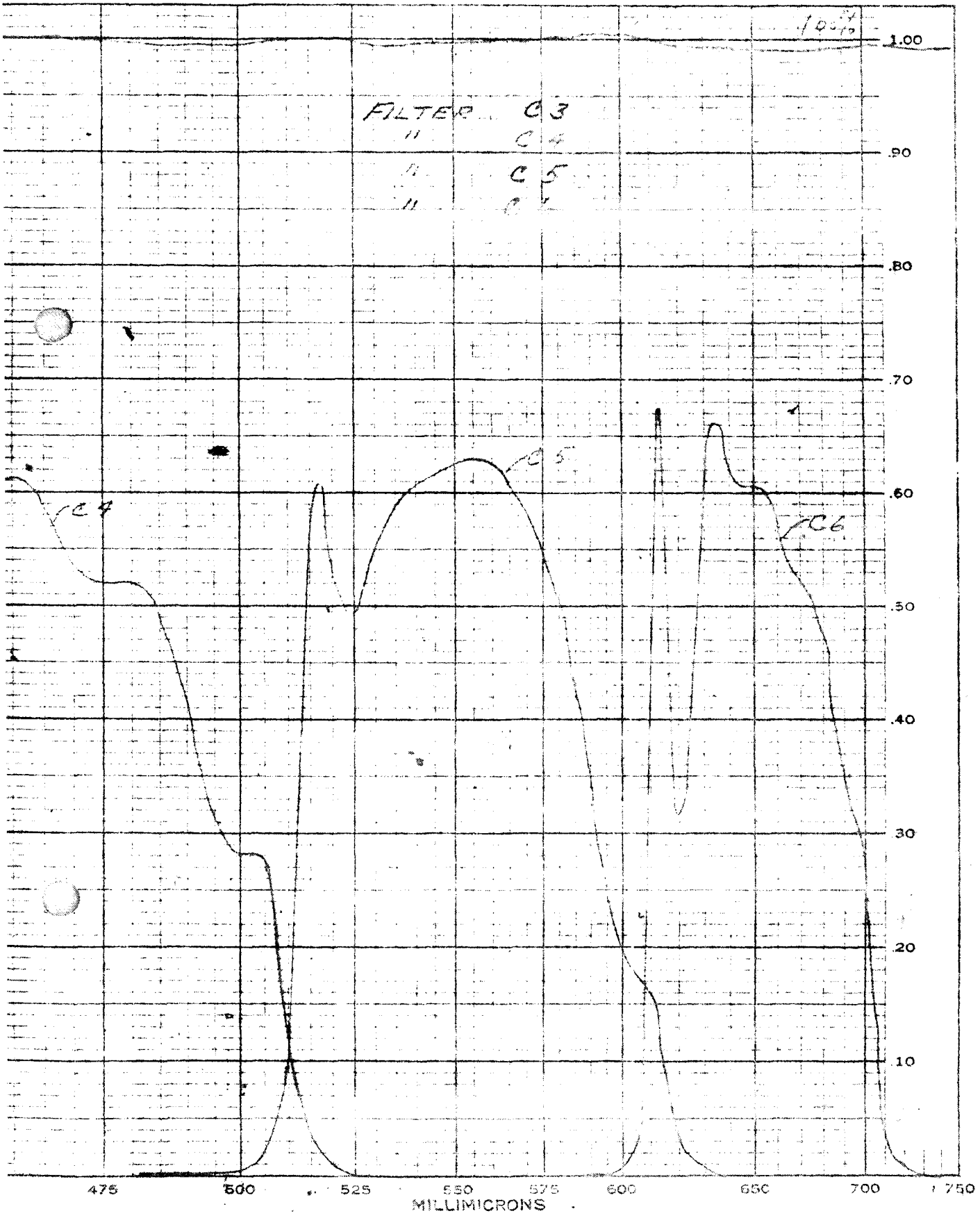

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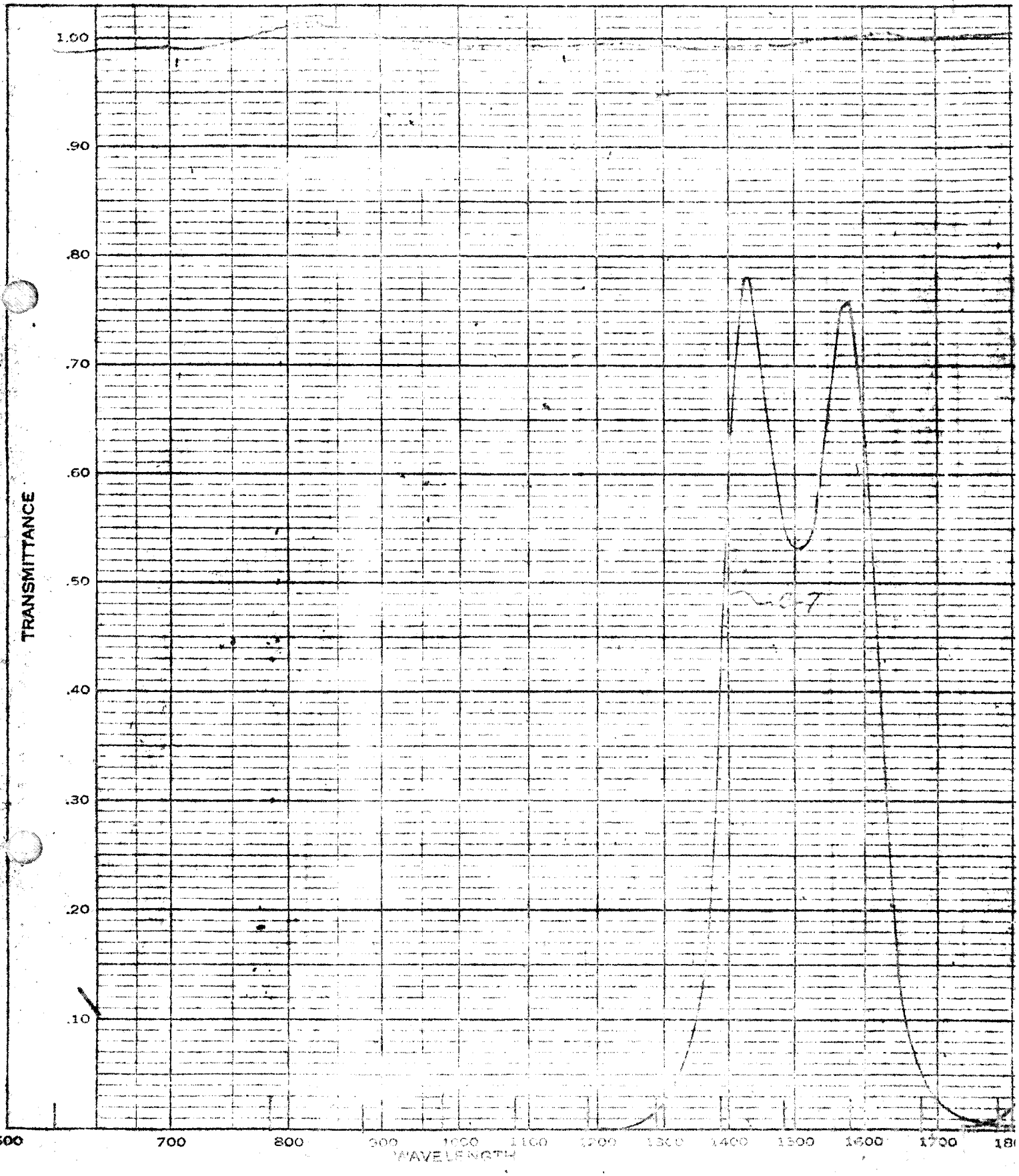

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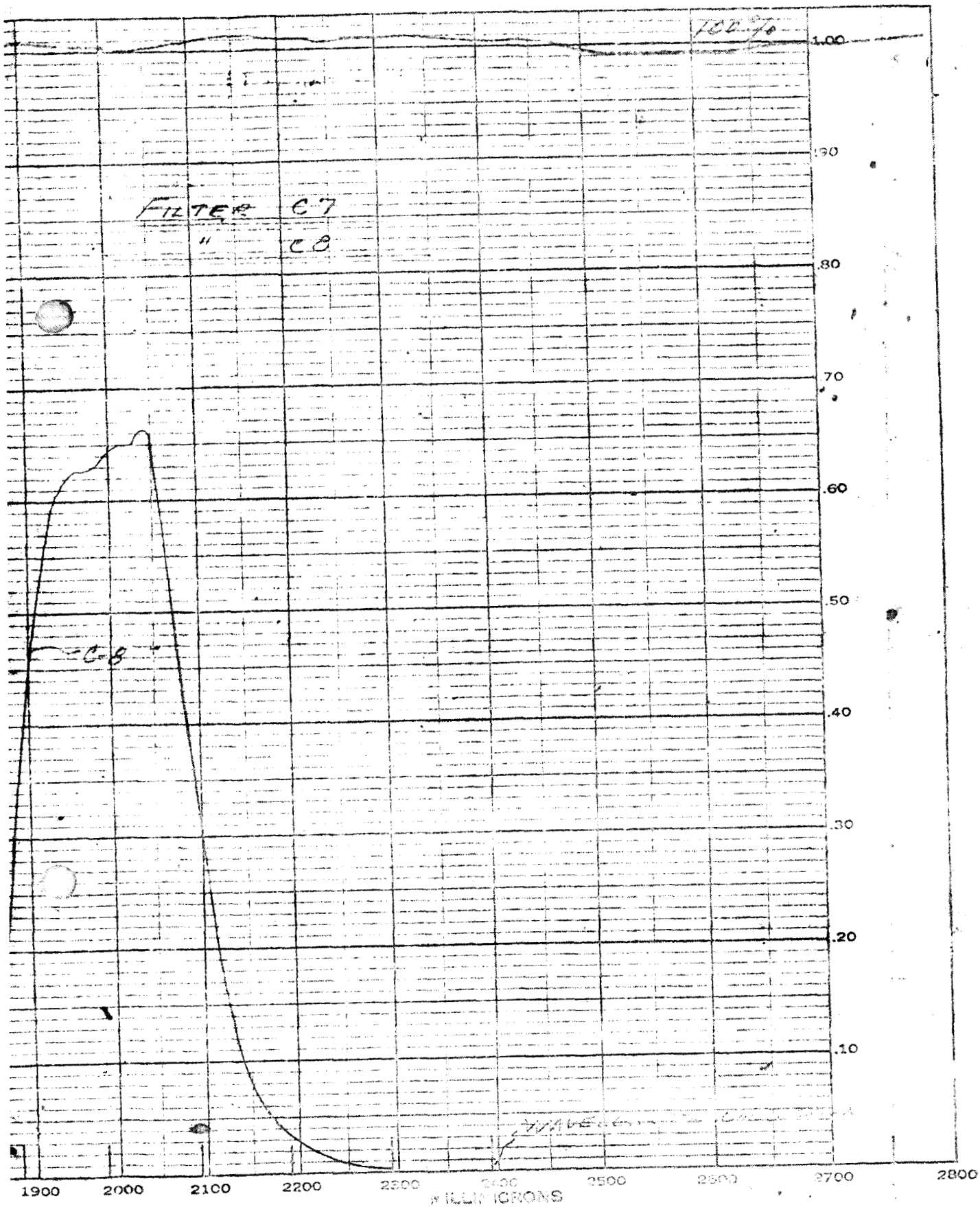
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