EVALUATION OF ELASTOMERIC CONCRETE FOR USE AS AN EXPANSION JOINT NOSING MATERIAL

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Foreword

The elastomeric concrete systems tested are intended for use in expansion joints, particularly those in bridges, which may experience large movements. The typical expansion joint consists of elastomeric concrete, metal extrusions with attached reinforcing bars, and a neoprene strip, foam, or other type seal. An illustration of a typical joint appears in Figure 1. Expansion and contraction take place within the seal, not the elastomeric concrete. The function of the elastomeric concrete is to bond the extrusions to the road surface while achieving a smooth and durable transition area. The reason for using an elastic material is to absorb the shock of traffic impact and prevent cracking in the end dam or nosing area adjacent to the joint. Elastomeric concrete is a relatively new product and, as such, the performance and properties desired are not well established.

Elastomeric concrete typically consists of two fluid binder components, aggregate and fines or powdered filler. The binders studied were prepared from polyurethane and epoxy components which were modified by addition of plasticizers and extenders. The concrete is prepared by first mixing the binder components and then adding the aggregate materials. Curing takes place with or without application of heat, depending on the particular manufacturer's instructions.

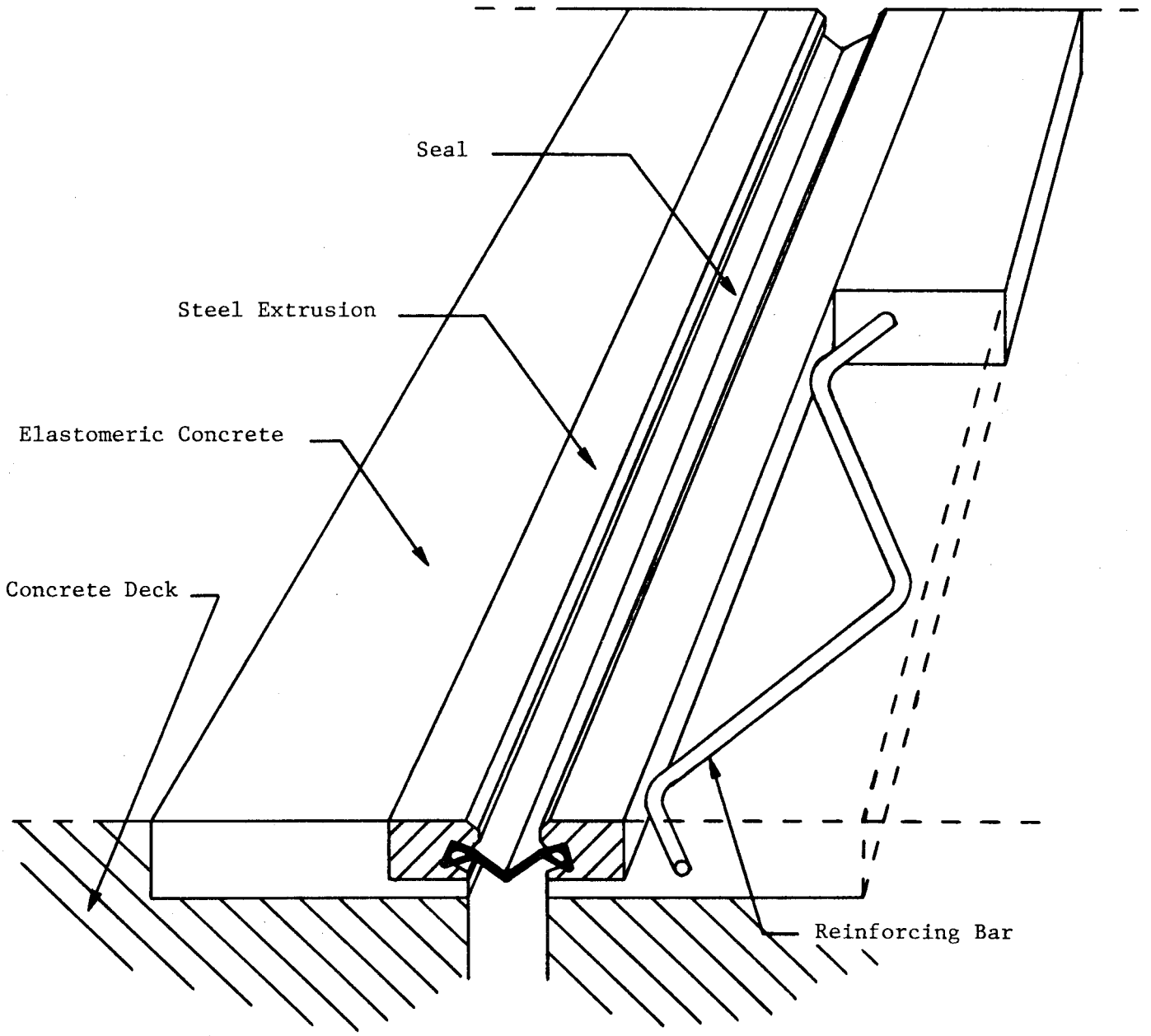


Figure 1

Typical Elastomeric Concrete Expansion Joint

Subject

Elastomeric concrete for use as an expansion joint end dam material.

Objectives

The objectives of this project were to evaluate commercially-available elastomeric concrete materials, define desirable material properties, and develop a specification for use of these materials in the construction of elastomeric type expansion joints.

Conclusions

This investigation resulted in development of test methods and data suitable for characterization of the elastomeric concretes tested. The methods and test results have been used to prepare a specification for elastomeric concrete which may be found in Appendix 2.

The properties which are most important for these materials appear to be flexibility, elasticity, and bond strength. Flexibility and elasticity allow the material to absorb shock caused by traffic impacting on the extrusions. Bond to the deck surface and the extrusions must be maintained in dry and wet conditions. A combination of compressive strength and elasticity is required for the materials to resist permanent deformation under the dynamic loads encountered. Also important in characterizing the binder are its tensile strength, tensile stress behavior, and tear resistance.

The primary components of current elastomeric concrete binders are epoxies and polyurethanes which contain plasticizers, extenders, and wetting agents. Results from this project indicate the difficulty in obtaining adequate flexibility and bond strength together in one material. A mixture of polyurethane and epoxy is apparently best able to provide the desired properties.

The specification is written to provide a material with excellent flexibility and bonding characteristics. One of the four products tested meets all of the requirements specified. It is anticipated that the other materials may be modified to meet the specification. The flexibility requirements in this specification are expected to assure satisfactory performance over the range of temperatures to be encountered in use.

In order to provide an acceptable basis of comparison and simplify the specimen preparation, the specification stipulates that there shall be no heat-curing of the elastomer after the components have been mixed. Although the results presented for Brands B and C are for heat-cured specimens, the information in Table II and observations made during testing indicate that after a seven-day cure there is no noticeable difference between heat-cured and non-heat-cured specimens. This validates the specification requirement concerning curing and the use of the Brands B and C data towards setting specification requirements.

Materials

The elastomeric concrete systems tested were proprietary products which were in no way altered. These materials were obtained from the manufacturers, packaged in component form.

The elastomeric concretes consisted of two binder components, an aggregate, and in some cases, a powdered filler. The binder components were polyurethane and epoxy resins and hardeners, some of which were modified by addition of plasticizers, extenders, wetting agents, and pigments. These components, fluid at their mixing temperatures, were combined to form a viscous material to which was added the aggregate and filler, if any. Curing of the elastomeric concrete was possible with or without application of heat. The component temperatures and ratios for mixing specified by the manufacturers are shown in Table I.

TABLE I

Elastomeric Concrete Mixing Information

Producer	Material	Component	Parts by Weight	Temperature
Brand A	A1	Part 1	7.5	Ambient
		Part 2	1	Ambient
		Aggregate A1	16.4	Ambient
Brand A	A2	Part 1	7.5	Ambient
		Part 2	1	Ambient
		Aggregate A2	28.9	Ambient
Brand B	B	Part A	1	140°F
		Part B	1.7	140°F
		Aggregate B	13.5	140°F
Brand C	C	Part A	1	160°F
		Part B	1.08	160°F
		Aggregate C	8.0	160°F
Brand D	D1	Part A	4	160°F
		Part B	1	212°F
		Filler	4	160°F
		Aggregate D1	3.2	160°F
Brand D	D2	Part A	4	160°F
		Part B	1	212°F
		Filler	2.6	160°F
		Aggregate A2	7.8	160°F
		Aggregate D2	8.2	160°F

Aggregate A1 was a 20-30 mesh graded Ottawa sand which was acquired following recommendations from the manufacturer. The initial recommendation was nonspecific, merely calling for sand. A #10 Ottawa sand was suggested for use, but this material was unavailable and the Ottawa Silica Corporation of Ottawa, Illinois, indicated that they did not produce this material. The 20-30 mesh Ottawa sand was chosen as the most similar available material. Further conversation with Producer A resulted in the use of Aggregate A2, a siliceous sand meeting their requirements shown in Table II. This aggregate was not provided by Producer A.

TABLE II

Aggregate A2 Gradation

U.S. Standard Sieve Size	Percent Passing
3/8"	100 minimum
#4	90-100
#8	75-100
#16	50-85
#30	25-60
#50	10-30
#100	1-10
#200	0-3

The aggregates used with Brands B and C were supplied by the manufacturers. They were very similar, both being a mixture of coarse rock, sand, and fines. In both cases, the fines were the major constituent.

Producer D provided their own filler material, Aggregate D1, and Aggregate D2. The filler was a fine, gray powder. Aggregate D1 was composed of fiberglass bundles of approximately one-quarter inch length and 0.04 inch diameter. Each bundle contained three strands of fibers which were rolled together and cemented. Aggregate D2 was a coarse granite of uniform gradation. Aggregate A2, the siliceous sand meeting the requirements set forth in Table II, was used in conjunction with Aggregate D2 to give Material D2.

A silicone lubricant, Dow Corning Stopcock Grease, was used as a mold release agent.

Test Methods

The elastomeric concretes are generally supplied as a binder-aggregate system. It was believed, however, that the binder material would be the controlling factor of the finished material properties. As a result, testing was done on the binder as well as the binder-aggregate system.

Tests used to evaluate the binder material follow:

1. Tear Resistance (ASTM Test Method D 624-81, Die C).
2. Tensile Strength, Ultimate Elongation (ASTM Test Method D 638-82a).
3. Compression Set (ASTM Test Method D 395-78, Method B).
4. Durometer Hardness (ASTM Test Method D 2240-81, Type D).
5. Water Absorption (ASTM Test Method D 570-81).
6. Heat Shrinkage (ASTM Test Method D 1299-55).
7. Impact Strength.
8. Pot Life.
9. Artificial Weathering (ASTM Test Method D 3408).
10. Tensile Shear Strength (ASTM Test Method D 1002-72).
11. Brookfield Viscosity.
12. Infrared Absorption Spectroscopy.

Tests used to evaluate the binder-aggregate system follow:

1. Compressive Strength (ASTM Test Method D 695-80).
2. Resilience.
3. Bond Strength to Concrete.
4. Wet Bond Strength to Concrete.
5. Density.

Complete details of the unreferenced tests may be found in the following text. General descriptions along with any deviations from the referenced procedures are given for the other tests listed.

Test specimens were cured at 73 ± 4°F and 50 ± 10 percent relative humidity for seven days before testing or further conditioning unless otherwise specified. Specimens for Tear Resistance, Tensile Strength and Ultimate Elongation, Compressive Set, Durometer Hardness, Water Absorption, and Impact Strength were oven-aged for 30 days at 140 ± 4°F.

The Tear and Tensile-Elongation specimens were loaded using an Instron Model 1122 testing machine. Serrated grips were used with an initial jaw separation of two and one-half inches. Crosshead speeds of 2 and 20 inches per minute were used to determine the maximum load and elongation. Only the lower speed was used to obtain stress-strain data from the tensile specimens. Elongation measurements were based on one-inch bench marks and on the original jaw separation. Stress-strain data was initially taken based on the one-inch bench marks, but this method proved to be difficult to perform and the reproducibility was poor. This method required the use of hand-held calipers to determine the elongation. The majority of stress-strain data was taken based on the amount of jaw separation because the testing machine provided a digital readout of the crosshead travel. Use of this method required uniformity of the entire tensile specimen and vertical centering of the specimen in the jaws. Very good reproducibility was obtained and this method was adopted as the preferred method. It was noted that the elongation of the tear specimens at failure was reproducible for a given binder material. The elongation at tear in inches represents the amount of crosshead travel required to tear the specimen when using an initial jaw separation of two and one-half inches. The initiation of tear was determined visually and for the materials tested coincided with the maximum tensile load carried by the tear specimens.

Compression of the Compression Set specimens was to 75.0 ± 0.2 percent of their original thickness. After 22 hours at 158°F, the specimens were removed from the compression device and allowed to cool for 30 minutes before remeasuring the thickness.

The Water Absorption, Heat Shrinkage, and Impact Strength test specimen was the 2.5 inch disk described in Preparation of Test Specimens. The Water Absorption specimens were dried at 140°F for 24 hours prior to their initial weighing. They were immersed in 77 ± 2°F water for seven days. The measurement of water absorbed was based on weight gain.

Specimens for Heat Shrinkage, which is based on dimensional changes, were maintained at 158°F for 14 days. The Impact Strength test was an adaptation of the Impact Strength section of Test Method Tex-614-J. Test specimens were conditioned before each impact to 32°F or -20°F. The 32°F specimens were conditioned in an ice-water bath and the -20°F specimens were conditioned in a refrigerated compartment. Temperature conditioning between test impacts was for at least five minutes. Each specimen was dried, if wet, and placed on a machined steel plate at a temperature of 70 to 80°F. A one-pound steel ball was dropped onto the center of the specimen from an initial height of five feet. This drop was made within ten seconds of removal of the specimens from their low temperature environment. The drop height was increased in one-half foot intervals until the specimen failed by cracking.

The Pot Life test called for 100 grams total of binder material to be mixed by spatula for two minutes in a six-ounce ointment can. In order to correlate with field installation, the binder components were at their recommended application temperature prior to mixing and were maintained in their recommended curing temperature environment throughout the test. The material was probed with a clean glass stirring rod in one-minute intervals to determine the time at which gelling occurred. Initial binder temperatures were: Brand A: 77°F, Brand B: 140°F, Brand C: 160°F, and Brand D: 170°F. After mixing, Brands A and D remained in an ambient environment while Brands B and C were placed in 140°F and 158°F ovens, respectively.

The Artificial Weathering test cycle consisted of 102 minutes of light only and 18 minutes of light and water. This cycle was repeated for a total of 22 hours daily and for 400 ± 10 hours total exposure. The effects were determined from visual examination of the specimens.

The ends of the steel Tensile Shear Strength specimens were placed in the testing machine grips and the joints subjected to tensile loading

at a rate of 0.05 inch per minute. The strengths were obtained from the maximum loads and the overlap areas determined as explained in Specimen Preparation.

Viscosities of the binder components at 77 ± 1°F were determined using a Brookfield Synchro-Lectric Viscometer. The samples were placed in a container allowing at least one inch clearance between the spindle and container. An acceptable reading was one which occurred between 20 and 80 percent of full-scale. The spindle speed used was 20 rpm, with the exceptions of Brand C Part A, where speeds of 5 and 10 rpm were used and Brand A Part 2, where 50 rpm was used.

Infrared absorption spectra were obtained for the binder components covering the range 4000 to 600 cm^{-1} using a Perkin-Elmer Model 521 Grating Infrared Spectrophotometer. Cast films of the following components were analyzed without modification: Brand A Part 2, Brand B Part 2, Brand C Part 1, Brand D Part 1, and Brand D Part 2. The other three components, Brand A Part 1, Brand B Part 1, and Brand C Part 2, contained pigments which had to be removed. This was accomplished by dissolving the components in toluene, centrifuging the pigments out, decanting, and evaporating the toluene. The spectra were obtained for the materials, known as the vehicle, resulting from this process.

The Compressive Strength and Resilience tests used the two-inch cube described in Specimen Preparation. In both cases, the crosshead speed was 0.05 inch per minute. For the Resilience test, the original thickness of the cubes was measured to the thousandth of an inch at the center of opposing faces. The specimens were compressed 0.10 or 0.15 inch and the load removed. After five minutes recovery time, the thickness of the specimens was remeasured. The percent recovery was determined from the thickness measurements as follows:

$$\text{Percent Recovery} = \frac{0.10 \text{ in.} + \text{Final Thickness} - \text{Initial Thickness}}{0.10 \text{ in.}}$$

or

$$\text{Percent Recovery} = \frac{0.15 \text{ in.} + \text{Final Thickness} - \text{Initial Thickness}}{0.15 \text{ in.}}$$

The Bond Strength to Concrete and Wet Bond Strength to Concrete tests used the briquette specimen described in Specimen Preparation. All of the specimens were subjected to tensile loading using the Riehle briquette tester. The Bond Strength specimens were tested after a one-week dry cure. The Wet Bond Strength specimens were submersed in 73 ± 4°F water for seven days after their dry cure. The specimens rested in a horizontal position while submersed such that the entire bond surface was readily exposed to water.

Density of the cured elastomeric concrete was determined using cast two-inch cubes. The cubes were weighed and the volume taken to be eight cubic inches.

Due to the relatively simple nature of Brand A, Part 2, other physical property tests were run in an effort to determine the composition. A distillation was run according to ASTM Method D 86-78 using ambient collection and initial charge temperatures. A water bath at 60 to 70°F was used for condensation. Density at 77 ± 1°F was determined by pycnometer according to ASTM D 1475. The refractive index of Brand A, Part 2, was determined using a Bausch and Lomb refractometer.

Specimen Preparation

Certain properties of the binders created problems in the preparation of test specimens. The binders possessed great bond strengths to the molds which were overcome by using Teflon mold surfaces when possible and silicone lubricant on metal mold surfaces. The high viscosities of the binder components caused flow problems and air entrainment. These problems were especially apparent when making thin-layer specimens for the tensile and tear tests. The Brand C binder was the most viscous, making it difficult to obtain good quality specimens. The Brand D binder required special methods of preparation. The material gave off nitrogen gas as a by-product of its curing reaction. This gas, in the form of entrained bubbles, was removed by the use of vacuum, causing the binder

to set up faster. Another technique for removing the nitrogen bubbles was raising the binder temperature, thus lowering the viscosity. This also accelerated the cure rate. Careful control of the component temperatures and use of vacuum allowed a fluid binder material without entrained nitrogen to be obtained.

Specimens of the binder for the Tensile and Tear tests were prepared from cast sheets with dimensions 6.5 x 4.5 x 0.1 inch. These were prepared in specially designed molds consisting of two flat, rigid Teflon surfaces which sandwiched a thin metal plate outlining the area of the sheet. The mold was held together with bolts in order to achieve a uniformly thick sheet. Maintaining the Teflon surfaces smooth by sanding allowed the binder sheet to release from the mold easily. The tensile and tear specimens were stamped as soon as the cured sheet was removed from the mold. The tensile specimens were prepared using the Type IV die with dimension WO equal to one inch as shown in ASTM Test Method D 638-82a. This is the same as Die C in ASTM Test Method D 412-80. The tear specimens were prepared using Die C in ASTM Test Method D 624-81. The specimens were obtained with a single hammer blow to the die when possible. As the binders continued to cure, it became increasingly difficult to obtain these specimens. The Brand C material became somewhat brittle if cured several days and would crack under the hammer blows required to stamp the specimens. The Brand D material did not embrittle, but became too tough for the die to penetrate. In many cases the specimens had concavity on their edges caused by the cutting action of the die. This was removed by sanding to produce a squared-off edge. Tensile and tear specimens whose thickness did not fall between 0.10 to 0.13 inch were discarded.

Disk specimens were prepared for use in the Water Absorption, Heat Shrinkage, Impact Strength, and Durometer Hardness tests by casting the binder in metal rings. These rings had their inner surface lightly coated with silicone lubricant and were placed on a flat Teflon base. After curing, the lubricant was removed by lightly rubbing the edges with ethanol, which

quickly evaporated. The disks were wet-sanded with #180 wet-dry sandpaper to produce flat, parallel faces and to achieve the required thickness of 0.375 ± 0.005 inch. The diameter of the specimens was 2.50 ± 0.05 inches. Specimens for the Compression Set test were prepared using the same method so as to have a 1.0 ± 0.05 inch diameter and 0.50 ± 0.01 inch thickness.

A 2 x 6 x 0.1 inch binder specimen was cast on a 3 x 9 inch aluminum panel for the Artificial Weathering test. No asbestos-cement or tin panels were prepared.

Tensile Shear Strength steel strips with dimensions 1 x 8 x 0.064 ± 0.005 inches were prepared for use by blasting the end half-inch with 36 mesh garnet abrasive at 50 to 75 psi. This lap area was cleaned with 1,1,1-trichloroethane and allowed to dry. The binder material was mixed at recommended application temperature and applied in a single coat to each of the lap surfaces. Test joints were prepared by bonding together the lap surfaces of two steel strips and applying one to two psi to the joint until the binder cured. After a seven-day cure, excess binder was removed from the specimens by filing and the overlap distance was measured.

Test specimens for the Compressive Strength and Resilience tests were prepared from the binder-aggregate mixture in the form of two-inch cubes. The molds described in ASTM Test Method C 109-80 were used with a light coating of silicone lubricant as a mold-release agent. Irregularities on the cubes were removed in order to produce flat surfaces and clean edges.

Briquette specimens were prepared for the bond strength tests. The elastomeric concrete was cast against a mortar briquette half derived from a briquette prepared in accordance with ASTM Test Method C 190-82. The briquette halves were prepared by sawing the briquettes in half at the centerline perpendicular to the long axis, sandblasting the surface

with 36 mesh garnet abrasive, and blowing the surface clean with compressed air. The briquette halves were placed in their original mold and the elastomeric concrete was cast into the remaining mold space. This resulted in specimens which were half mortar and half elastomeric concrete having a bond area of one square inch.

Two of the manufacturers recommended heat-curing of their product immediately after placement. To reflect this, specimens of their materials were subjected to their recommended heat-curing immediately after preparation. The heat-curing was for two hours at 160°F for Brand C and four hours at 140°F for Brand B. The Brand A and Brand D materials were not heat-cured.

Test Results and Discussion

Manufacturers have contended that elastomeric concrete should be an elastic material able to absorb the shock caused by traffic traveling over and impacting upon the extrusions. Rigid end-dam materials have shown a tendency to crack longitudinally. With this in mind, an attempt to determine the elastic behavior of the elastomer systems was undertaken. Many other physical properties were studied, also. Tests were performed on the binder alone and on the binder-aggregate system. The majority of the tests were performed on the binder because this material lends flexibility and elasticity to the product and because there existed important differences in the various binders. Although the elastomeric concretes are provided as a complete binder-aggregate system, the primary product being sold is the binder.

Results of the tests are shown in Tables III through X. The values reported are averages, followed by the range of values obtained within parentheses. The lists of tests include information, such as crosshead speed, necessary to differentiate between variations of a single test. The specimens were cured seven days unless indicated by "Oven Aged Material."

TABLE III

Binder Component Properties

Test	Brand A	Brand B	Brand C	Brand D
Pot Life (Minutes)	26[1]	23[2]	14[3]	6[4]
Viscosity of Components (cP)	7200 (#5)[5]	6500 (#5)	180,000 (#7)	30,000 (#6)[6]
	70 (#1)	21,000 (#6)	32,000 (#6)	32,000 (#6)

1 - Components were 77°F before mixing. No heat was added.

2 - Components were 140°F before mixing. Material was maintained in a 140°F oven after mixing.

3 - Components were at 158°F before mixing. Material was maintained in a 158°F oven after mixing.

4 - Components were heated to 158°F and 212°F before mixing. No heat was added.

5 - Numbers in parentheses are spindle numbers of viscometer spindles used.

6 - Only one component was fluid at 77°F.

TABLE IV

Tensile and Tear Properties

Test	Brand A	Brand B	Brand C	Brand D
Tear Resistance (lb/in.) Crosshead 2 in./min.	100 (80-115)	175 (150-210)	215 (190-240)	260 (230-290)
Tear Resistance (lb/in.) Oven Aged Material 2 in./min.	270 (210-310)	225 (220-230)	285 (270-310)	450 (420-475)
Tear Resistance (lb/in.) 20 in./min.	140 (110-165)	245 (235-260)	260 (255-275)	290 (250-340)
Elongation at Tear (in.) 2 in./min.	0.50 (0.4-0.65)	1.15 (1.1-1.2)	0.45 (0.4-0.5)	1.85 (1.5-2.0)

TABLE IV (Continued)

Test	Brand A	Brand B	Brand C	Brand D
Elongation at Tear (in.) Oven Aged Material 2 in./min.	0.25 (0.2-0.3)	0.80 (0.75-0.85)	0.15 (0.12-0.18)	1.50 (1.3-1.7)
Tensile Strength (psi) 2 in./min.	700 (550-900)	950 (775-1100)	860 (750-1100)	1450 (1000-2200)
Tensile Strength (psi) Oven Aged Material 2 in./min.	1250 (1100-1450)	1300 (1050-1500)	1600 (1400-1700)	3700 (2700-4800)
Tensile Strength (psi) 20 in./min.	880 (850-950)	1000 (900-1150)	1050 (985-1130)	1500 (1100-2100)
Ultimate Elongation Bench Marks 2 in./min.	70% (68-80)	175% (150-200)	150% (125-170)	320% (270-380)
Ultimate Elongation Jaw Separation 2 in./min.	55% (52-60)	150% (125-160)	90% (64-104)	280% (200-360)
Ultimate Elongation Oven Aged Material Jaw Separation 2 in./min.	50% (48-56)	120% (95-145)	14% (10-20)	290% (220-340)
Ultimate Elongation Jaw Separation 20 in./min.	68% (56-72)	130% (120-140)	60% (54-70)	270% (200-340)

TABLE V

Selected Binder Properties

Test	Brand A	Brand B	Brand C	Brand D
Durometer Hardness (Type D)	46	34	49	30
Durometer Hardness (Type D) Oven Aged Material	53	39	58	44
Water Absorption (percent by weight)	3.2% (3.1-3.4)	1.1% (1.0-1.2)	0.65% (0.6-0.7)	1.5% (1.4-1.6)
Water Absorption (percent by weight) Oven Aged Material	3.4% (3.3-3.5)	1.2% (1.1-1.2)	0.68% (0.6-0.75)	1.5% (1.4-1.6)
Compression Set (percent)	43% (38-45)	47% (44-50)	80% (78-81)	70% (62-77)
Compression Set (percent) Oven Aged Material	17% (15-20)	37% (35-40)	69% (65-75)	38% (35-40)
Heat Shrinkage (percent by length)	0.6% (0.5-0.7)	0.7% (0.6-0.9)	1.2% (1.0-1.4)	1.6% (1.4-1.7)
Impact Strength (ft·lb) at 32°F	7+	7+	6	7+
Impact Strength (ft·lb) Oven Aged Material at 32°F	7+	7+	5-	7+
Impact Strength (ft·lb) at -20°F	7+	7+	5-	7+
Impact Strength (ft·lb) Oven Aged Material at -20°F	7+	7+	5-	7+
Tensile Shear Strength (psi)	620 (510-760)	880 (770-950)	1150 (920-1370)	620 (500-780)

TABLE VI

Artificial Weathering Results

Brand A - Weathered specimen hardened by seven Type D durometer units when compared to a similar specimen not subjected to weathering. There was no change in the appearance of the weathered specimen.

Brand B - Weathered specimen hardened by nine Type D durometer units when compared to a similar specimen not subjected to weathering. The surface evidenced chalking, resulting in a smooth, dull finish. There was no cracking, flowing, or blistering.

Brand C - Weathered specimen hardened by 13 Type D durometer units when compared to a similar specimen not subjected to weathering. The surface evidenced chalking, resulting in a smooth, dull finish. There was no cracking, flowing, or blistering.

Brand D - Weathered specimen hardened by six Type D durometer units when compared to a similar specimen not subjected to weathering. There was no chalking, cracking, flowing, or blistering. The specimen darkened and lost its bond to the aluminum panel.

TABLE VII

Results of Tests Performed on the Binder-Aggregate System

Test	Brand A	Brand B	Brand C	Brand D
Compressive Strength (psi)	1500[1] (1300-1700) 1700[2] (1600-1800)	2500 (2400-2600)	2900 (2700-3100)	3
Resilience (% Recovery) 5% deflection	90%[4]	84%	60%	96%[5] 95%[6]
Resilience (% Recovery) 7.5% deflection	70%[7]	77%	59%	95%[8] 93%[9]
Bond Strength to Concrete (psi)	500+	500+	500+	270 (215-345)
Mode of Failure	Concrete	Concrete	Concrete	Bond
Wet Bond Strength to Concrete (psi)	115 (95-165)	300 (200-405)	400+	115 (85-150)
Mode of Failure	Bond	Bond	Concrete	Bond
Density of Cured Material (lb/ft^3)	108[10] 119[11]	138	127	95[12] 129[13]

1 - Ottawa sand (aggregate A1).
2 - Siliceous sand (aggregate A2).
3 - No compressive strength obtained for this material.
4 - Siliceous sand (aggregate A2).
5 - Granite/sand (aggregates D2, A2).
6 - Fiberglass (aggregate D1).
7 - Ottawa sand (aggregate A1).
8 - Granite/sand (aggregates D2, A2).
9 - Fiberglass (aggregate D1).
10 - Ottawa sand (aggregate A1).
11 - Siliceous sand (aggregate A2).
12 - Fiberglass (aggregate D1).
13 - Granite/sand (aggregates D2, A2).

Physical property information obtained for Brand A, Part 2 is shown in Table VIII.

TABLE VIII

Physical Properties of Brand A, Part 2

Density at 77°F - 8.27 lb/gallon
Refractive Index at 77°F - 1.505
Distillation: Initial Boiling Point - 410°F

Volume Recovered	Temperature
10 ml	595°F
20 ml	616°F
30 ml	619°F
40 ml	620°F
50 ml	620°F
60 ml	621°F
70 ml	621°F
80 ml	621°F
90 ml	621°F
100 ml	622°F

Infrared absorption spectra for the binder components are located in Appendix 4. The ordinate is percent absorption. The spectra were prepared such that the background absorption for the different materials was nearly constant. However, absolute absorption levels for this type of spectra are highly variable and may have little significance. Relative absorption levels of the various peaks within a spectrum are significant for functional group and compound identification. The lower abscissa is marked in wave numbers (cm^{-1}) and the upper abscissa in wavelength (microns). Preparation of samples used to obtain the spectra is outlined in Test Methods.

Stress-Strain curves were prepared in conjunction with the Tensile Strength and Compressive Strength tests. The tensile stress-strain data were obtained in the form of discrete pairs of deflection and load values. The deflection values were obtained from the instrument digital readout of crosshead travel by use of an event marker in the recorder. Load values were then read from the recorder chart at the selected and marked points of deflection. Compressive stress-strain data pairs were obtained by use of a dial micrometer attached to the machine crosshead. Load readings were taken directly from the testing machine load scale. For both the tensile and compressive curves, load values for the various specimens were averaged for each deflection value. The individual specimen compressive stress-strain curves were first corrected graphically so as to pass through the origin. The stress-strain curves obtained each represent the average of several specimens. The stress-strain curves appear in Graphs 1-7.

The primary benefit of the Tear Resistance test is for general characterization of the binder as a material with toughness. The results of this test were highly reproducible and no problems with specimen quality were observed. The range of values obtained is not significant and the minimum performance obtained appeared to be satisfactory. The Brand A specimens did, however, flake or crumble slightly around the edges where the die had

cut. Record was kept of the Elongation at Tear when the reproducibility of this elongation was noticed. This elongation is apparently a function of the flexibility of the binder materials. The use of powdered fillers, as in some of the proprietary aggregates, may adversely affect the tear resistance and possibly the resistance to cracking of the elastomeric concrete. Therefore, this test is not necessarily a direct indicator of the elastomeric concretes' performance, but it does provide important information about the binder material. It should be noted that the strength recorded was the maximum load carried by the specimen, corresponding to the initiation of tear, and does not necessarily reflect the ability of the material to resist tearing once a tear has been created. The effect of oven aging was to increase the tear strength and reduce the tear elongation. Both effects are typical of hardening of the binder. There is little merit in an increasing tear strength with age as determined by this method. Brand A showed a 170 percent increase in tear strength with aging, while the others changed by only 30 to 55 percent.

The oven aged tear elongation results have significance in that they show signs of embrittlement. This was apparent in Brand A and especially Brand C. The Brand A material had flexibility, but behaved as if it contained a filler, whereas the Brand C material was very rigid and emitted a sharp, hollow noise when dropped on a hard surface. The Brand A material retained 50 percent and the Brand C material only 33 percent of its original tear elongation.

The tensile specimens were the most difficult to prepare. Problems encountered included entrained air bubbles, nonuniform specimen thickness, and curvature at the edges where the die had cut. As a result, a large number of specimens were discarded either before or after loading. Even after eliminating specimens with obvious flaws, the values obtained for the tensile strength had greater variation than for results of other tests. The ultimate elongation results were more reproducible than the tensile strength results. The original tensile strengths of the binders

were all acceptable and, except for Brand D, fell within a small range. The differences in the binders showed up in the elongation results, which are probably more significant for these materials. The tensile stress-strain properties of the original binder materials are shown in Graphs 1 and 2. Graph 2 shows the entire range of behavior while Graph 1 shows the low-stress range of interest for setting specification requirements. Graph 1 shows a marked difference in the tensile behavior of Brand C. Even though Brand C has adequate ultimate elongation in its original state, it loads up so rapidly that it is, in effect, a rigid material. At an elongation of under five percent, the binder has a tensile strength greater than that of concrete (approximately 500 psi) and any subsequent elongation is of little value. Graph 3 shows the tensile stress-strain curves for the aged binder materials. There is no curve shown for Brand C because of its extremely small elongation. The effects of aging are further illustrated in Graphs 4, 5, and 6 which compare original to aged properties for Brands A, B, and D. The effect of aging was to increase the tensile strength, particularly of Brand D, and decrease the ultimate elongation. For Brand C, this decrease was substantial, indicating the embrittlement that this material incurs. The decrease in elongation for the other materials was very small. The Brand B binder showed the least change in stress-strain behavior with aging. The Brand A material showed a substantial increase in load at low elongation. Table IX shows selected stress-strain properties which indicate the flexibility of the various binders. It can be seen that Brands A, B, and D give excellent elongation at 500 psi stress and Brands B and D are best able to maintain their elasticity after aging. The stress data show Brand B's ability to resist hardening with aging.

TABLE IX

Selected Binder Stress-Strain Properties

Property	Brand A	Brand B	Brand C	Brand D
Tensile Stress at 20% Strain				
Original Property	315	400	700	380
Oven Aged Material	800	640	-	740
Tensile Stress at 40% Strain				
Original Property	490	520	730	460
Oven Aged Material	1000	770	-	980
Tensile Strain at 500 psi				
Original Property	42%	37%	3%	52%
Oven Aged Material	4%	9%	-	10%

The Compression Set test is most applicable to materials which will experience sustained static loads. As such, its applicability to elastomeric concrete, which will undergo intermittent dynamic loading, is somewhat limited. The results of this test do not correlate well with those of the Resilience test. The best performance was shown by Brands A and B.

The hardness values obtained are in agreement with the elongation results in that the softer materials have greater elongation. The effects of aging also correlate fairly well. The reproducibility of the Water Absorption results was the best of any of the tests performed. None of the materials showed increased absorption due to oven aging. A high absorption value was obtained for Brand A, possibly contributing to the poor wet bond strength associated with this material. All of the binders performed well on the Heat Shrinkage test. None of them changed in physical appearance in any way, including warping. The shrinkages observed were all minor, considering the specimens contained no aggregate. Requirements for hardness, water absorption, and heat shrinkage appear to be less significant in controlling the performance of the elastomeric concretes. Although heat shrinkage could shorten the life of an elastomeric concrete, the results do not indicate any problems.

The Impact Strength test was intended to detect brittleness in the binder as a result of aging and low temperature. The test was performed with four different conditions as outlined in Table I. Brands A, B, and D passed in all four cases at the highest drop point. The Brand C material failed consistently at the lowest drop point with the exception of the least severe test case, where the average failure was six foot-pounds. These results agree with other test results which show the relative brittleness of the Brand C binder material. This test was performed on the binder material without aggregate because the binder properties are the controlling factor.

As indicated in the footnotes to Table V, the pot life was determined differently for each of the binder materials. The temperature and heating conditions used were intended to duplicate the recommended methods of field placement. It is desirable to have a material with sufficient working time to allow placement of a large quantity and with sufficient fluidity to get flow around and below the extrusions, thus filling all void space. The material must set rapidly enough, however, and have sufficient viscosity to give satisfactory placement on inclined surfaces. The pot life values determined in the laboratory will generally be longer than those encountered in actual use of the materials, due to the volume of material involved and the heat generated. The results show a problem with the Brand D material in that the pot life was only six minutes. This material did not show a gradual increase in viscosity as others did, instead the entire mass gelled quickly. Due to the various test conditions employed, it is difficult to compare the pot life values or set a test requirement for pot life. Observations of the gelling behavior are of as much significance as the pot life values obtained. The Brand D material presents several problems with placement. The application of vacuum after mixing is an operation requiring specialized equipment which consumes a portion of the limited working time available. Addition of the filler and aggregate extends the working life of the Brand D material, such that it flows and can be worked with satisfactorily. This mixture is, however, viscous and tends to be somewhat stringy. The

Brand C binder is very viscous and does not flow well without being trowelled. The Brand A and B systems flowed well. In none of these systems was aggregate settling apparent although this is a possibility when placed in larger volumes. This problem is most likely to occur in the Brand A material, since it has the lowest viscosity of the four at mixing conditions.

The Artificial Weathering results were discussed in Table VI. None of the materials displayed any serious problems. Brands B and C showed more tendency to chalk than the other brands and all of the materials hardened to some degree.

Results of the Tensile Shear Strength test showed a fairly wide range of values for each material. There are a large number of variables which must be specified in this test. The most important factor was probably the thickness of the binder between the laps. This was controlled by application of the binder at elevated temperatures using a consistent technique followed by placing pressure on the overlap area. Brand C had the greatest strength and was the only material that failed cohesively. The other materials failed adhesively. These results combined with the bond strength to concrete tests show the Brand C material to have superior adhesive properties.

Infrared Absorption Spectroscopy was used as part of an effort to identify the materials being tested. Due to the complexity of the binder components, relatively little could be determined from the spectra. The manufacturers provided some information about their products which, in combination with the spectra, gave a basic knowledge of the binder compositions. All of the binders are two-component thermosets. The Brand A material is apparently an epoxy which contains a butyl glycidyl ether diluent and pigments in the resin and uses a polyamide curing agent. The Brand B material is a mixture of polyurethane, epoxy, plasticizers, and extenders, one of these being coal tar pitch. Polyurethane is probably the primary component. Brand C is a similar mixture of poly-

urethane, epoxy, and softening agents including coal tar pitch. The infrared spectra of the Brand B and C components were nearly identical, but the differences in properties suggest the Brand C material is primarily an epoxy. The Brand D material is a polyurethane which contains no epoxy components.

Compressive loading of the two-inch cubes yielded the stress-strain curves shown in Graph 7 and the compressive strengths of the elastomeric concretes. Two different aggregates were used with Brands A and D, causing wide variation in the properties of the products. As in the tensile loading, the Brand C material was the most rigid and loaded up the quickest. This material had the greatest compressive strength and showed a small amount of cracking when its ultimate strength was reached. The Brand B material had a response similar to that of Brand C, though not as rigid. Its strength was only slightly less. There was little difference in the compressive strengths of Brand A with the two aggregates used. Aggregate 2 produced a more rigid product than aggregate 1, reaching its ultimate strength with approximately half the strain of the other. The ratio of aggregate to binder specified, as shown in Table IX, probably had as much affect on the Brand A elastomeric concrete as the type aggregate. The Brand A2 material was more heavily loaded with aggregate. The two aggregates specified for Brand D gave very different results. This material was very flexible and gave no ultimate compressive strength even after 20% strain. Brand D aggregate 2 provided much greater strengths than aggregate 1 with no appreciable loss in flexibility. Aggregate 1, fiberglass bundles, had a much lower density than the other aggregates, thus lowering the weight ratio as shown in Table X.

The Resilience test was devised to determine the elasticity of the elastomeric concrete after compressive loading. Since the elastomeric concrete is not normally subjected to static loading, the combination of strength and resilience must be considered. The Brand D material was easily the most resilient of the materials tested. The Brand C

material showed the least recovery. The Brand A aggregate 1 and Brand D aggregate 1 showed signs of separation from the binder after loading. It must be noted that the specimens were subjected to an equal deformation, not an equal load. This provides information about rigidity as well as ability to recover from deformation. The compression testing results indicate that Brand C is the least acceptable material. The Brand A1 material has such low strength that it may undergo excessive deformation.

TABLE X

Properties of Compression Specimens

Material	Weight Ratio Aggregate to Binder	Strain at Ultimate Strength	Stress at 5% Strain
Brand A1	1.9	0.17	950
Brand A2	3.4	0.10	1400
Brand B	5.0	0.14	1500
Brand C	3.8	0.11	2300
Brand D1	1.4	-	300
Brand D2	3.7	-	840

The bond strength tests were reproducible in terms of the type of failure, but showed a wide range of values for the strength of both the bond and the concrete. Brands A, B, and C had stronger bonds than the tensile strength of concrete and failure was totally, or primarily, in the concrete. The geometry of the specimens was such that the minimum cross-sectional area coincided with the bond. It was, therefore, unlikely for failure to be completely within the concrete. The Brand D specimens failed cleanly in adhesion with a considerably lower strength than that of the other materials. The effects of water, as shown by the Wet Bond Strength to Concrete test, were pronounced for Brands A and D. The Brand C bond strength remained stronger than the concrete strength, which decreased to about 400 psi from 500 psi. The Brand B material failed at the bond, but maintained a bond strength of 300 psi. These

results indicate the possibility of the Brands A and C materials losing their bond to the roadway.

The test results were reviewed with the purpose of determining the relative performance of the elastomeric concretes. The Brand A material had a low wet bond strength, relatively low tear resistance, low elongation at tear, high water absorption, and low ultimate elongation. The tensile stress-strain curve shows appreciable hardening due to aging. This material can be characterized as one with relatively little flexibility, poor bond characteristics, and good elasticity. Brand B showed no weaknesses, having excellent flexibility and bonding properties and good elasticity. The major attribute of Brand B was its ability to resist hardening with aging, as seen in the very small changes in the properties after aging. The Brand C material had poor elongation at tear, particularly after aging, poor impact strength, poor ultimate elongation after aging, low resilience, and rigidity as shown by the tensile and compressive stress-strain curves. The brittleness of this material is best shown by its low ultimate elongation after aging which made it impractical to obtain a stress-strain curve. Brand C did show excellent bonding properties to concrete and steel. However, the material had poor flexibility and elasticity and was susceptible to hardening with aging. The Brand D material possessed the best flexibility and elasticity of any of the materials. However, the bonding properties were poor and the preparation of the finished elastomeric concrete was difficult. Even after hardening due to aging, the material possessed excellent flexibility.

Selection of test methods to be used to establish specification requirements was based on the relative importance of the properties determined. It was decided that the most important properties were flexibility, elasticity, and bond strength along with a general characterization of the compressive and tensile behavior. These properties should be retained after aging, also. The flexibility is shown by the ultimate elongation and the tensile and compressive stress-strain curves.

The impact strength and resilience tests indicate the degree of elasticity. Bond strength is shown by the tensile shear strength test as well as the wet and dry concrete bonding tests. The tear resistance test can be used to define the binder as a material with tenacity.

The objective behind setting requirements for the above tests was to eliminate poor performance in the tests reflective of the critical properties. Three of the materials showed poor performance in at least one of these tests and were considered undesirable for use. A specification was prepared for use with elastomeric concretes and may be found in Appendix 2. The Brand B material complies with the requirements of this specification. This specification has no requirements for the other materials used in expansion joint construction. Appendix 3 gives a comparison of the proposed requirements to the test results for those properties. This specification stipulates that there shall be no heat curing of the elastomeric concrete after preparation of the specimens. Due to the length of ambient cure (one week), it was thought that the heat curing would have little effect on the test results. Some of the tests were performed on the Brands B and C materials without heat curing in order to check this. Typical results are shown in Table XI. All other data shown in this report are for the heat-cured specimens.

TABLE XI

Effect of Initial Heat Curing

Material	Test	Heat-Cured Results	Ambient-Cured Results
Brand B	Tensile Strength	950 psi	1050 psi
Brand B	Ultimate Elongation	150%	150%
Brand C	Tensile Strength	860 psi	800 psi
Brand C	Ultimate Elongation	88%	83%
Brand C	Compressive Strength	2900 psi	2750 psi

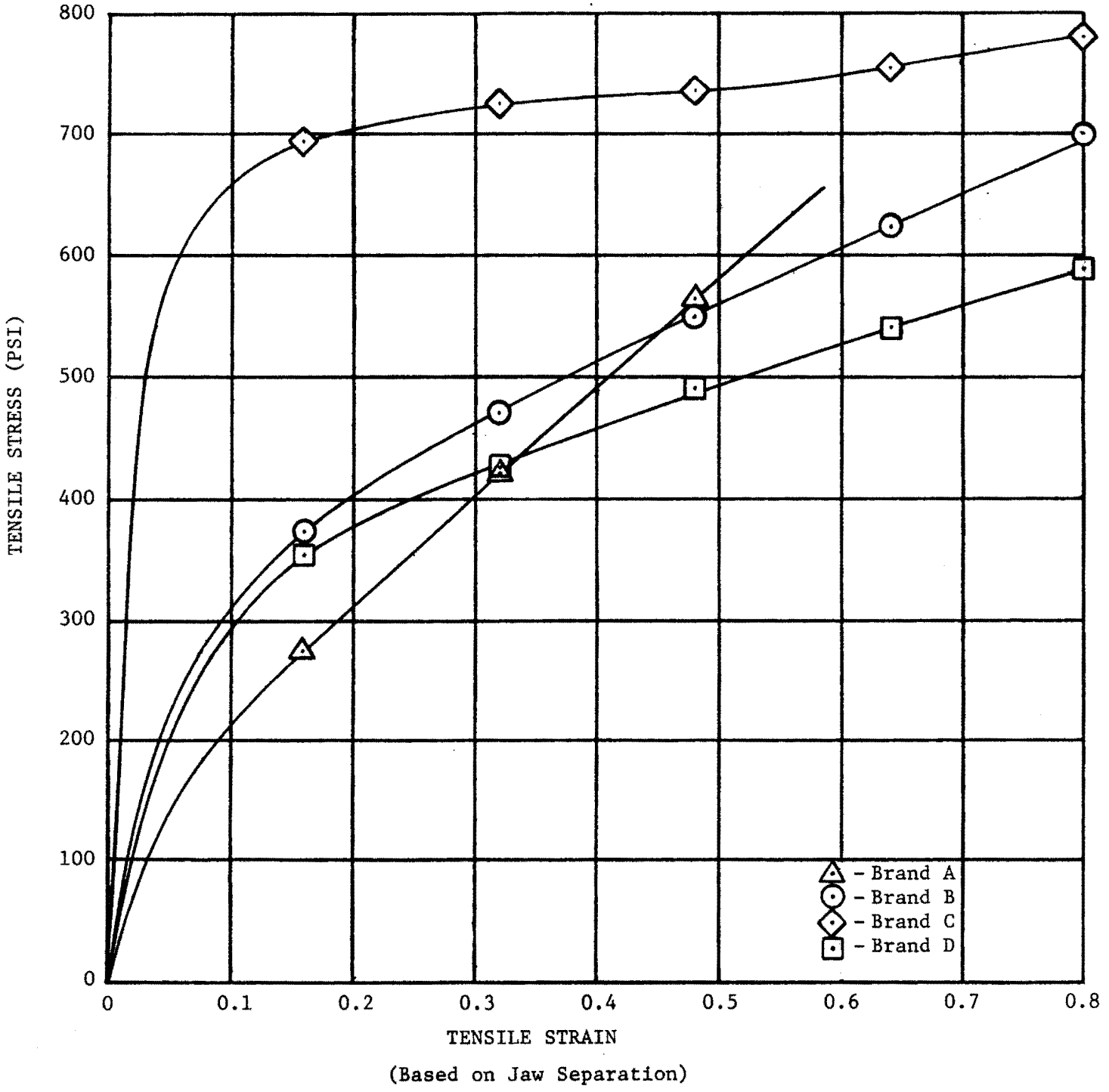
These are tests which showed a relatively wide range of results and the differences above reflect the typical variation in test results. Results for other tests, such as Water Absorption and Impact Strength, showed no change. This agreement of results has lead to the conclusion that there is no significant difference in the heat-cured and non-heat-cured materials after a seven-day ambient cure.

APPENDIX 1

GRAPH 1

BINDER TENSILE STRESS-STRAIN DIAGRAM

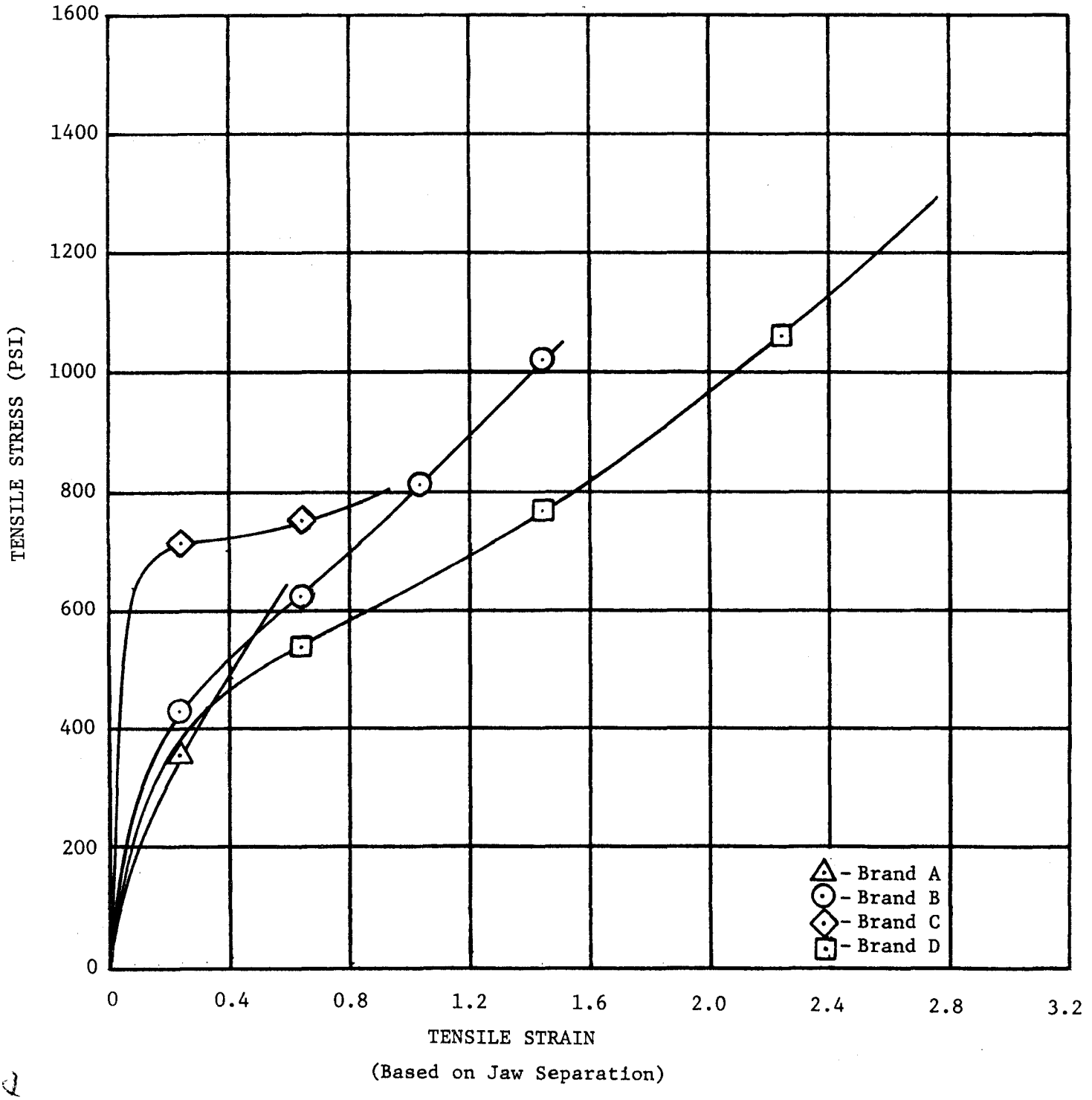
SEVEN-DAY CURE



GRAPH 2

BINDER TENSILE STRESS-STRAIN DIAGRAM

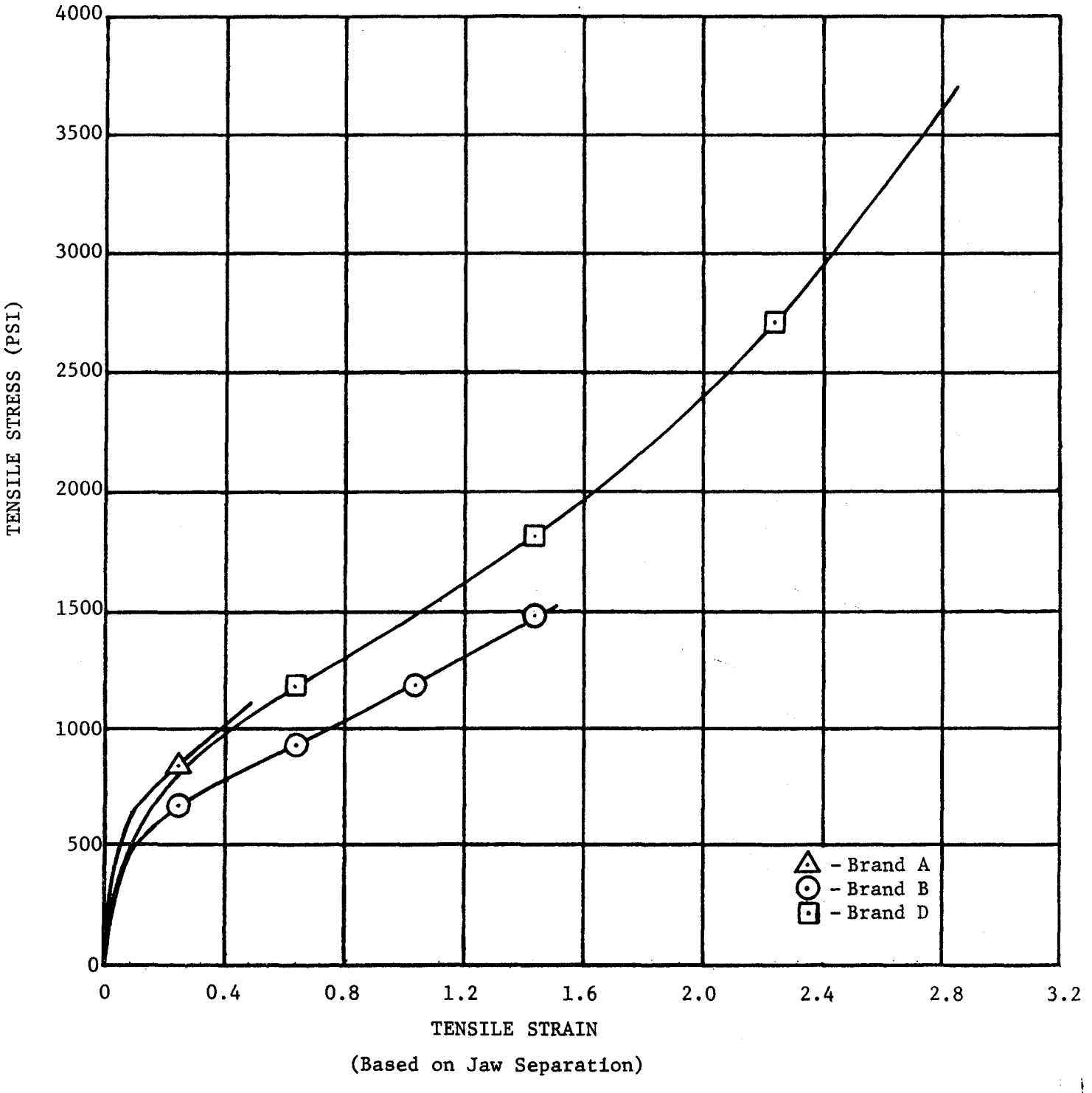
SEVEN-DAY CURE



GRAPH 3

BINDER TENSILE STRESS-STRAIN DIAGRAM

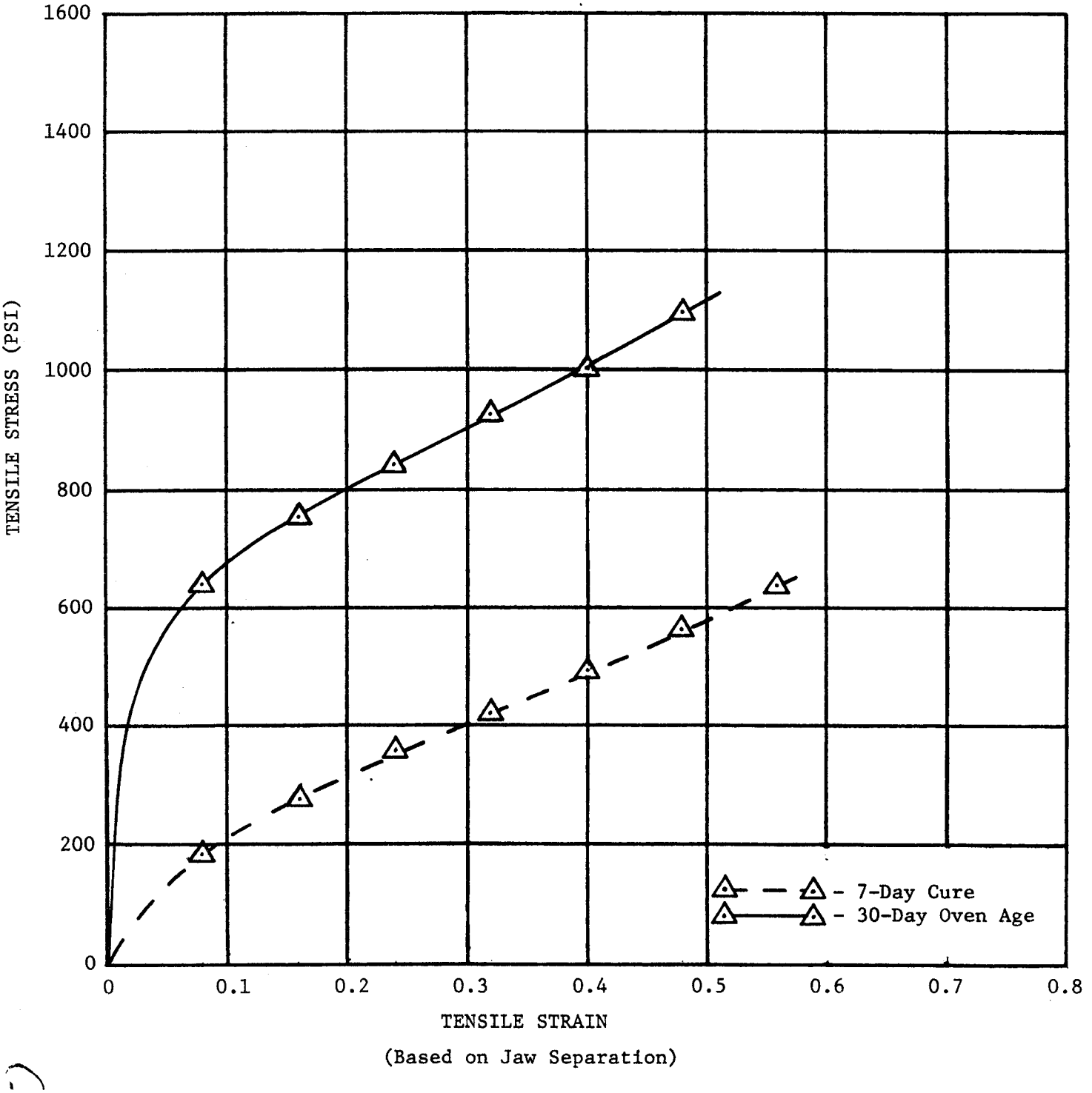
OVEN-AGED MATERIAL



GRAPH 4

BINDER TENSILE STRESS-STRAIN DIAGRAM

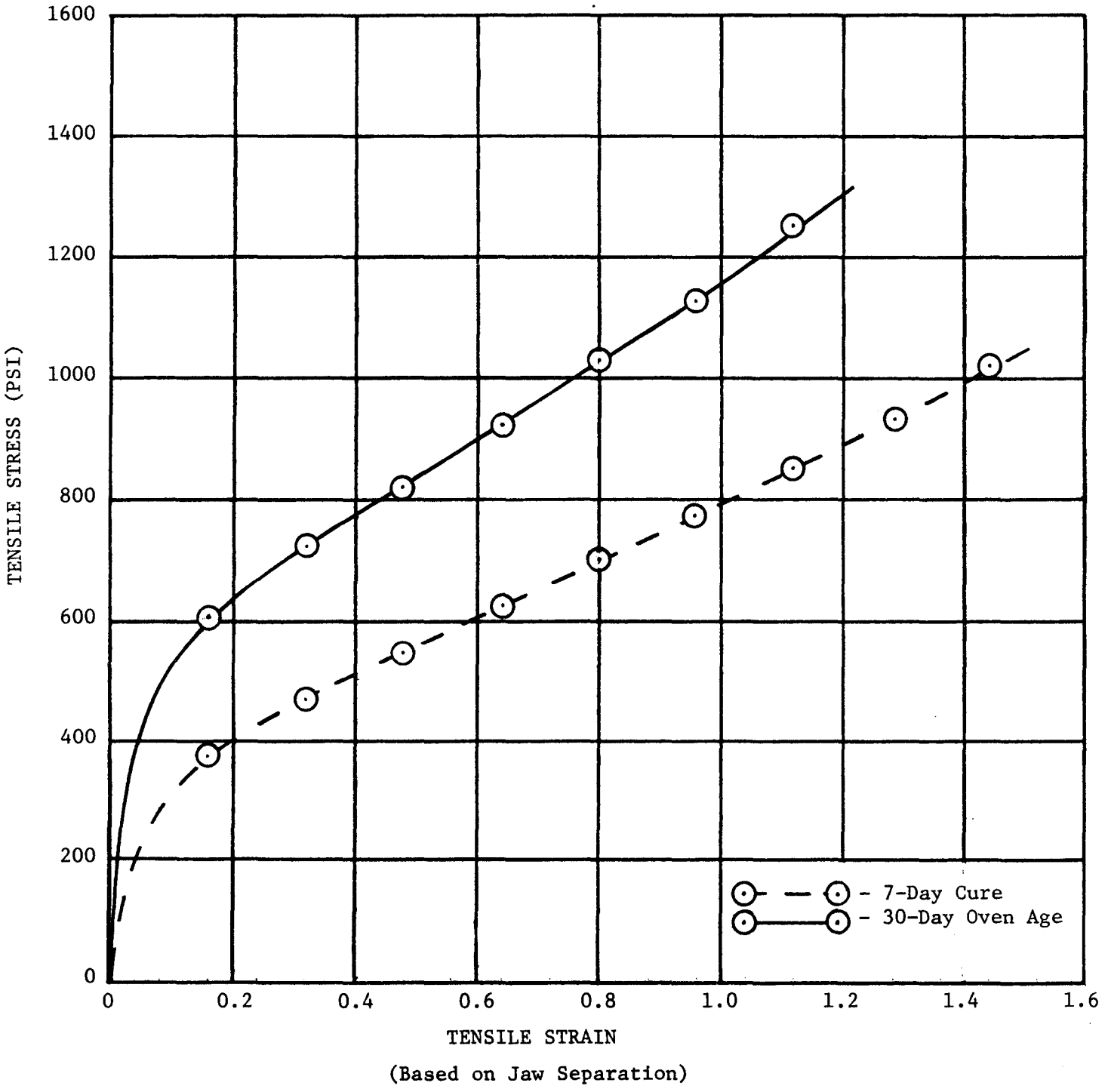
BRAND A MATERIAL



GRAPH 5

BINDER TENSILE STRESS-STRAIN DIAGRAM

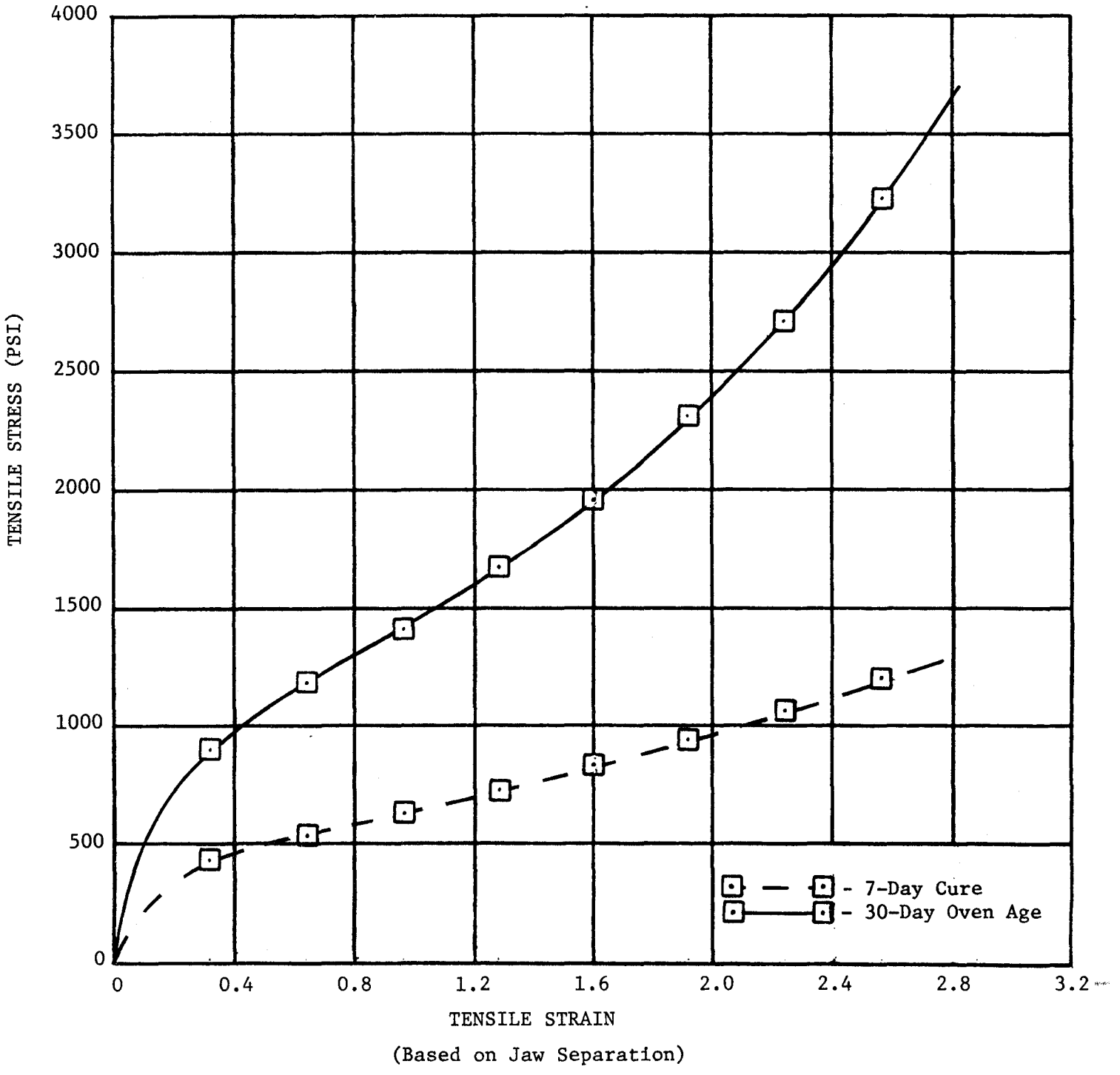
BRAND B MATERIAL



GRAPH 6

BINDER TENSILE STRESS-STRAIN DIAGRAM

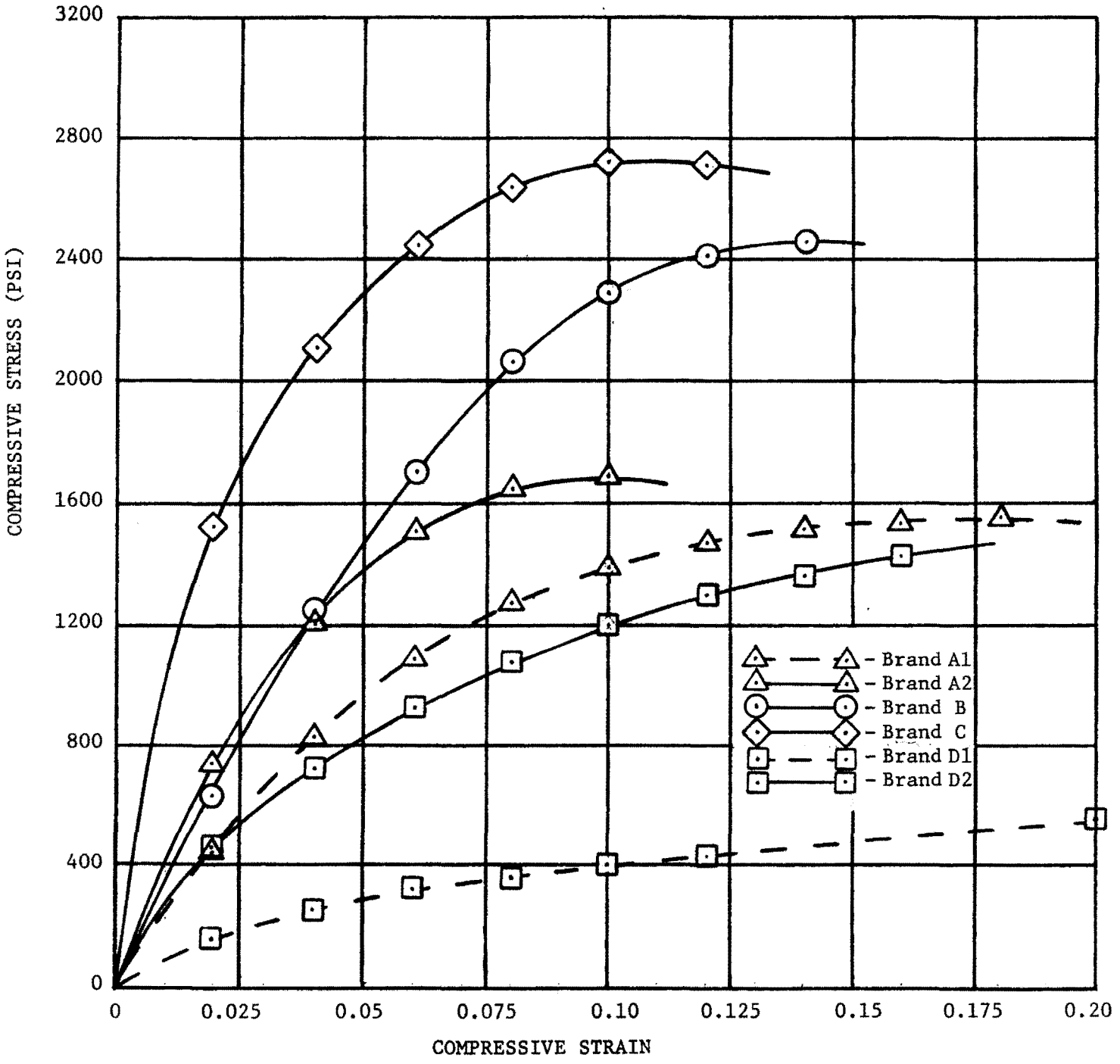
BRAND D MATERIAL



GRAPH 7

ELASTOMERIC CONCRETE COMPRESSIVE STRESS-STRAIN DIAGRAM

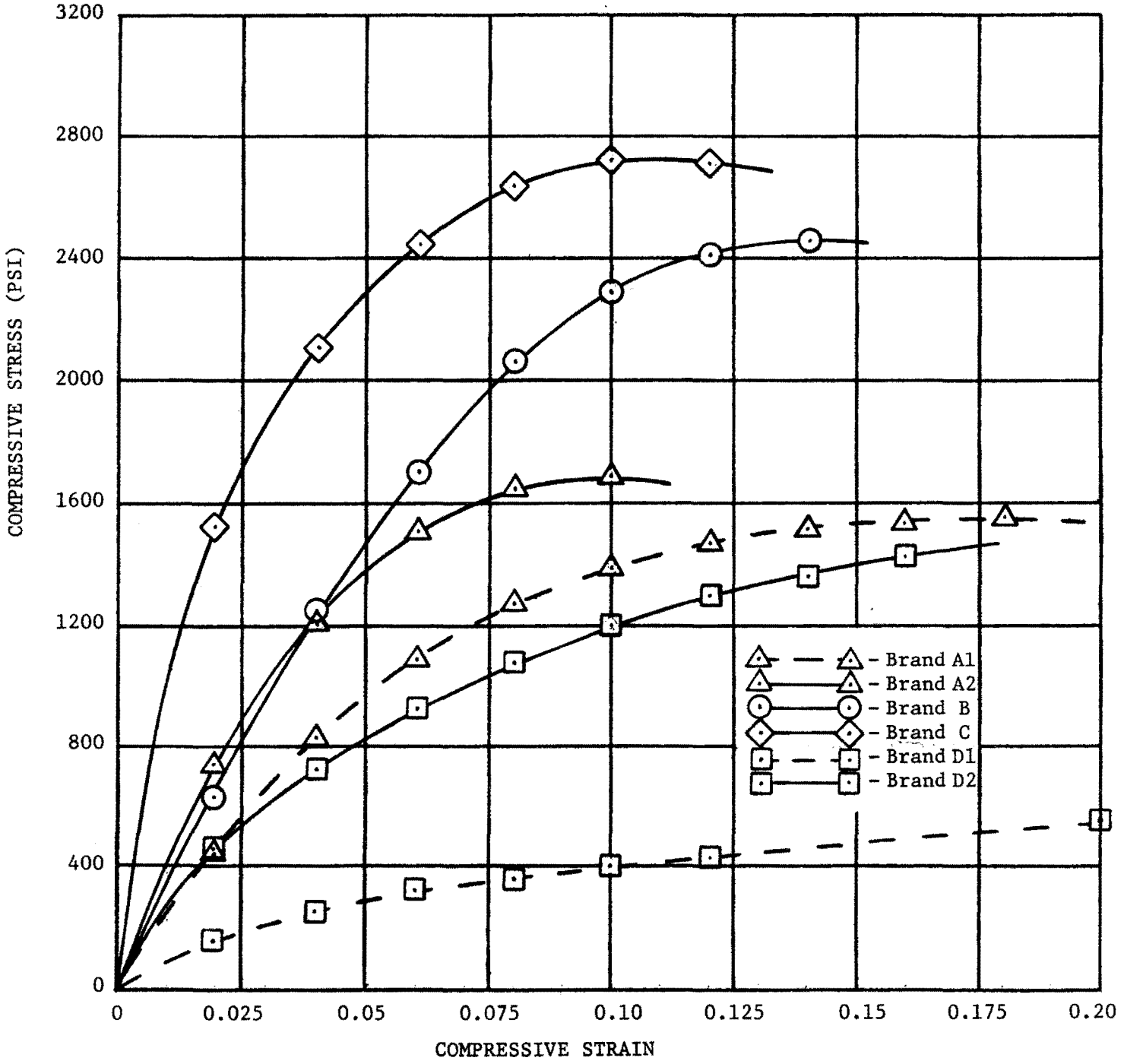
SEVEN-DAY CURE



GRAPH 7

ELASTOMERIC CONCRETE COMPRESSIVE STRESS-STRAIN DIAGRAM

SEVEN-DAY CURE



APPENDIX 2

Suggested Specification for Elastomeric Concrete

Elastomeric Concrete. The elastomeric concrete shall consist of resin and hardener components which, when mixed, comprise the binder portion, and aggregate, which may include powdered filler material, according to the recommendations of the manufacturer. The freshly-mixed elastomeric concrete shall be of a consistency and have sufficient working life at the recommended application temperature that it can be placed without flow problems and will satisfactorily wet the concrete and steel surfaces.

A. Physical Requirements. The binder and binder-aggregate system shall meet the following requirements when prepared and tested using the specified methods. Binder and aggregate components are to be heated to the manufacturer's suggested temperatures before mixing, but no heat is to be applied to the material after mixing. Test specimens are to be cured at 23 ± 2°C and 50 ± 10 percent relative humidity for seven days prior to testing unless they are to be oven aged. Oven aging specimens are to be maintained at 140 ± 4°F for thirty days prior to testing.

Requirements for the binder after seven-day cure:

	Test	Method	Requirement Min	Max
1.	Brittleness by Impact (ft·lb)	As in Testing Requirements of this specification	7	-
2.	Tensile Strength (psi)	ASTM D 638-82a as modified by Testing Requirements of this specification	500	-
3.	Tensile Stress (psi)	ASTM D 638-82a as modified by Testing Requirements of this specification	-	500
4.	Ultimate Elongation (%)	ASTM D 638-82a as modified by Testing Requirements of this specification	50	-
5.	Tear Resistance (lb/in.)	ASTM D 624-81 as modified by Testing Requirements of this specification	80	-

Requirements for binder after thirty-day oven aging:

1.	Brittleness by Impact (ft·lb)	As in Testing Requirements of this specification	7	-
2.	Tensile Strength (psi)	ASTM D 638-82a as modified by Testing Requirements of this specification	500	-
3.	Tensile Stress (psi)	ASTM D 638-82a as modified by Testing Requirements of this specification	-	1000
4.	Ultimate Elongation (%)	ASTM D 638-82a as modified by Testing Requirements of this specification	50	-

Requirements for aggregate and filler:

The aggregate and filler materials used shall be those recommended by the binder manufacturer and shall be of a gradation such that all

material shall pass a five-eighths inch sieve and a minimum of 95 percent by weight of the aggregate-filler mixture shall pass a one-half inch sieve. The aggregate and filler materials shall be mixed with the binder using the mixing ratios and temperatures specified by the manufacturer.

Requirements for the complete binder-aggregate mixture after seven-day cure:

	Test	Method	Requirement Min	Max
1.	Wet Bond Strength to Concrete (psi)	As in Testing Requirements of this specification	200	-
2.	Compressive Stress (psi)	ASTM D 695-80 as modified by Testing Requirements of this specification	750	-
3.	Resilience (%)	As in Testing Requirements of this specification	75	-

B. Testing Requirements. The Brittleness by Impact specimen is a cast disk with a 2.50 ± 0.05 inch diameter and a 0.375 ± 0.005 inch thickness. The faces are sanded flat and parallel. The specimen is conditioned before each test impact to 32°F by immersion in ice water or other means. Conditioning between test impacts is for a minimum of five minutes. The specimen is removed from its low-temperature environment, dried and placed on a dry machined steel plate. Within ten seconds of removal, a one-pound steel ball is dropped onto the center of the specimen from an initial height of five feet. The drop height is increased in one-half foot intervals until the specimen fails by cracking. The average value determined from four test specimens shall be expressed in foot-pounds and reported as the result.

The Tensile Strength, Tensile Stress, and Ultimate Elongation tests are in accordance with ASTM D 638-82a using the Type IV specimen with dimension WO of one inch. This corresponds to Die C in ASTM D 412-80.

Thickness and width of the specimen are to be determined. Crosshead speed is two inches per minute. Elongation measurements are based on an initial testing machine jaw separation of two and one-half inches. Tensile Stress is measured at twenty percent (one-half inch) elongation. At least five specimens shall be loaded with the three above values determined for each specimen. Specimens with obvious flaws shall be discarded.

A minimum of four Die C specimens shall be chosen for the determination of Tear Resistance. An initial testing machine jaw separation of two and one-half inches and a crosshead speed of two inches per minute shall be used.

Mortar briquette halves shall be prepared for use in Wet Bond Strength to Concrete, as explained in Set Time of Test Method Tex-614-J. The elastomeric concrete is cast against a briquette half in the original briquette mold. After the seven-day cure, the specimens are immersed in 23 ± 2°C distilled or deionized water for seven days in a horizontal position, such that the entire bond surface is exposed to the water. After the period of immersion, the specimens are removed from the water and subjected to tensile loading with the Riechle briquette tester. A minimum of four specimens shall be tested and an average tensile breaking stress determined based on a one-inch cross-sectional area.

Three two-inch cast cubes shall be prepared for use with the Compressive Stress and Resilience tests. The specimens are prepared so as to have flat, parallel opposing faces without irregularities. Thickness of the specimen is measured at the center of opposing faces to within one-thousandth of an inch. Compressive stress is measured at five percent deflection (0.10 in.), at which point the load is removed. The specimen is allowed to recover for five minutes and the thickness is remeasured. Resilience is determined as percent recovery and is calculated as:

$$\% \text{ Recovery} = \frac{0.10 \text{ in.} + \text{Final Thickness} - \text{Initial Thickness}}{0.10 \text{ in.}}$$

C. Prequalification and Sampling Requirements. Each elastomeric concrete system must be prequalified prior to use on Department projects. To obtain prequalification, the manufacturer shall forward to the Materials and Tests Engineer, 38th and Jackson Streets, Austin, Texas 78703, samples of the material and certified results from testing for compliance with the requirements of this specification.

After an elastomeric concrete system has been approved by prequalification, samples shall be taken from material supplied to each project, submitted to the Materials and Tests Engineer, and tested for compliance with specification requirements. A minimum of one gallon total of the binder components shall be supplied with sufficient aggregate for this amount of binder.

Any change in the formulation of a prequalified elastomeric concrete system will cause the manufacturer to be subject to repeating the prequalification process.

D. Packaging Requirements. Reactive components shall be packaged in air-tight containers and protected from light and moisture. Aggregate and filler materials shall be packaged so as to be protected from moisture or other contamination.

E. Basis for Rejection. Materials failing to meet any requirement of this specification shall be subject to rejection.

APPENDIX 3

Comparison of Specification Requirements to Material Properties

Test	Requirements Min	Requirements Max	Brand A	Brand B	Brand C	Brand D
Impact Strength (ft·lb)						
Original Property	7	-	7+	7+	6	7+
Aged Material	7	-	7+	7+	5	7+
Tensile Strength (psi)						
Original Property	500	-	700	950	860	1450
Aged Material	500	-	1250	1300	1600	3700
Tensile Stress (psi)						
Original Property	-	500	315	400	700	380
Aged Material	-	1000	800	640	-	740
Ultimate Elongation (%)						
Original Property	50	-	55	150	90	280
Aged Material	50	-	50	120	14	290
Tear Resistance (lb/in.)	80	-	100	175	215	260
Wet Bond Strength (psi)	200	-	115	300	400	115
Compressive Stress (psi)	750	-	1400 950	1500	2300	840 300
Resilience (%)	75	-	90	84	69	96 95

APPENDIX 4

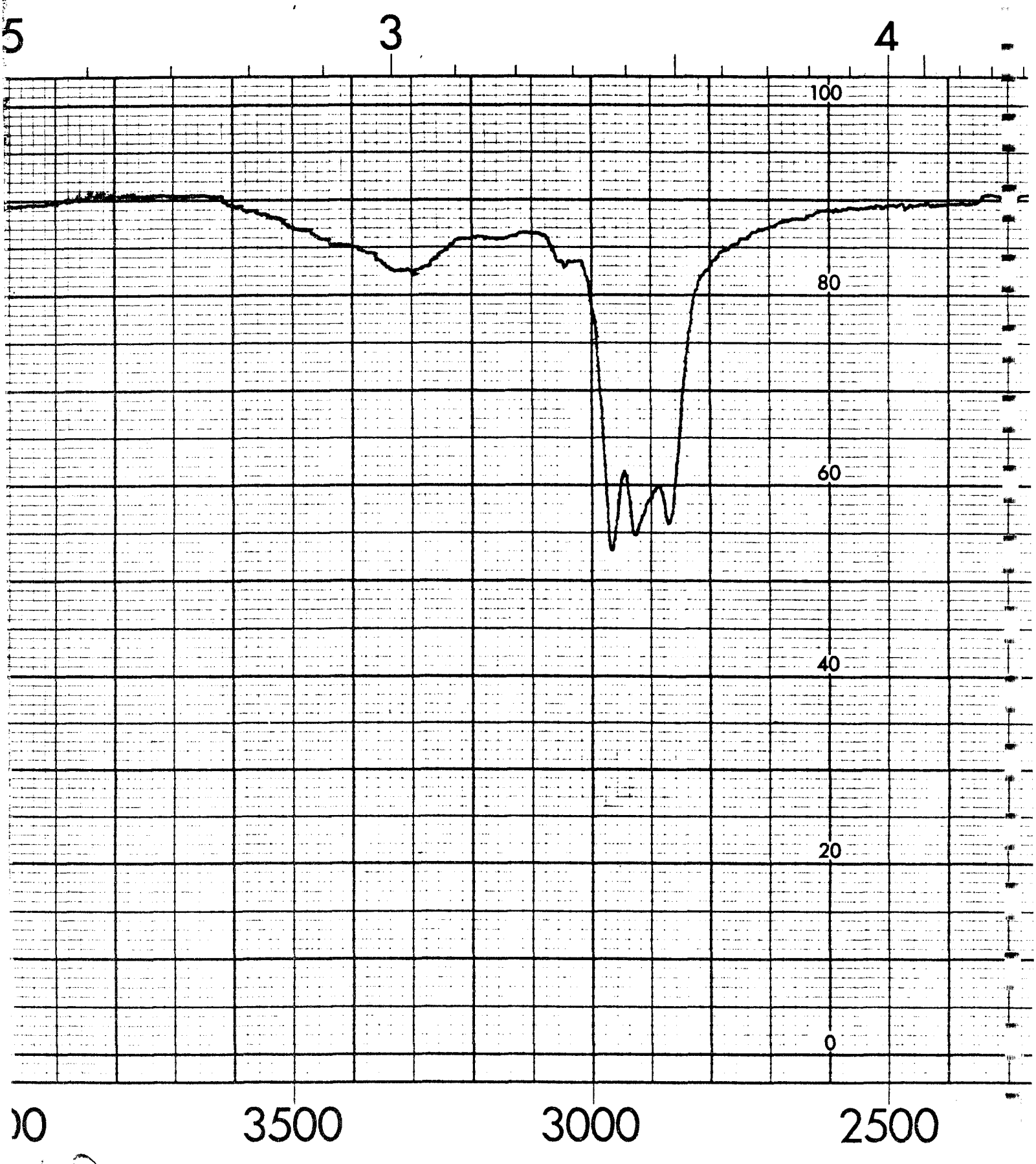
The following infrared spectra were obtained using a Perkin-Elmer Model 521 Grating Infrared Spectrophotometer. The instrument control settings used in all cases were as follows:

Slit Program	1000
Gain	4
Attenuator Speed	1100
Scan Time	10
Suppression	0
Scale Expansion	1X
Source Current	0.7 amp

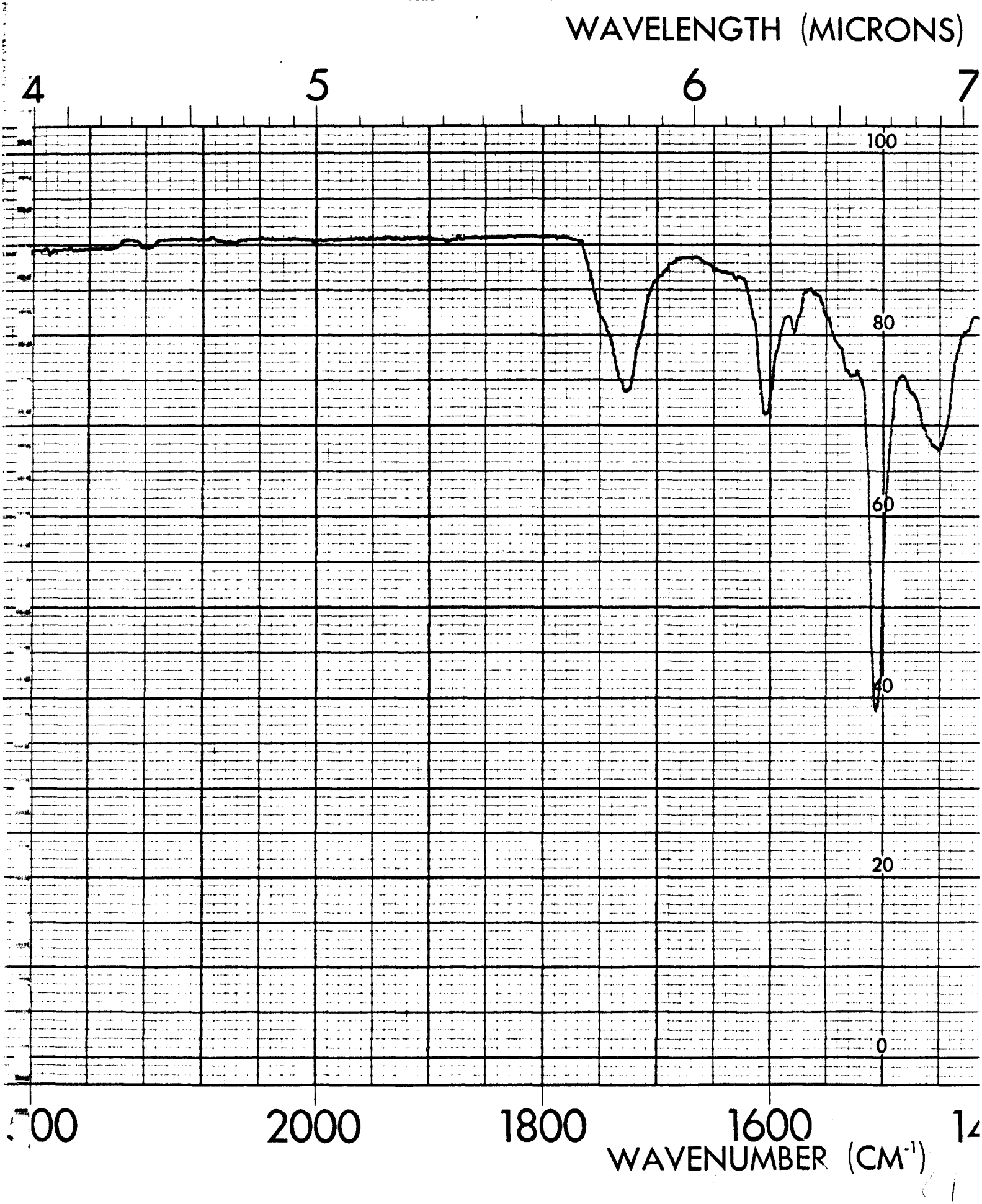
Samples were prepared with an uncontrolled thickness as either a cast film on a single plate or a film sandwiched between two plates. Brand A Part 1, Brand B Part 1, and Brand C Part 2 contained pigments which had to be removed before analysis could be accomplished. These components were thinned with toluene, centrifuged, and decanted in order to separate the pigment. After evaporating the toluene, the remaining material was analyzed. The plates used for analysis were as follows:

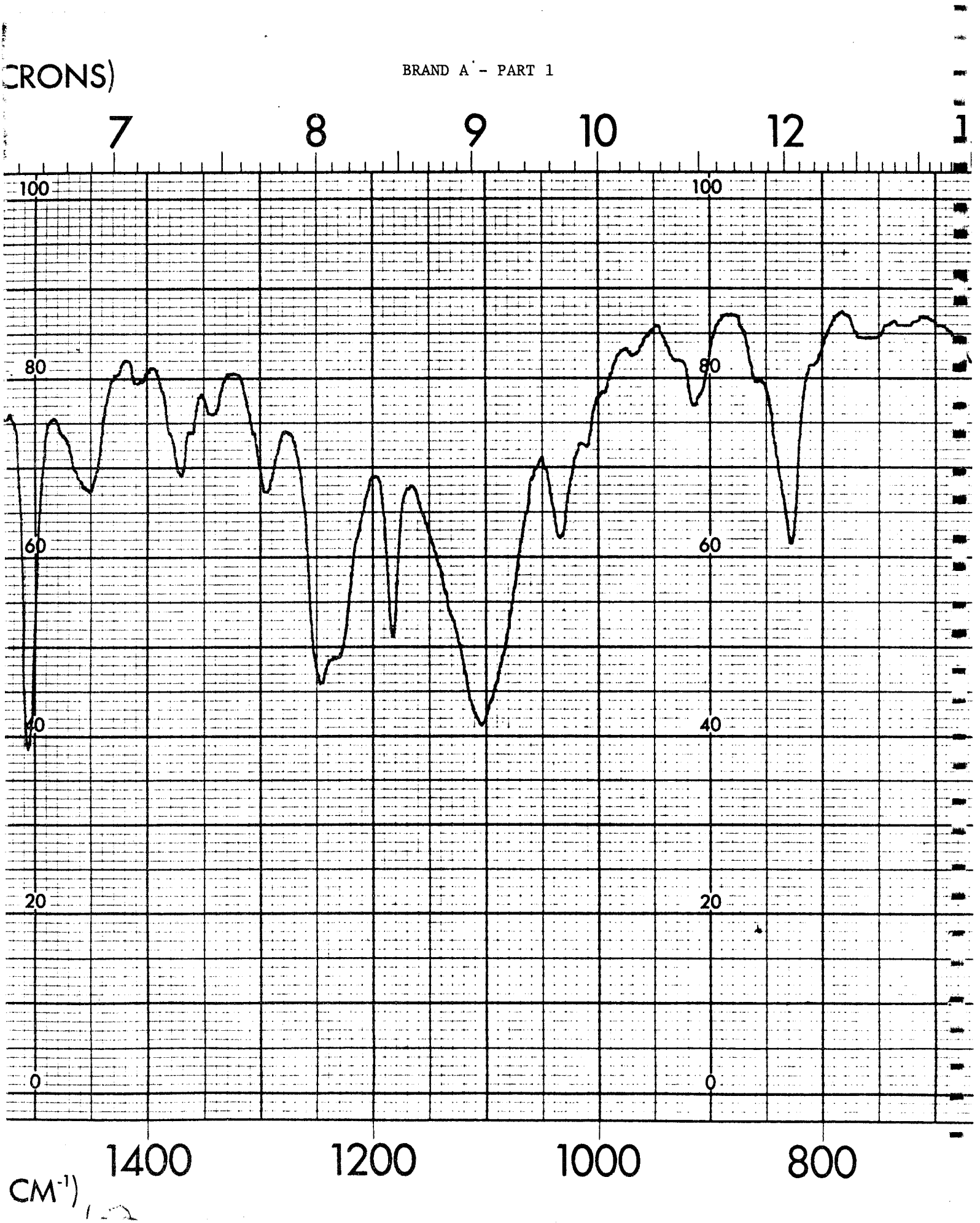
Brand A Part 1	NaCl plate
Brand A Part 2	NaCl plates
Brand B Part 1	NaCl plate
Brand B Part 2	NaCl plates
Brand C Part 1	NaCl plates
Brand C Part 2	NaCl plate
Brand D Part 1	NaCl plates
Brand D Part 2	KSR plate

BRAND A - PART 1

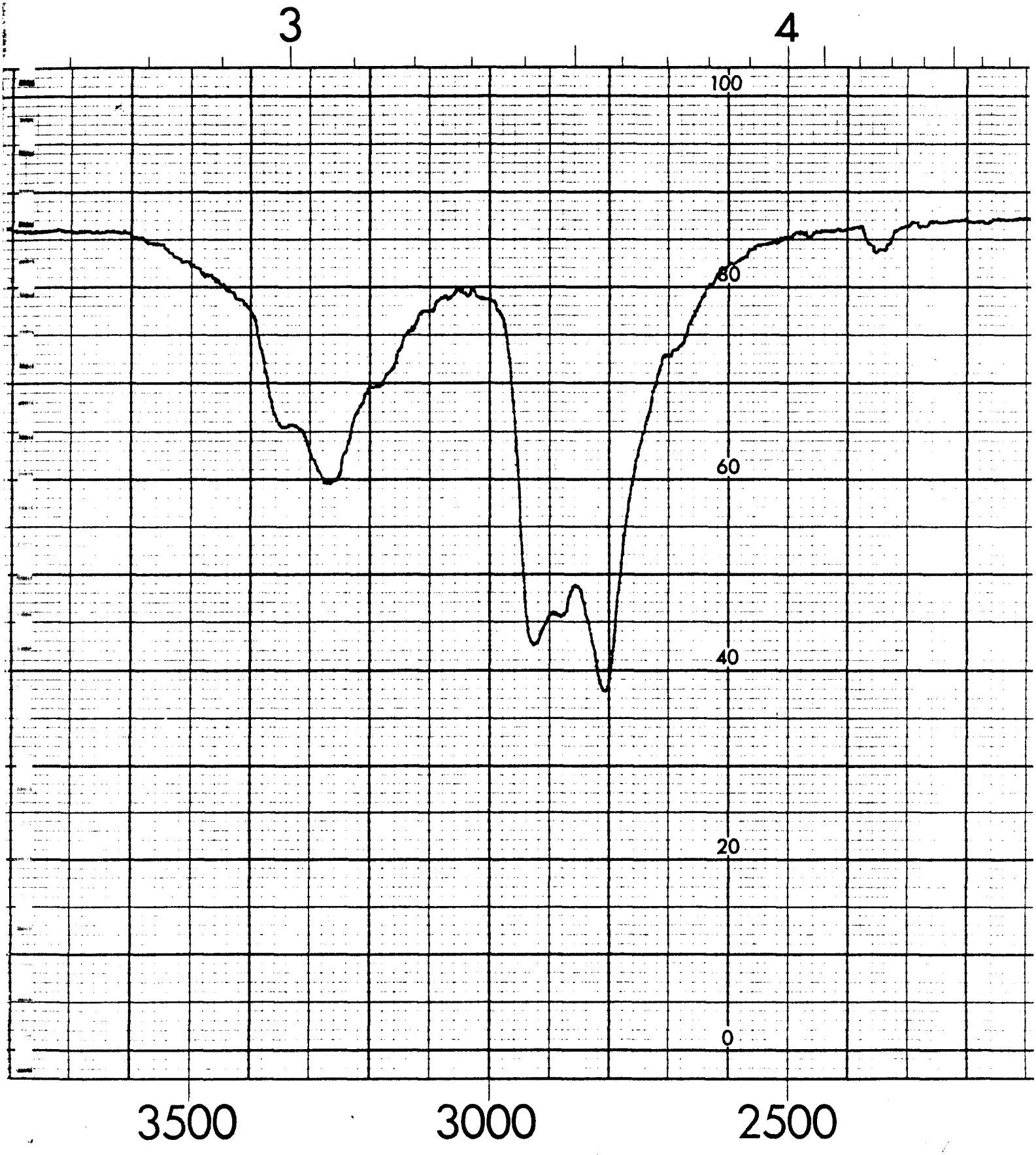


BRAND A - PART 1




CRONS)
BRAND A - PART 1
7
8
9
10
12
100
80
60
40
20
0
1400
1200
1000
800
CM-1)

BRAND A - PART 2



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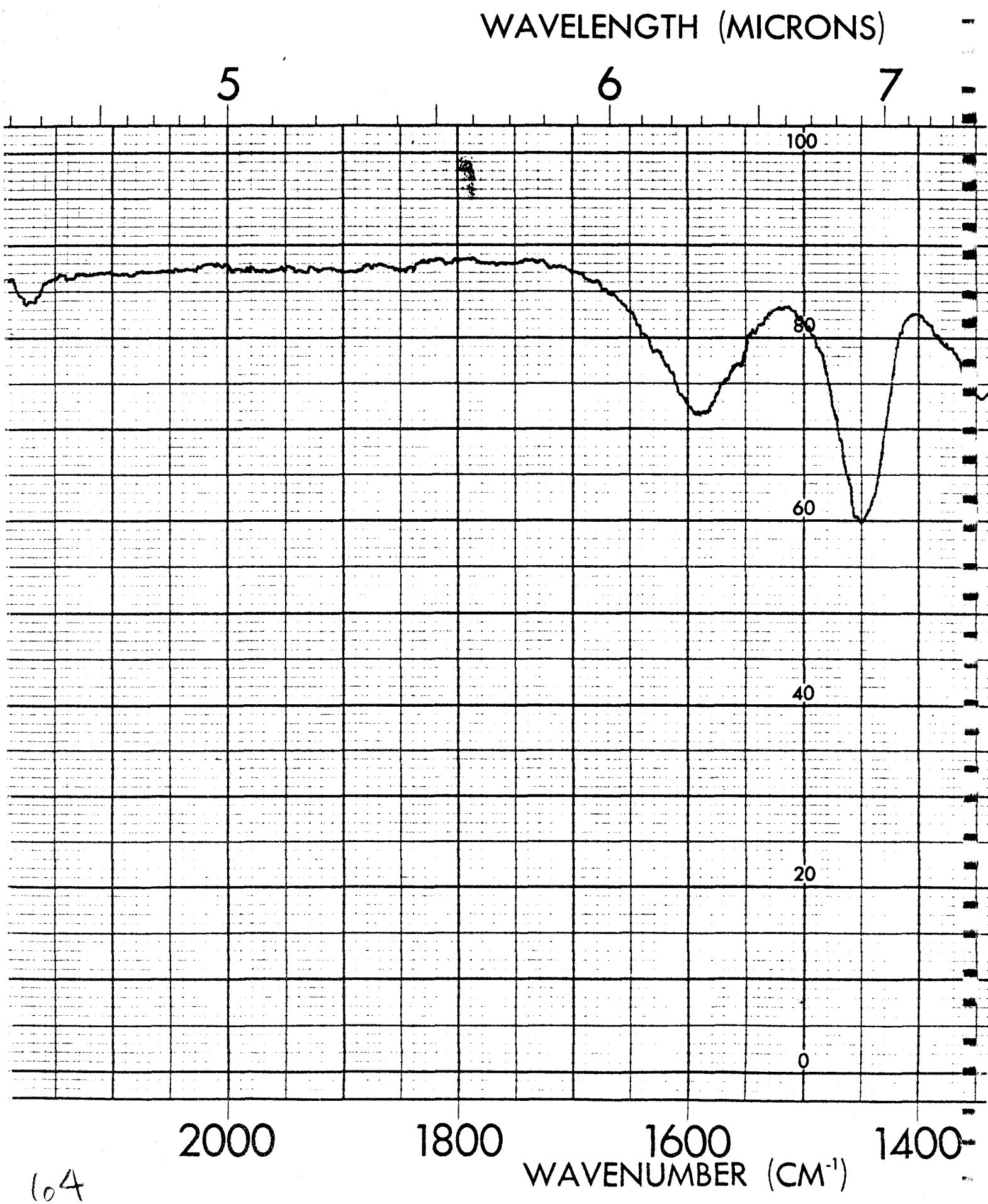

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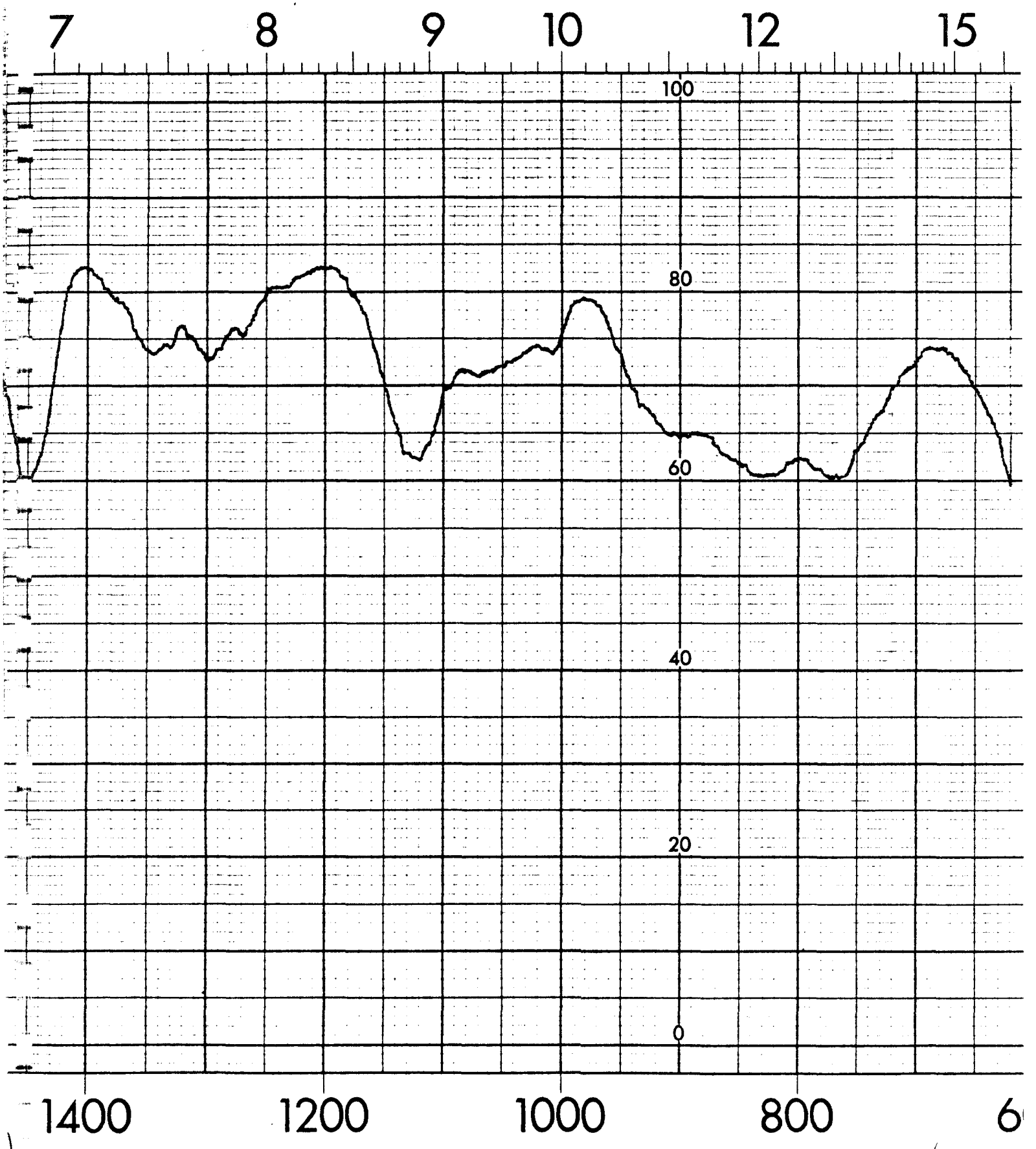

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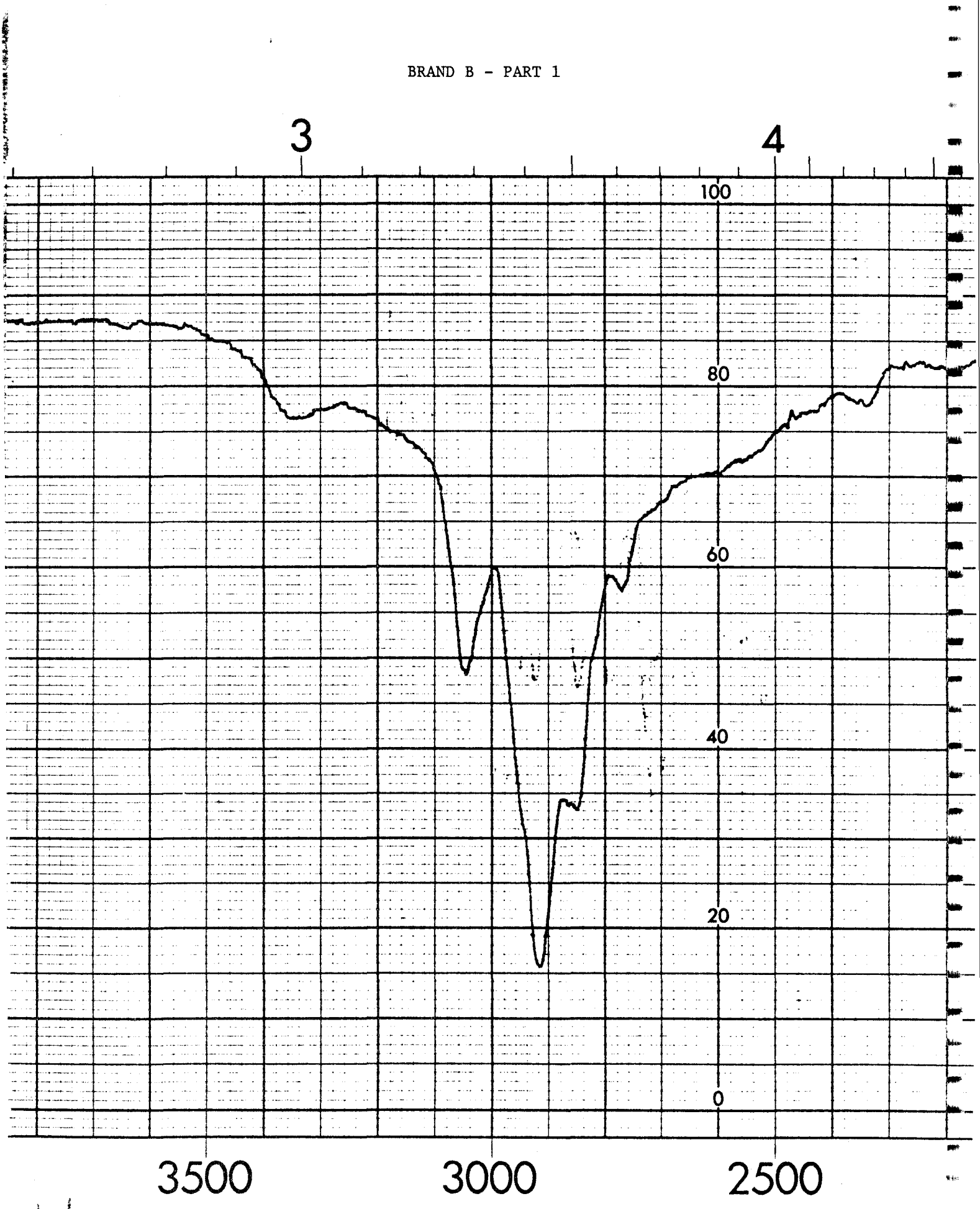

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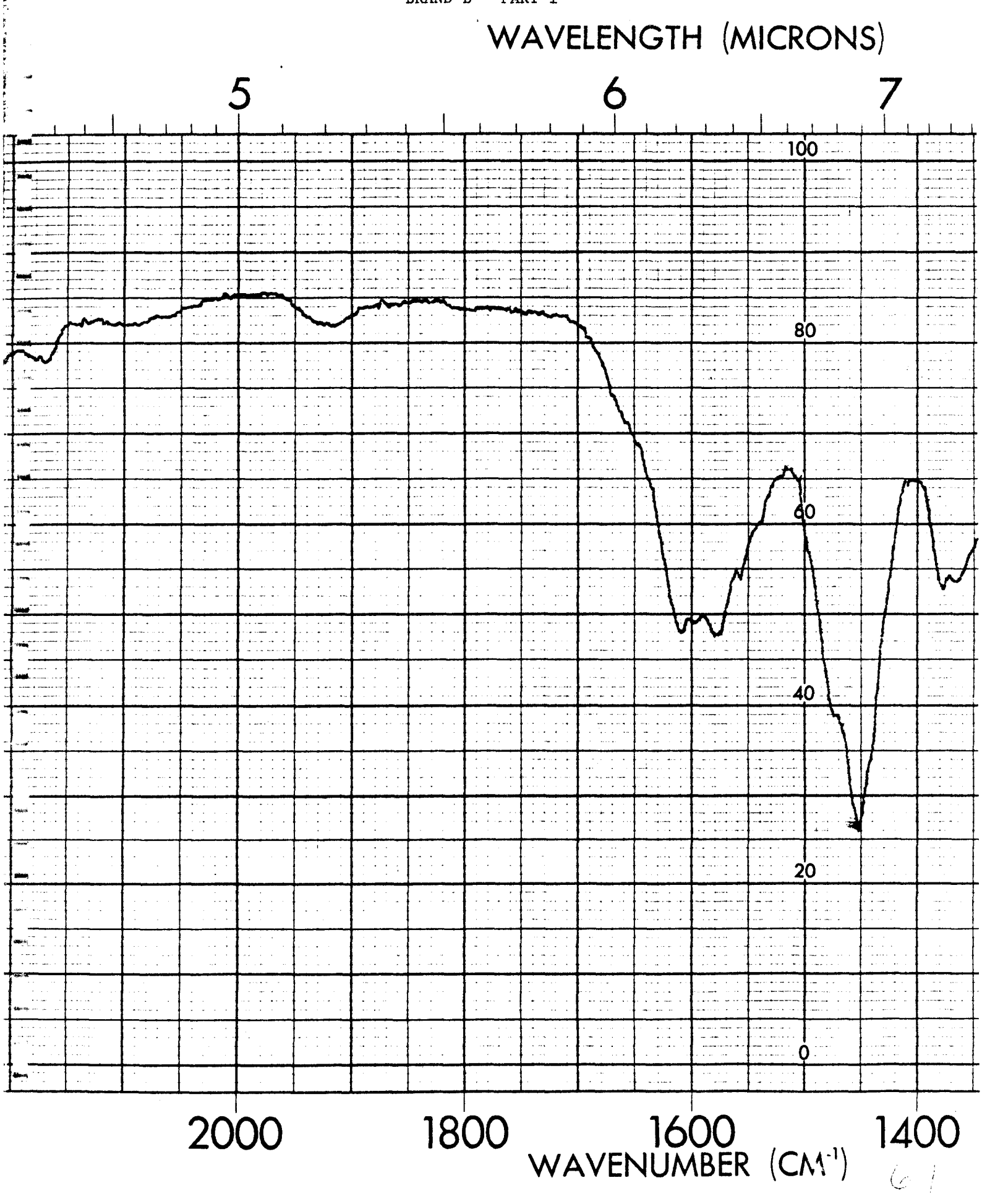

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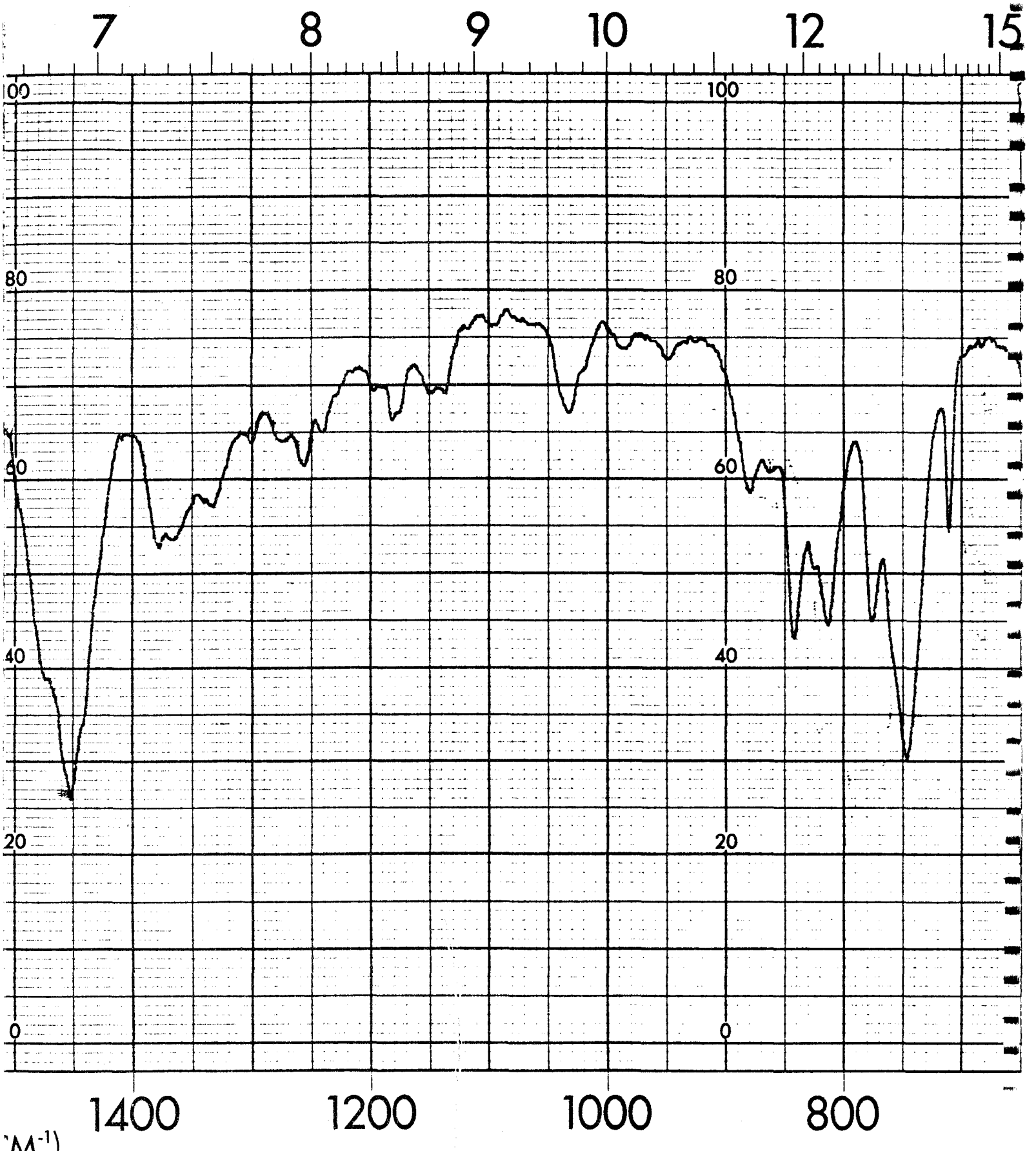

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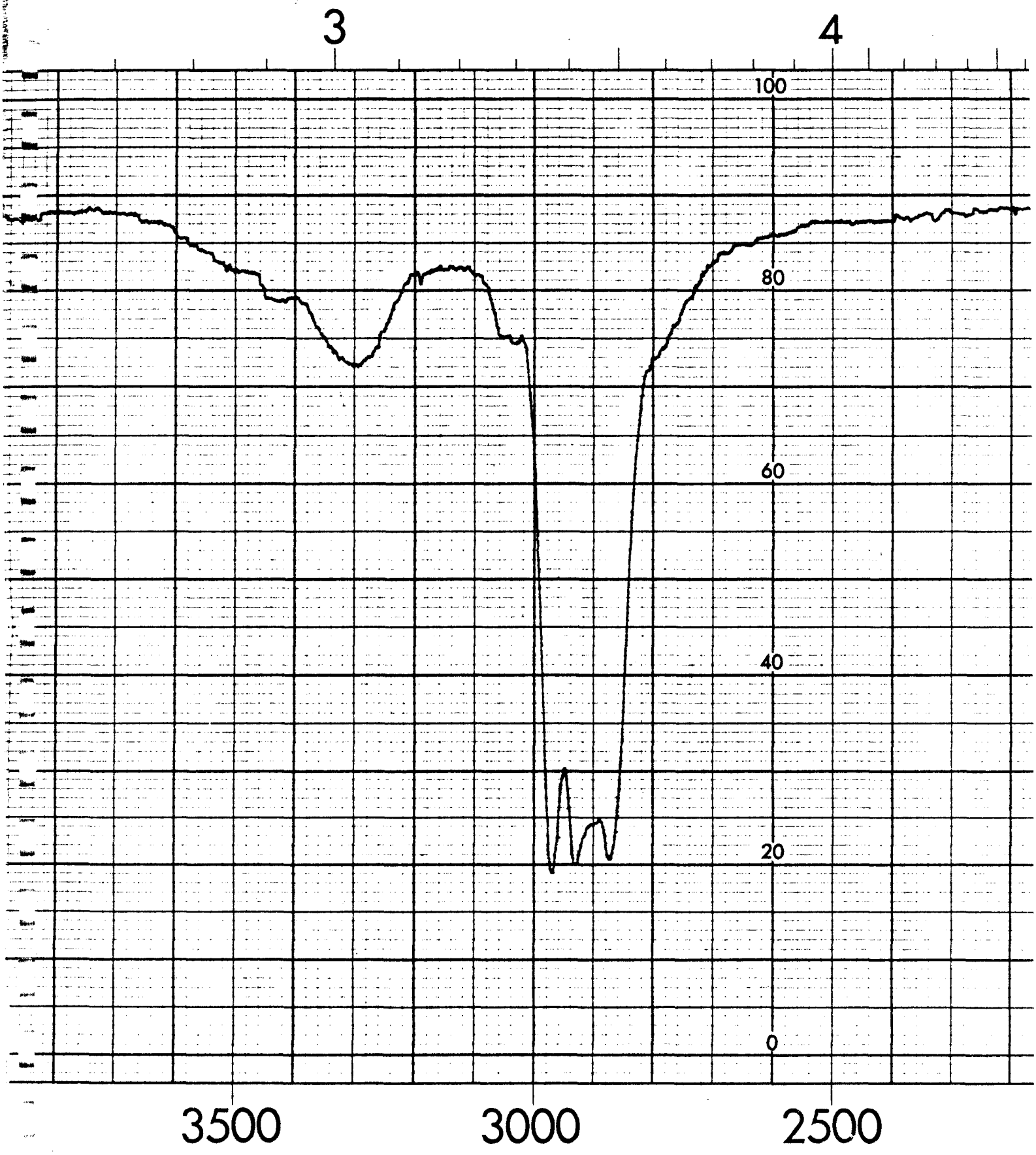

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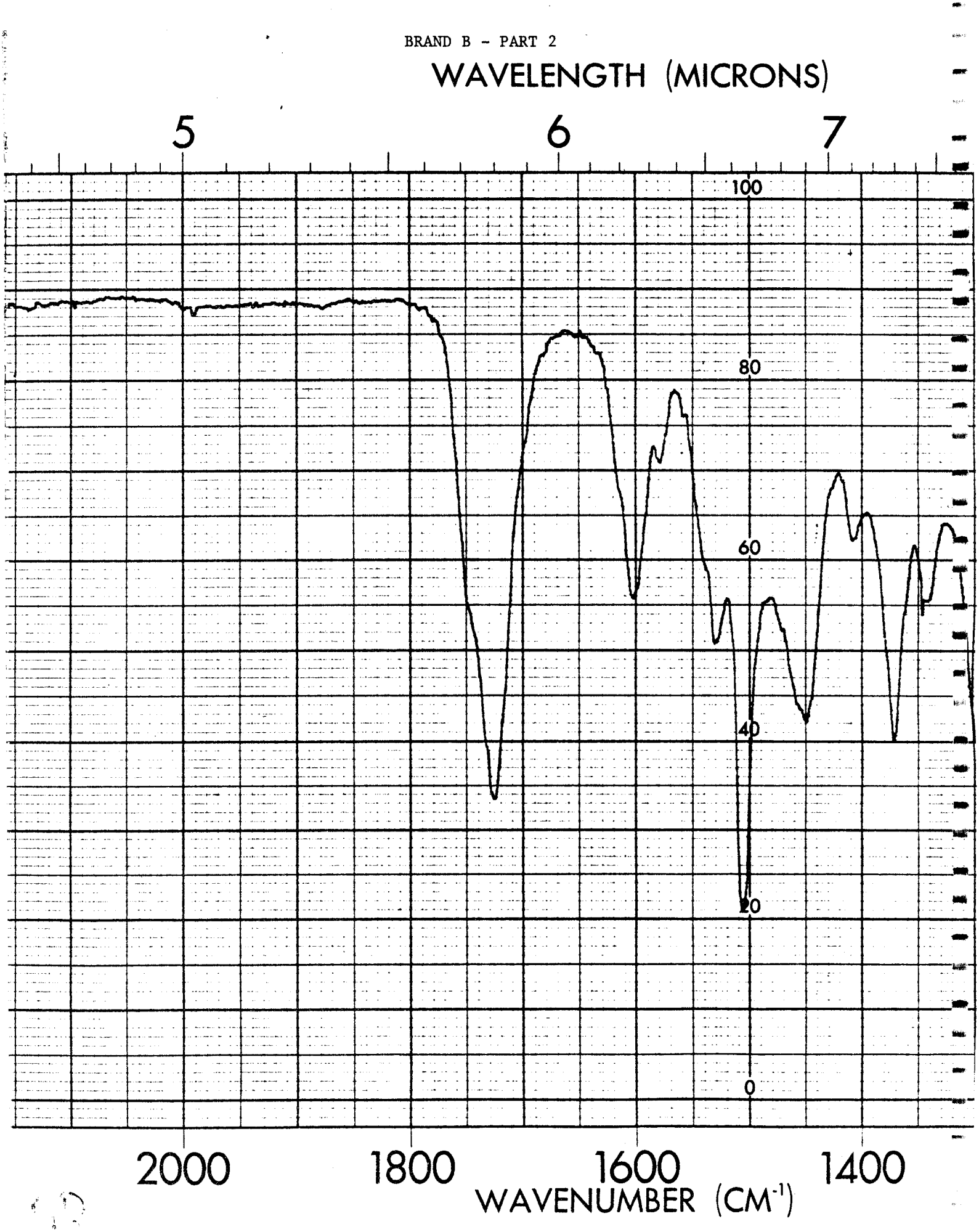

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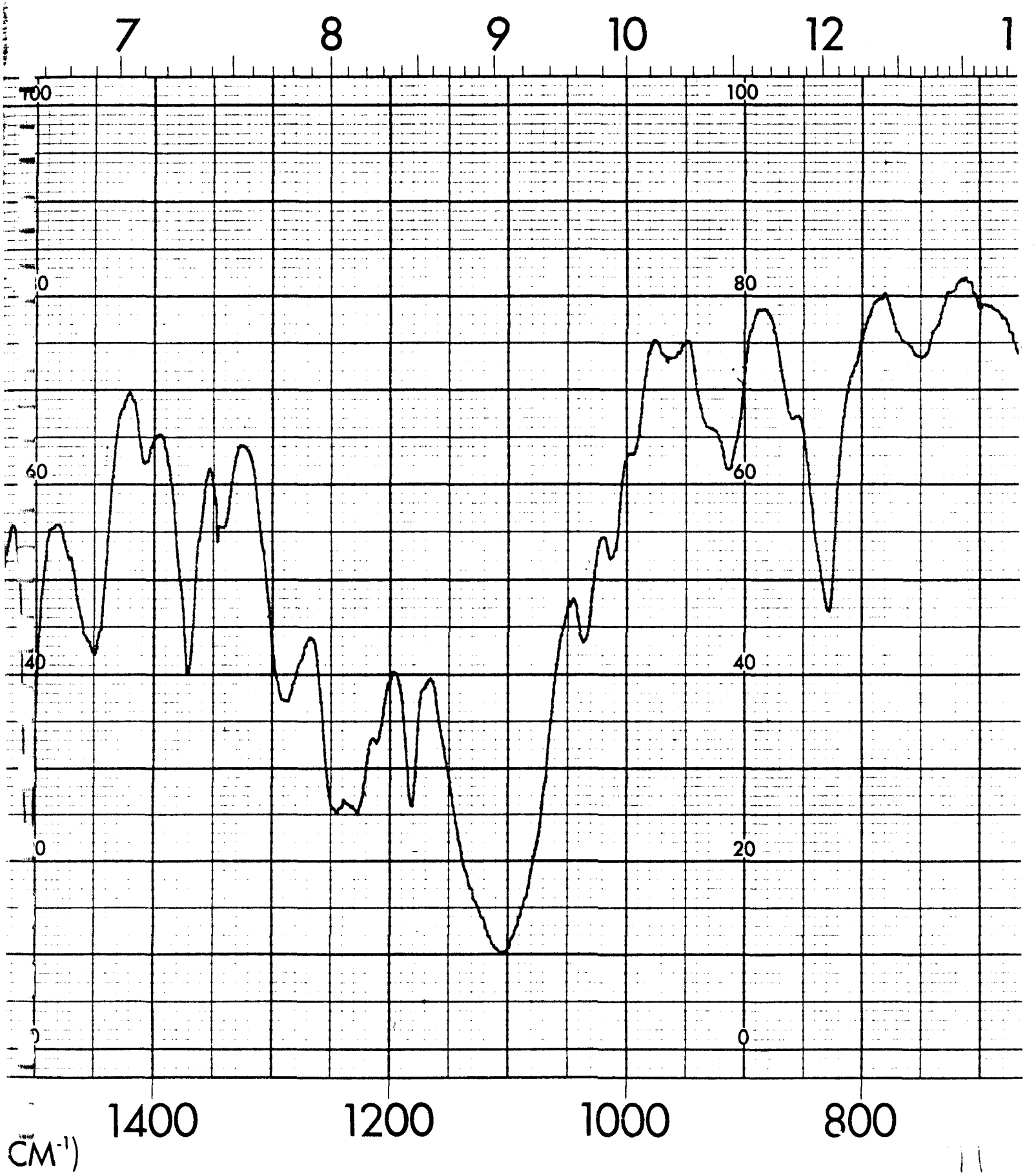

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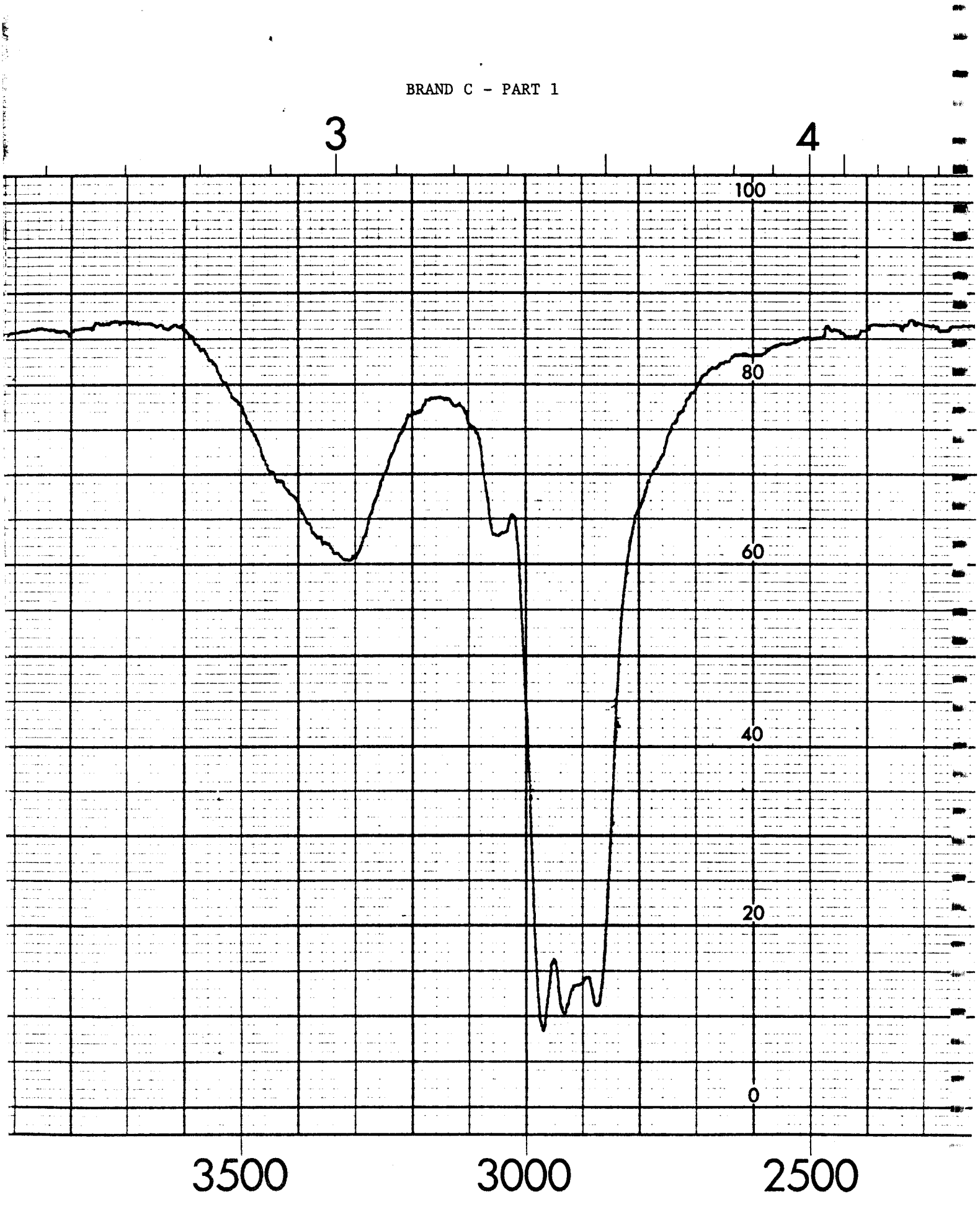

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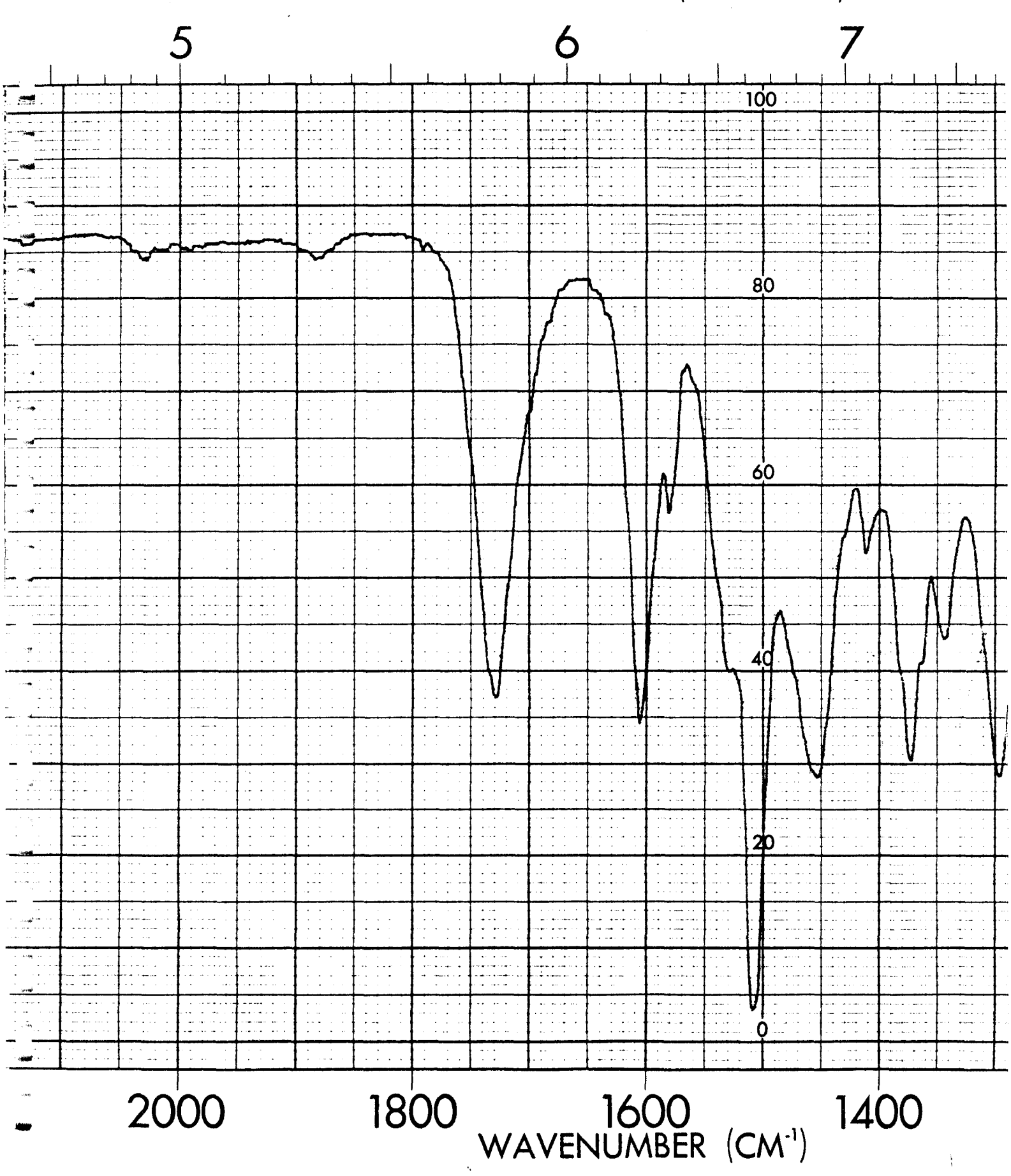

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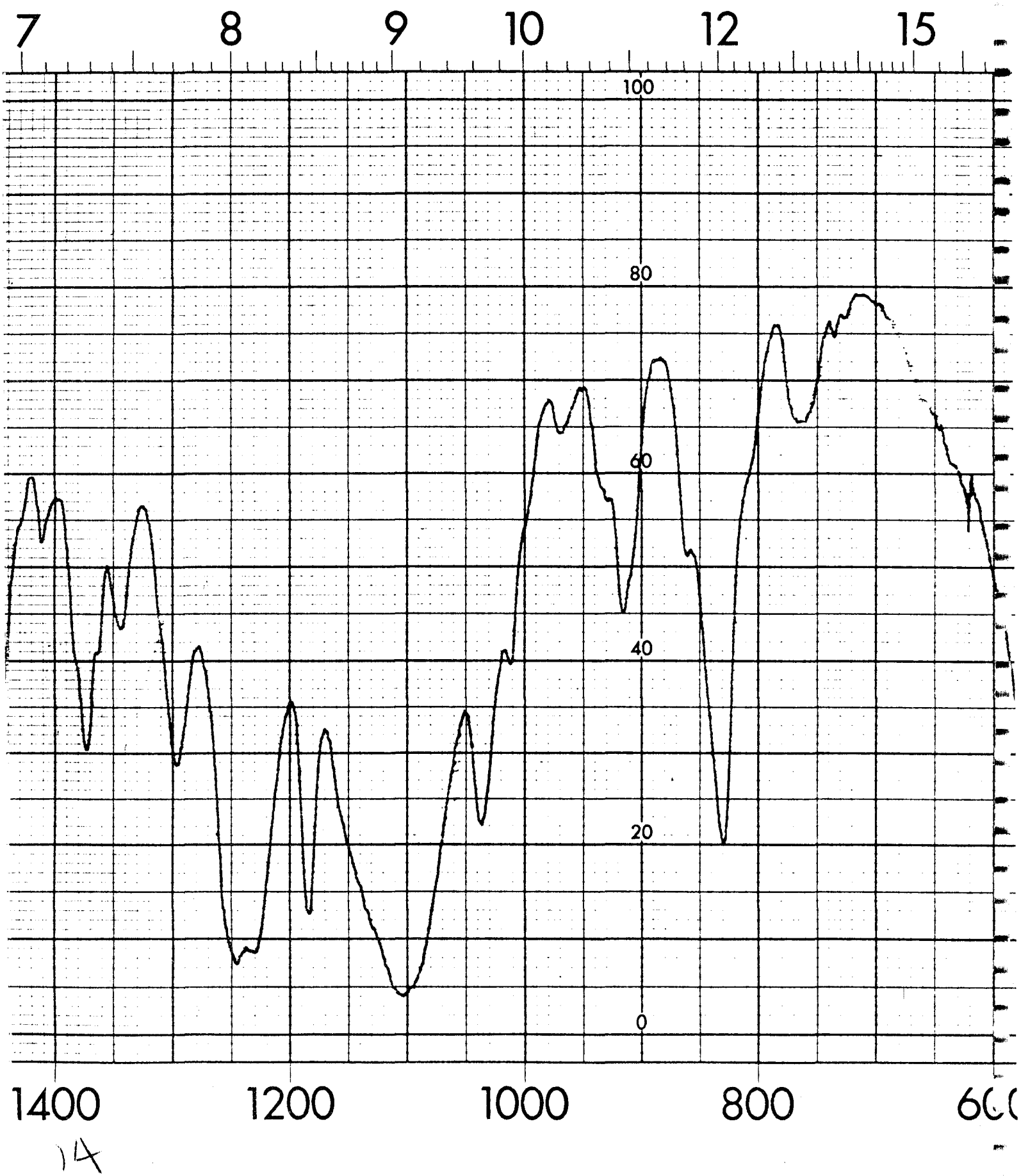

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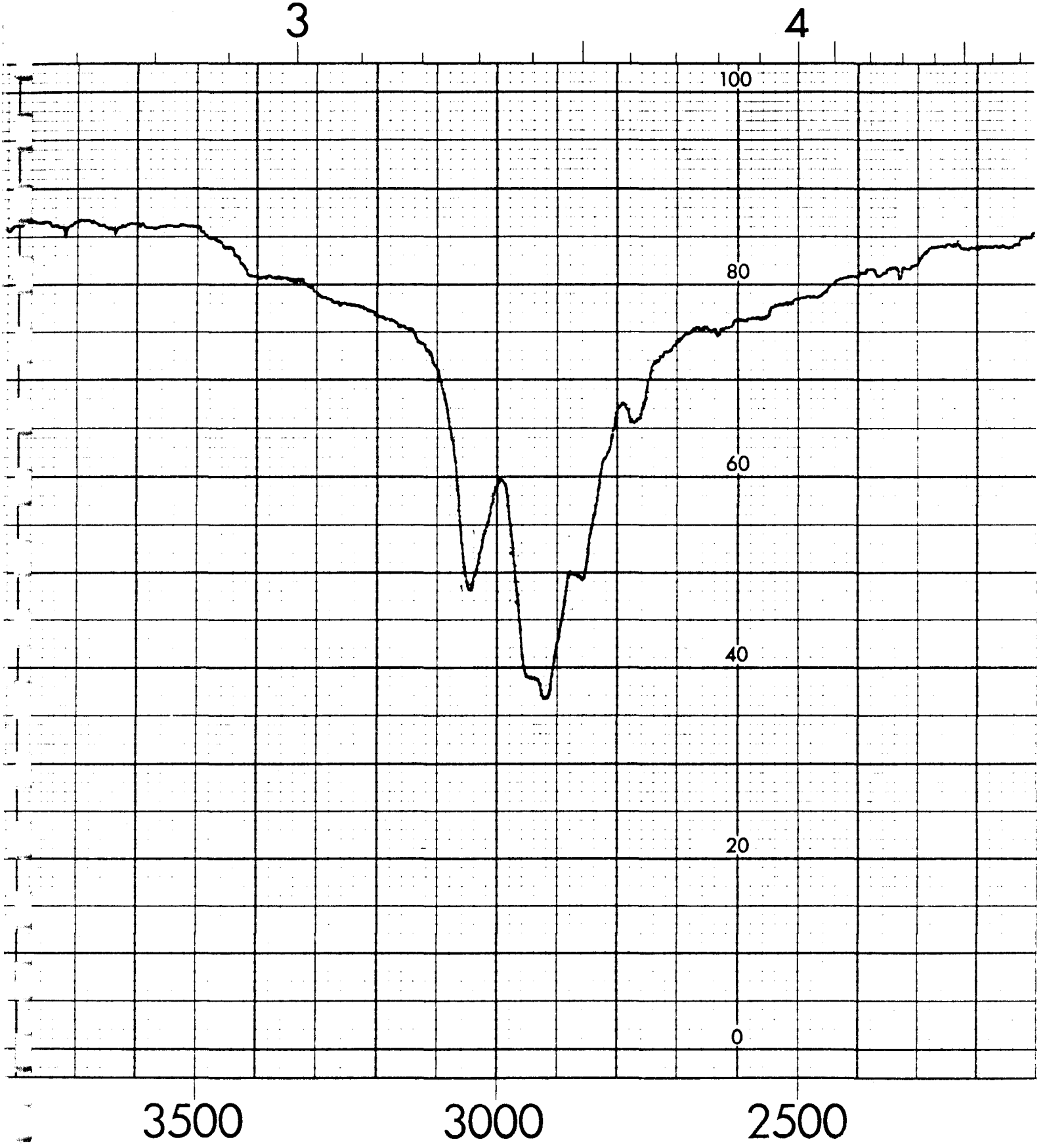

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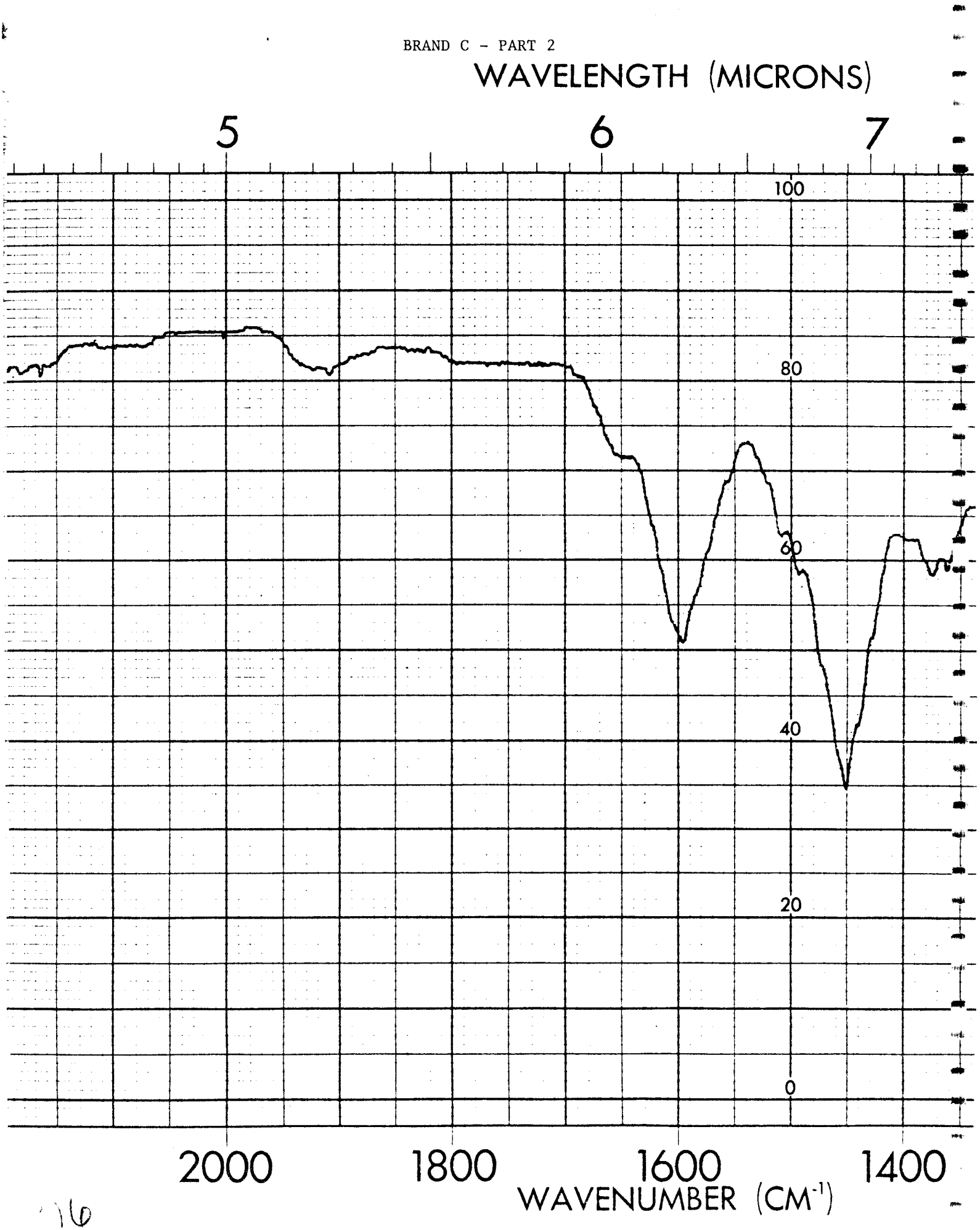

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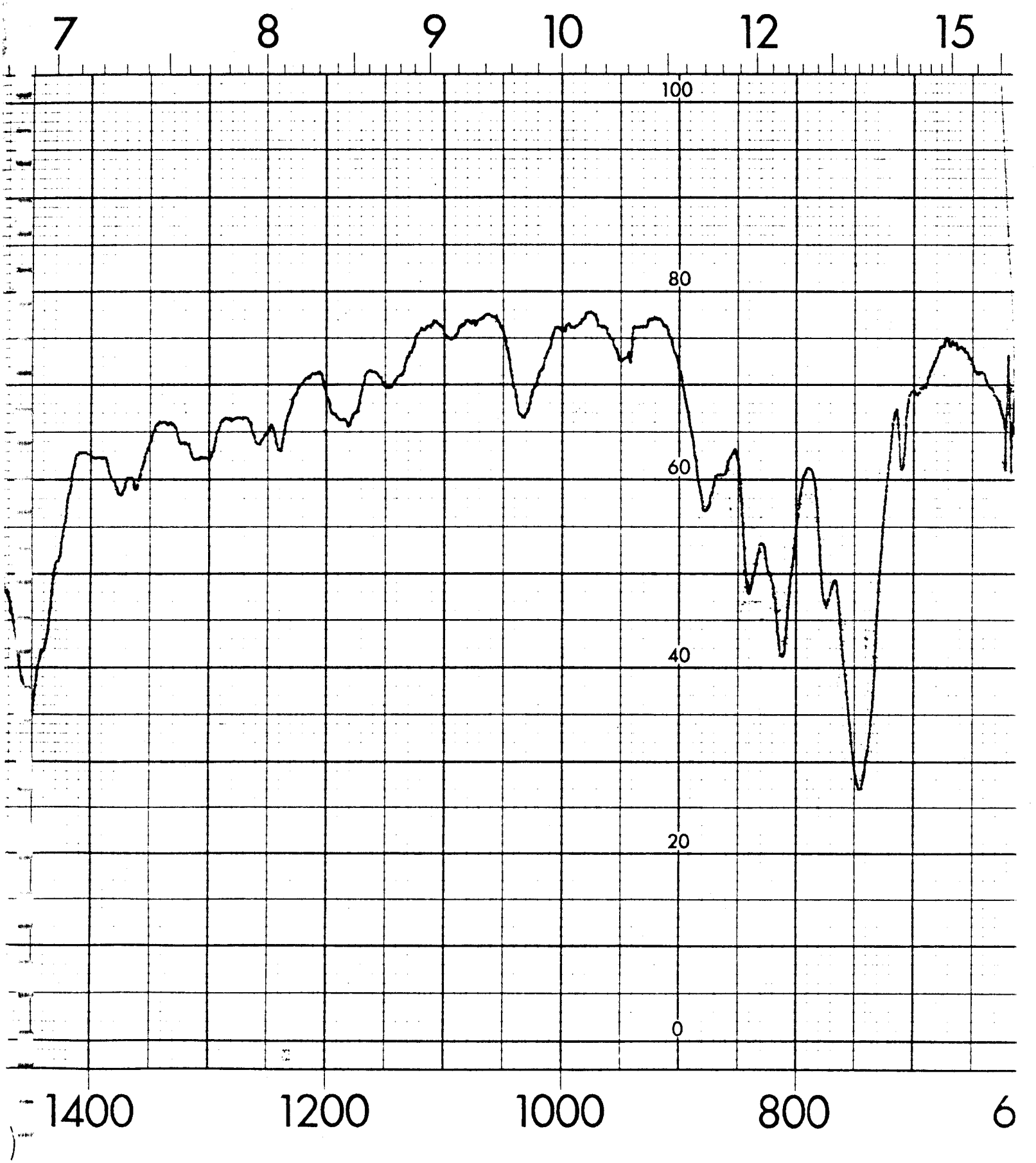

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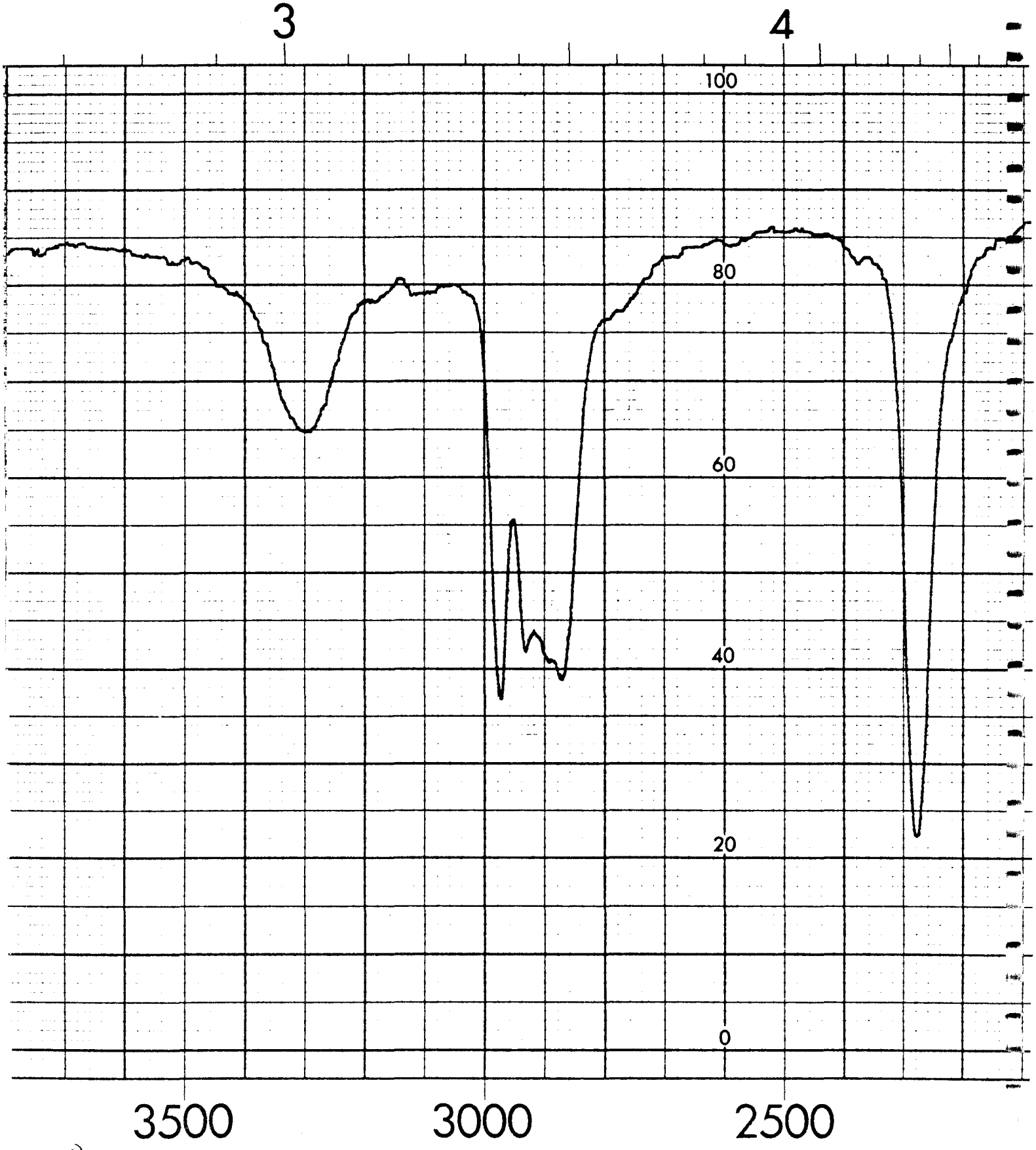

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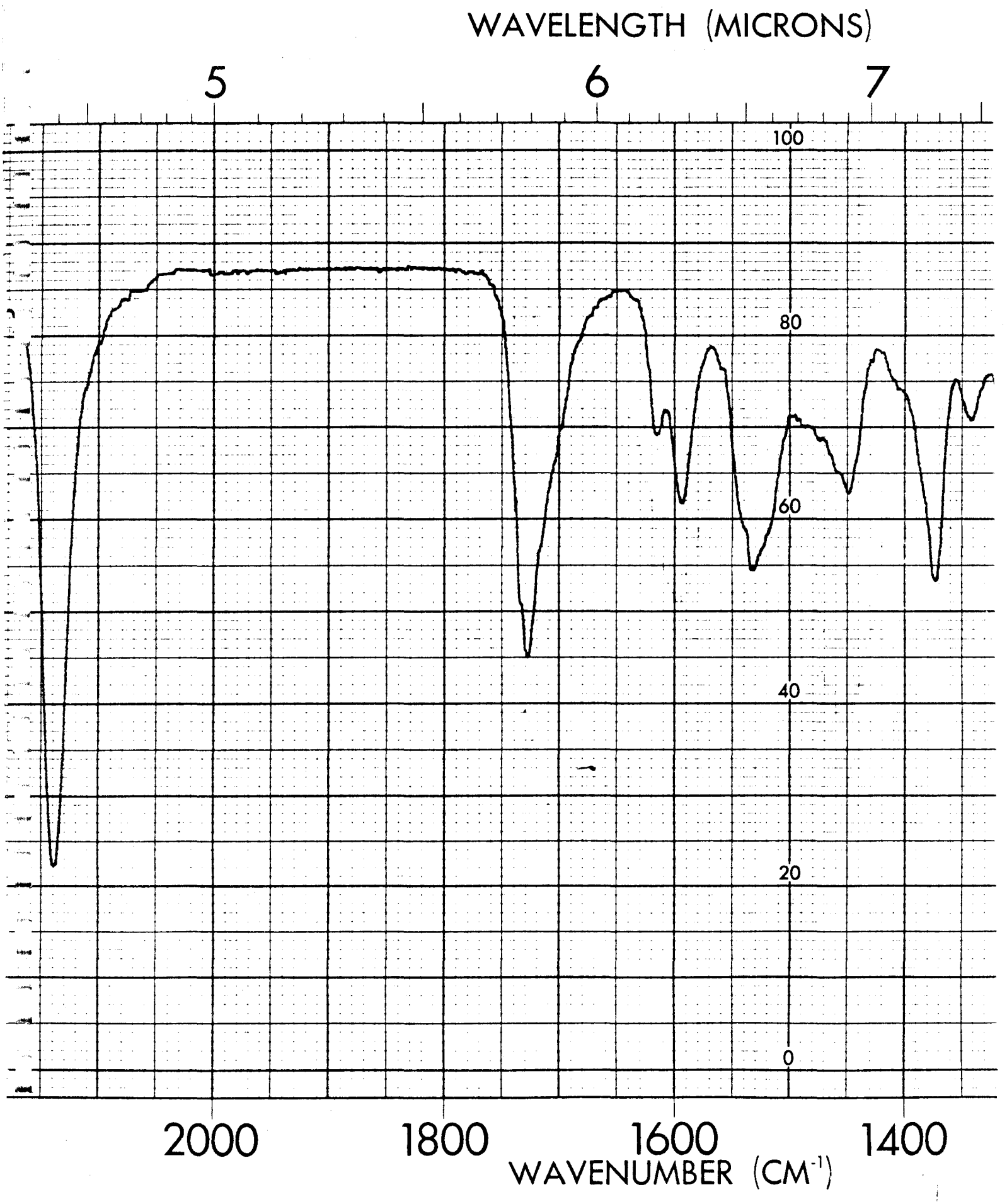

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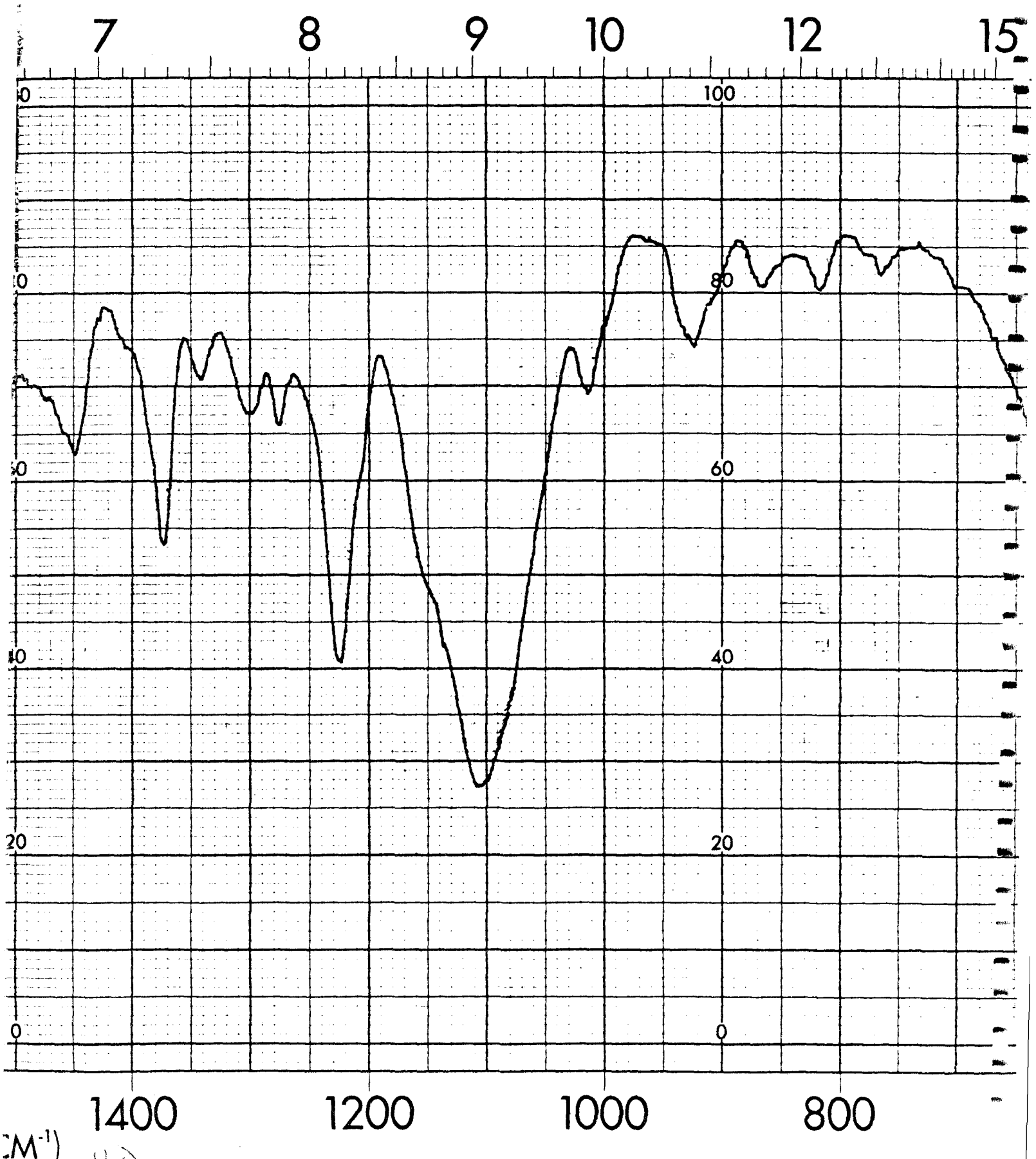

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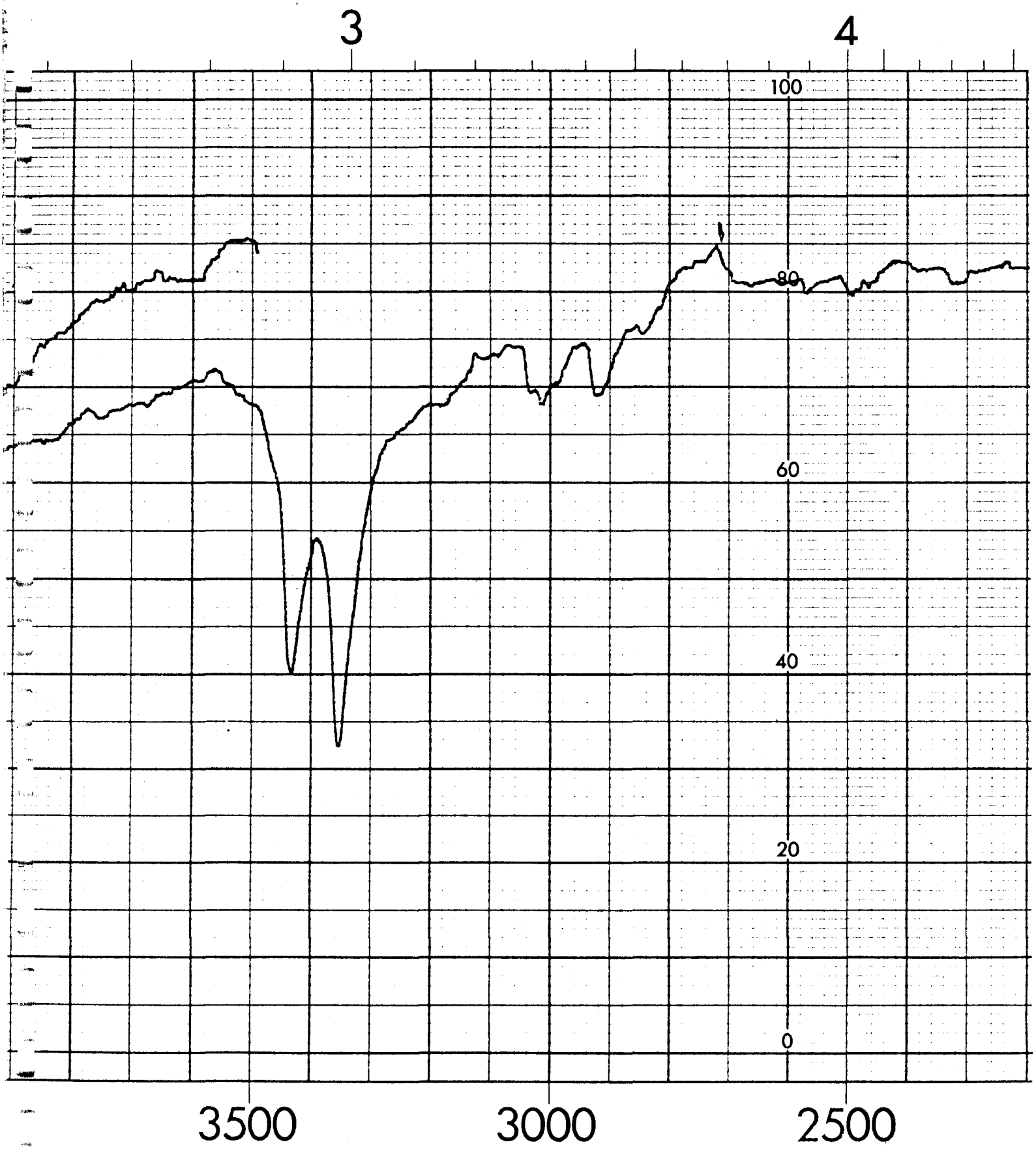

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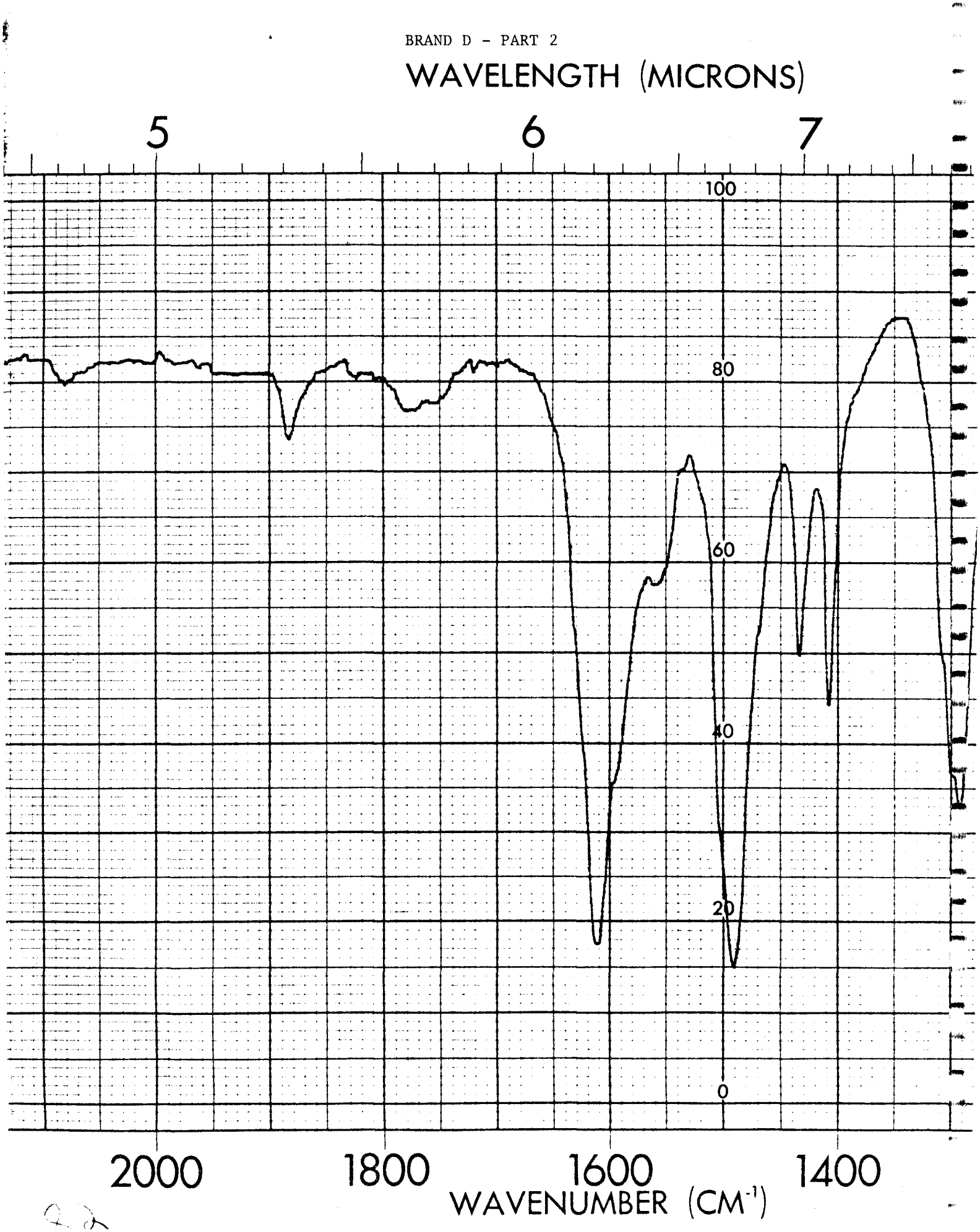

BRAND D - PART 2