NRL Report 6392

Infrared Spectra of Plastics and Resins

Part 2 - Materials Developed Since 1954

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Chemistry Division

May 23, 1966

U.S. NAVAL RESEARCH LABORATORY
Washington, D.C.

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PREVIOUS REPORT IN THIS SERIES

"Infrared Spectra of Plastics and Resins," Part 1, R. E. Kagarise and L. A. Weinberger, NRL Report 4369, May 26, 1954.

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Part 2—Materials Developed Since 1954

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Sixty-one polymeric materials, most of which have been developed since 1954, were studied. Infrared transmittance curves in the region from 4000 to 400 cm^{-1} are presented for 46 of these. Curves for the 15 remaining ones are not shown, but are compared to those in each group that are identical or similar to them. Where possible, the spectra are discussed briefly in terms of the structural groups present.

Methods based on infrared absorbance ratios are used to estimate the densities of some polyethylene polymers and some acrylonitrile-butadiene-styrene (ABS) terpolymers. In the case of polyethylene, these ratios can also be related to the crystalline content of the polymer.

The procedure for identification of unknown spectra given in "Infrared Spectra of Plastics and Resins," Part 1, NRL Report 4369, May 26, 1954, is extended to include the newer polymeric materials.

INTRODUCTION

Many new plastics and resins have been developed since previous work on the infrared spectra of these materials (1,2) was issued. As a result, these spectra are inadequate for reference in the identification of many polymeric samples currently being studied at this Laboratory, and thus the past work has been extended. This report gives representative infrared spectra for most of the major classes of commercial plastics and resins developed since 1954. Brief interpretations of the spectra in terms of correlations between group frequency and structure are also given.

EXPERIMENTAL PROCEDURES AND PRESENTATION OF DATA

A Beckman Model IR-12 spectrophotometer was used to obtain the spectra, and operating parameters were a scanning speed of 80 cm^{-1}/min, a pen response time of 2 sec, a gain of 3%, a SB/DB energy ratio of 1, and a suppression level of 1.5.

Various methods (1,3) were used to prepare the plastic and resin samples for infrared absorption measurements, depending on the solubility and physical characteristics of the material under study. These included casting a film from a solution of the plastic or resin on a KBr plate or on the surface of liquid Hg, imbedding the plastic in a powdered KBr pellet, melting the plastic between two salt plates, and attenuated total reflectance techniques.

Reflectance spectra are given for those plastics which could not be prepared for transmission measurements by one of the above methods. A Wilks Scientific Attenuated Total Reflectance Unit equipped with a 50 by 20 by 2 mm KRS-5 prism was used for these measurements.

In many cases, the infrared spectra of the polymeric films showed absorption bands due to residual solvent. Moderate heating of the films in a vacuum always removed this, but in some films no solvent bands were observed after normal evaporation of the solvent from the polymer solution at room temperature.

Table 1 lists the commercial or trade name, the chemical name, and the source or manufacturer of each of the polymeric materials studied. It also gives the spectrum number and the form of the sample used for transmission measurements. When measurements were taken on films, the solvent used to cast the film is also listed.

The chemical structure and chemical name (if known), the commercial name, and the source or manufacturer of the plastic or resin are given on each spectrum. All spectra are shown at the end of the report.

NRL Problem C07-01; Project RR 001-01-43-4803. This is an interim report; work on the problem is continuing. Manuscript submitted January 26, 1966.

TABLE 1
List of Materials Studied

Commercial or Trade Name	Chemical Name	Source or Manufacturer	Spectrum Number	Form of Sample	Solvent
I. Acrylics					
Lucite, 763497	Poly(methyl methacrylate)	duPont	1	film	CH_2Cl_2
Zerlon-150	Methyl methacrylate-styrene copolymer	Dow Chemical	2	film	CH_2Cl_2
Bavick 11-X-1	Methyl methacrylate-α-methylstyrene copolymer	J. T. Baker Chemical Co.	3	film	C_6H_6 (hot)
Implex	Modified poly(methyl methacrylate)	Rohm and Haas	4	film	$HCON(CH_3)_2$
II. Acrylonitrile polymer and copolymer					
Orlon	Polyacrylonitrile	duPont	5	KBr disc	
Hycar 1562	Acrylonitrile-butadiene copolymer	B. F. Goodrich	6	liquid film	
III. Allyl Resins					
Dapon 35		FMC Corp.	7	film	$CHCl_3$
Dapon M		FMC Corp.	8	film	$CHCl_3$
IV. Cellulose Propionate					
Forticel	Cellulose acetate propionate	Celanese Corp.	9	film	$CH_3COC_2H_5$
V. Fluorinated Polymers					
Teflon FEP fluorocarbon	Fluorinated ethylene-propylene copolymer	duPont	10*	commercial film (0.0005 in. thick)	
Tedlar PVF film	Poly(vinyl fluoride)	duPont	11	commercial film (0.0005 in. thick)	
Kynar	Poly(vinylidene fluoride)	Pennsalt Chem. Corp.	12	film	CH_3COCH_3
PR-143	Perfluorinated polyether	duPont	13	liquid film	
FX 706	Fluorinated methyl methacrylate polymer	Minn. Mining and Mfg. Co.	14	film	$C_8F_6H_4$†
VI. Furane Resins					
X-5B Resin		Furane Plastics, Inc.	15	film (cured)	$CH_3COC_2H_5$
X-2 Resin		Furane Plastics, Inc.	16	film (cured)	$CH_3COC_2H_5$
VII. Polyacrylamide	Polyacrylamide	American Cyanamide	17	free film	H_2O
VIII. Polycarbonates					
K-1 Resin	Polycarbonate	Eastman Chemical Products	18	film	CH_2Cl_2
Merlon, M50 and M90‡	Polycarbonate	Mobay Chemical Co.	19	film	CH_2Cl_2
IX. Polyethers					
Celcon acetal copolymer	Polyformaldehyde	Celanese Corp.	20	film	$Cl_2C_6H_4$ (hot)§
Delrin acetal resin‡	Polyformaldehyde	duPont	–	film	$Cl_2C_6H_4$ (hot)§
Penton	Chlorinated polyether	Hercules Powder Co.	21	film	$Cl_2C_6H_4$ (hot)§
Phenoxy		Union Carbide	22	film	$CH_3COC_2H_5$
Polyphenylene oxide		General Electric	23	film	C_6H_6 (hot)

X. Polyimides					
Kapton polyimide film, Type H		duPont	24¶	film	
Kapton polyimide film, Type 150XHF (coated on one side with Teflon)		duPont	25¶	film	
Vespel, SP-1 polymer		duPont	26¶	test bar	
Doryl polyimide lacquer		Westinghouse	27	film	$HCON(CH_3)_2$
XI. Polyolefins and Copolymers					
A. Polyethylenes					
Polyethylenes 555E, 510E,‡ and RC1601‡	Polyethylene	Dow Chemical	28	film	$Cl_2C_6H_4$ (hot)§
Insulrad	Irradiated polyethylene	Electronized Chemicals Corp.	29	film	$Cl_2C_6H_4$ (hot)§
Polyethylene CAB-XL 1411		Cabot Corp.	30		$Cl_2C_6H_4$ (hot)§
Surlyn A, Ionomer Resin		duPont	31	film**	
Zetafin 30	Ethylene-ethyl acrylate copolymer	Dow Chemical	32	film	ClC_6H_5 (hot)
Elvax, Grades 310, 350,‡ and 360‡	Ethylene-vinyl acetate copolymer	duPont	33	film	$Cl_2C_6H_4$ (hot)§
Alathon‡	Ethylene-vinyl acetate copolymer	duPont	–	film	$Cl_2C_6H_4$ (hot)§
B. Polypropylenes					
Polypropylene	Polypropylene	G. T. Schjeldahl Co.	34††	commercial film (0.0006 in. thick)	
Oleform TD-229		Avisun Corp.	35	film	ClC_6H_5 (hot)
Olemer TD-350B		Avisun Corp.	36	film	ClC_6H_5 (hot)
Tenite Polyallomers 5321A, 5221A,‡ 5021A,‡ and 5B21A‡	Ethylene-propylene copolymer	Eastman Chemical Products	37	film	ClC_6H_5 (hot)
Ethylene-propylene copolymer, Type QX 4346.49‡	Ethylene-propylene copolymer	Dow Chemical	–	film	ClC_6H_5 (hot)
C. TPX-RT	Poly(4-methylpentene-1)	Imperial Chemicals, Ltd.	38	film	ClC_6H_5 (hot)
XII. Polysulfone	Polysulfone	Union Carbide	39	film	CH_2Cl_2
XIII. Polyurethanes					
CX-1046		Goodyear Tire and Rubber Co.	40	film	$CH_3COC_2H_5$
Adiprene L-100		duPont	41	film	$CH_3COC_2H_5$
XIV. Styrene Polymer and Terpolymers					
Styron, 690 27 and 475‡	Polystyrene	Dow Chemical	42	film	CH_2Cl_2
ABS Polymers, Cycolac H-1000, Cycolac GSM-1000,‡ Cycolac X-7 1000,‡ and Cycolac X-27 1000‡	Acrylonitrile-butadiene-styrene terpolymer	Marbon Chemicals	43	film	CH_2Cl_2
XV. Vinyl Polymers and Copolymers					
Bakelite Resin EHBC	Poly(vinyl ethyl ether)	Union Carbide	44	film	C_6H_{14}
Geon, Type 3005	Poly(vinyl dichloride)	B. F. Goodrich Chemical Co.	45	film	$CHCl_3$
Geon Resin 222	Vinyl chloride-vinylidene chloride copolymer	B. F. Goodrich Chemical Co.	46	film	CH_2Cl_2

*Spectrum in the region from 1350 to 1150 cm^{-1} was taken with an attenuated total reflectance unit.
†Xylene hexafluoride.
‡Transmittance curve is not presented. It is approximately the same as that shown for the preceding material.
§Ortho-dichlorobenzene.
¶Reflectance spectra using an attenuated total reflectance unit.
**Film formed by melting plastic between salt plates.
††Spectrum in the region from 3000 to 2800 cm^{-1} is of a film cast from a solution of polypropylene in xylene.

DISCUSSION

I. Acrylics

In recent years a number of modified acrylics have been developed. These are usually prepared by the copolymerization of styrene or α-methylstyrene with methyl methacrylate (4).

The spectra of three representative modified acrylics are shown in spectra 2, 3, and 4. For purposes of comparison, the spectrum of poly(methyl methacrylate) is given in spectrum 1. With the exception of the relatively weak bands at 3083, 3063, 3020, 1600, and 700 cm^{-1}, due to phenyl groups, the spectra of the copolymers closely resemble that of poly(methyl methacrylate). The variation in the relative intensity of the bands at 750 and 700 cm^{-1} is quite helpful in distinguishing between the copolymers.

II. Acrylonitrile Polymer and Copolymer

The bands at 3640, 3550, and 1625 cm^{-1} in spectrum 5 of polyacrylonitrile undoubtedly are due to impurities or additives, since they were not observed by Liang and Krimm (5), who have also made a detailed interpretation of the spectrum. Since a dilute solution of H_2O in acetonitrile gives rise to bands at 3630, 3540, and 1625 cm^{-1}, it seems reasonable to conclude that the above-mentioned bands in polyacrylonitrile are due to the presence of dissolved H_2O in the polymer.

The increased absorption at the CH_2 stretching frequency and the appearance of the $CH{=}CH_2$ deformation frequencies in the region from 1000 to 900 cm^{-1} readily differentiate between the spectrum of acrylonitrile-butadiene copolymer (spectrum 6) and that of polyacrylonitrile. No reasonable explanation can be given for the band at 1562 cm^{-1} in spectrum 6.

III. Allyl Resins

The principal allyl resins are the prepolymers of diallyl phthalate and diallyl isophthalate. They are thermosetting resins, which cure with peroxide catalysts by addition polymerization to give highly crosslinked materials.

The assignment of bands in the prepolymers Dapon 35 (spectrum 7) and Dapon M (spectrum 8) is difficult because of the complex structures of these resins.

IV. Cellulose Propionate

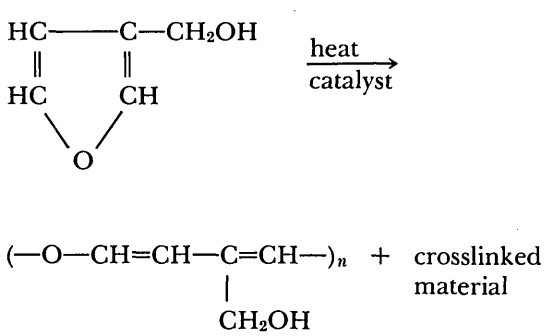
Cellulose actetate propionate (spectrum 9), generally called cellulose propionate, is prepared by treating fibrous cellulose with propionic and acetic acids. Molding and extrusion grades usually have a propionyl content of 42 to 47% and an acetyl content of 2.5 to 9% (4). These compositional differences result in a variation of the relative intensity of the CH_2 and CH_3 absorptions for the different grades of cellulose propionate. A detailed interpretation of cellulose spectra has been given elsewhere (1,3).

V. Fluorinated Polymers

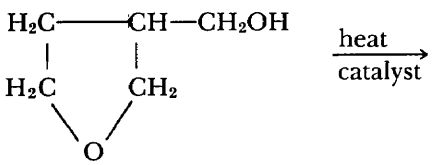
The infrared spectra of fluorinated polymers are characterized by very strong absorption bands in the region from 1300 to 1000 cm^{-1} due to the C—F stretching modes. Polymers with CF_2 groups also show characteristic absorption in the region from 700 to 500 cm^{-1} (6), as in spectra 10, 12, 13, and 14. In fluorinated ether and methacrylate polymers, the C—F and C—O—C stretching modes interact, and thus band assignments in simple terms are not possible for them.

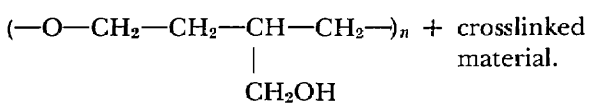
VI. Furane Resins

In the presence of an acid catalyst, furfuryl alcohol and tetrahydrofurfuryl alcohol polymerize to form thermosetting furane resins. Some typical reactions are:



and





Spectra 15 and 16 show the infrared absorption of two representative furane resins. Meaningful band assignments are difficult because of the complex structure of the resins.

VII. Polyacrylamide

The spectrum of polyacrylamide may be explained largely in terms of its chemical structure. As seen in spectrum 17, bands due to NH_2, C=O, CH, CH_2, and $NH_2C{=}O$ groups are present.

VIII. Polycarbonates

The three polycarbonate samples studied have similar spectra. Most of the bands in spectra 18 and 19 may be explained in terms of CH_3, C=O, C—O—C, and aromatic groups.

IX. Polyethers

The infrared spectra of the five polyethers studied may usually be interpreted in terms of group vibrations based on their chemical structure. A complete interpretation of the polyformaldehyde spectrum (Delrin and Celcon) has been given elsewhere (7,8).

X. Polyimides

Spectrum 24 of Kapton polyimide film, Type H, supports the chemical structure given for this polymer. Coating the film on one side with Teflon FEP polymer produces spectral changes in the region from 1300 to 1100 cm^{-1} (spectrum 25). This change may be attributed to the overlap of CF, aromatic CH, and aromatic ether vibrations.

Absorption in the region from 2950 to 2850 cm^{-1} in spectrum 26 of Vespel SP-1 polymer and in spectrum 27 of Doryl polyimide lacquer indicates the presence of aliphatic groups in these two polymers.

XI. Polyolefins and Copolymers

A. Polyethylenes

Zbinden (9) and Elliott (3) have discussed the spectrum of polyethylene in considerable detail. They also list references to additional infrared studies of polyethylene.

The spectra of Dow Chemical polyethylenes, grades 555E, 510E, and RC-1601, with respective densities of 0.934, 0.919, and 0.964 g/cc, show variations in the intensities of bands at 1472, 1460, 730, and 720 cm^{-1}, relative to the CH stretching bands.

The band at 730 cm^{-1} has long been associated with the degree of crystallinity in polyethylene, since it disappears in the spectrum of the melt (3,10,11). Since the crystalline contents and densities of the polyethylenes are directly related (10), a change in the absorptivity of the 730 cm^{-1} band with density is expected. Tobin and Carrano (11) have given absorptivity values for the crystalline band at 730 cm^{-1} and also for an amorphous band at 1300 cm^{-1} that may be used in determining the crystalline content of a polyethylene sample.

In addition, the bands at 1460 and 730 cm^{-1} may be used to determine the densities of polyethylene polymers. Figure 1 shows a plot of polymer density *vs* A(1460)/A(730), where, for example, A(1460) refers to the absorbance at 1460 cm^{-1}. The base line was taken at 1400 cm^{-1} for the 1460 cm^{-1} band and at 800 cm^{-1} for the 730 cm^{-1} band. There is a good linear relationship, but since the data are very limited, density values calculated from other A(1460)/A(730) values must be considered only approximate.

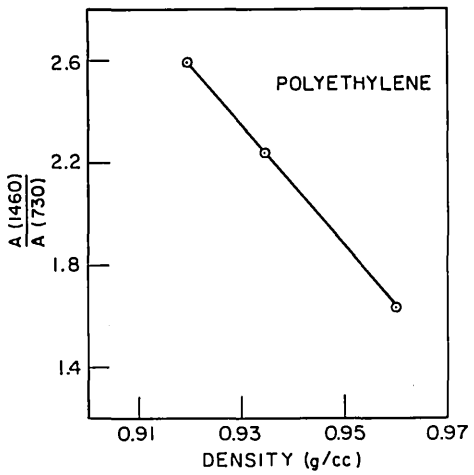


Fig. 1 — Relation between densities and absorbance values for polyethylenes. Using this plot, densities, calculated from A(1460)/A(730) should be regarded as only rough approximations.

Spectrum 29 of polyethylene crosslinked by high-energy radiation shows some C=O absorption at 1732 cm^{-1}. Polyethylene that has been chemically crosslinked (spectrum 30) exhibits a number of additional absorption bands, notably in the C=O stretching region and the region from 1400 to 1100 cm^{-1}. These may be due to the crosslinking agent and antioxidant additives.

Surlyn A is a member of a very recently developed family of polymers known as "ionomer resins" (12). The unique physical properties of these resins are attributed to the fact that the ionomers contain inorganic as well as organic components that are linked by both covalent and ionic bonds. The organic portion consists primarily of a main hydrocarbon chain (polyethylene) with attached pendant carboxyl groups. Some of these carboxyl groups are ionized and are linked to similar groups on adjacent chains through intermediate positively charged metal cations. Na^+, K^+, Mg^{2+}, and Zn^{2+} are frequently used. Spectrum 31 of Surlyn A is readily explained on the basis of such a structure. In addition to those bands normally observed for polyethylene, strong bands are present at 1710, 1555, and 1255 cm^{-1}. The 1555-cm^{-1} band is characteristic of an ionized carboxyl group, while the remaining two bands arise from covalent carboxyl groups.

The spectra of the ethylene-ethyl acrylate copolymer (spectrum 32) and the ethylene-vinyl acetate copolymer (spectrum 33) show bands characteristic of the component polymers. The ethylene-vinyl acetate copolymers, Elvax, grades 310, 350, and 360 have identical spectra, and the spectrum of Alathon resembles that of Elvax with reduced absorption at 1740, 1370, 1240, and 1020 cm^{-1}.

B. Polypropylenes

The infrared spectra of crystalline, amorphous, and deuterated polypropylenes have been studied by a number of workers (13-15), and detailed assignments of vibrational frequencies have been made. The absorption band at 1740 cm^{-1} in Avisun Corp.'s modified polypropylene (spectrum 35) and propylene copolymer (spectrum 36), indicates the presence of C=O groups in these polymers. The additional absorption in the region from 1100 to 950 cm^{-1} in spectrum 35 may be due to C—O—C groups.

Ethylene-propylene copolymer absorption in spectrum 37 resembles that of polypropylene in spectrum 34. A variation in the intensity of bands at 1375, 1358, 1165, 998, and 972 cm^{-1} relative to the band at 2840 cm^{-1} was observed for the various copolymers studied. In several polymers, weak bands were observed at 730 and 720 cm^{-1}, indicating the possible presence of $(CH_2)_n$ groups, with $n \geqslant 3$.

Infrared methods for the determination of propylene content in ethylene-propylene copolymers have been reported (16); however, the results are influenced by the degree of crystallinity in the copolymers and also by other unknown solid-state effects. Since no attempt was made to study copolymers of uniform crystallinity, these methods were not applied here.

C. Poly(4-methylpentene-1)

Spectrum 38 of poly(4-methylpentene-1) supports the chemical structure given for this polymer. In particular, it shows increased absorption in the CH_3 stretching and bending region over that observed in the spectrum of polypropylene.

XII. Polysulfone

Most of the bands in spectrum 39 of polysulfone may be explained in terms of the chemical structure given for this polymer.

XIII. Polyurethanes

Urethane polymers are formed by the reaction of an isocyanate group with a hydroxyl group. The general reaction may be represented by

$$R'-N=C=O \;+\; ROH \rightarrow R'-\underset{\underset{H}{|}}{N}-\underset{\underset{O}{\|}}{C}-O-R.$$

However, in order to form a polymer it is necessary that the reactants be multifunctional. For example, a diisocyanate will react with a dihydric alcohol to form a polyurethane. Since a variety of diisocyanates and polyhydroxy compounds are used in the preparation of commercial polyurethanes, the structures of these polymers are complex.

In the two urethane polymers studied (spectra 40 and 41), bands due to NH, CH_2, CH_3, C=O, and C−O−C groups are present. The band at 2280 cm^{-1} in spectrum 41 is probably due to residual unreacted isocyanate.

XIV. Styrene Polymer and Terpolymers

Four acrylonitrile-butadiene-styrene (ABS) terpolymers were studied, and spectrum 43 is representative of all of these. All samples exhibit similar spectra, differing only in the relative intensities of certain bands. Spectrum 42 of polystyrene is given for purposes of comparison with these spectra.

Figure 2 shows a plot of A(965)/A(2239) *vs* the densities of the polymers. The base line was taken at 835 cm^{-1} for the band at 965 cm^{-1} and 2360 cm^{-1} for the band at 2239 cm^{-1}. Densities were taken from the Marbon circular on Cycolac ABS polymers. A good linear relationship is found, and although the data are limited, the plot can give a rough estimate of the density of an ABS polymer sample if its A(965)/A(2239) is known.

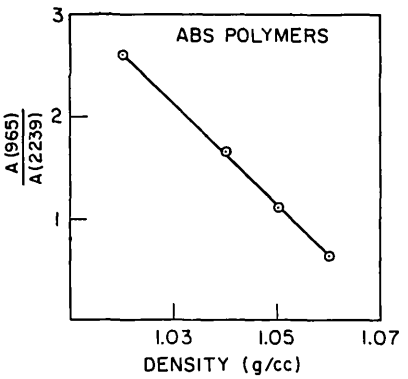


Fig. 2 – Relation between densities and absorbance values for acrylonitrile-butadiene-styrene (ABS) polymers. Using this plot, densities calculated from A(965)/A(2239) should be regarded as only rough approximations.

XV. Vinyl Polymers and Copolymers

Spectrum 44 of poly(vinyl ethyl ether) may be explained in terms of chemical structure; the outstanding feature is the intense band at 1100 cm^{-1} due to the C−O−C stretching mode. On the other hand, spectrum 45 of poly(vinyl dichloride) and spectrum 46 of vinyl chloride-vinylidene chloride copolymer are complex and cannot be completely explained in terms of CH, CH_2, CCl, and CCl_2 groups. For example, bands due to −OH and C=O are present in spectrum 45, and presumably arise from plasticizers or other additives.

APPLICATIONS

Figure 3 presents a scheme for the systematic analysis of a spectrum of an unknown plastic or resin. The chart is an expanded version of the one given in Part 1 of this series (1), to which the samples listed in Table 1 have been added. As explained in Part 1, this chart enables the unknown material to be classified as belonging to one or perhaps several broad families of polymers, such as acrylics, epoxides, and polyesters. Once this general classification has been made, the spectrum of the unknown can be compared with the reference spectra available for the particular type or types of polymers. This approach greatly reduces the number of spectral comparisons necessary to make an identification.

CONCLUSIONS

Many of the conclusions given in Part 1 of this series are equally valid for the present work and need not be discussed in any further detail. However, there are several whose validity or importance has been modified during the past 10 years, and these seem worthy of discussion.

Because of the marked increase in the number of commercial plastics and resins, it is exceedingly difficult to devise a simple system for identification. Therefore, the chart shown in Fig. 3 is considerably less useful than its predecessor. Obviously, the use of more sophisticated data-retrieval methods, such as sorting cards, IBM cards, or computer techniques, must now be contemplated.

The extensive use of copolymers and terpolymers has resulted in almost unlimited variability in the structure and composition of polymeric materials. Consequently, it is now virtually impossible for the analyst to make an identification in anything other than broad terms. The large number of commercial sources, coupled with batch-to-batch variations in composition, further complicate an already-confused situation.

ACKNOWLEDGMENT

The authors wish to express their appreciation to Mr. Ralph C. Taylor for helpful discussions and valuable assistance in collecting the samples used in this investigation.

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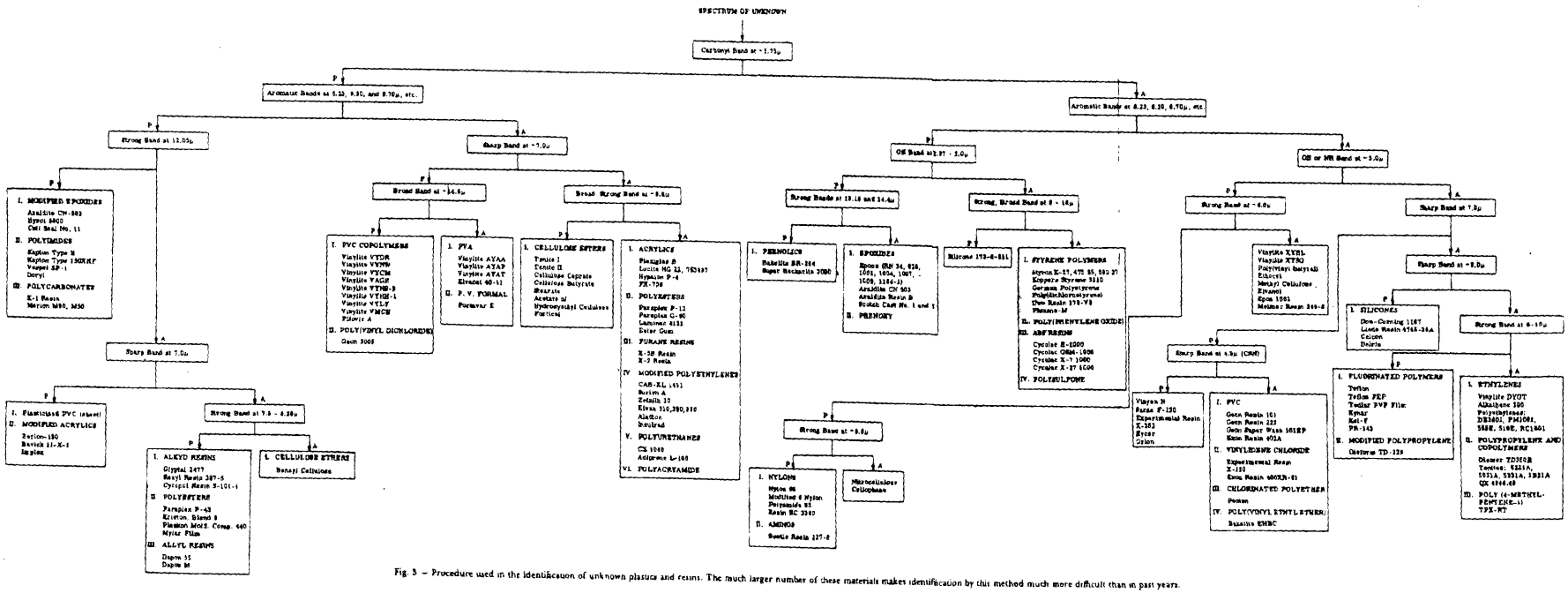
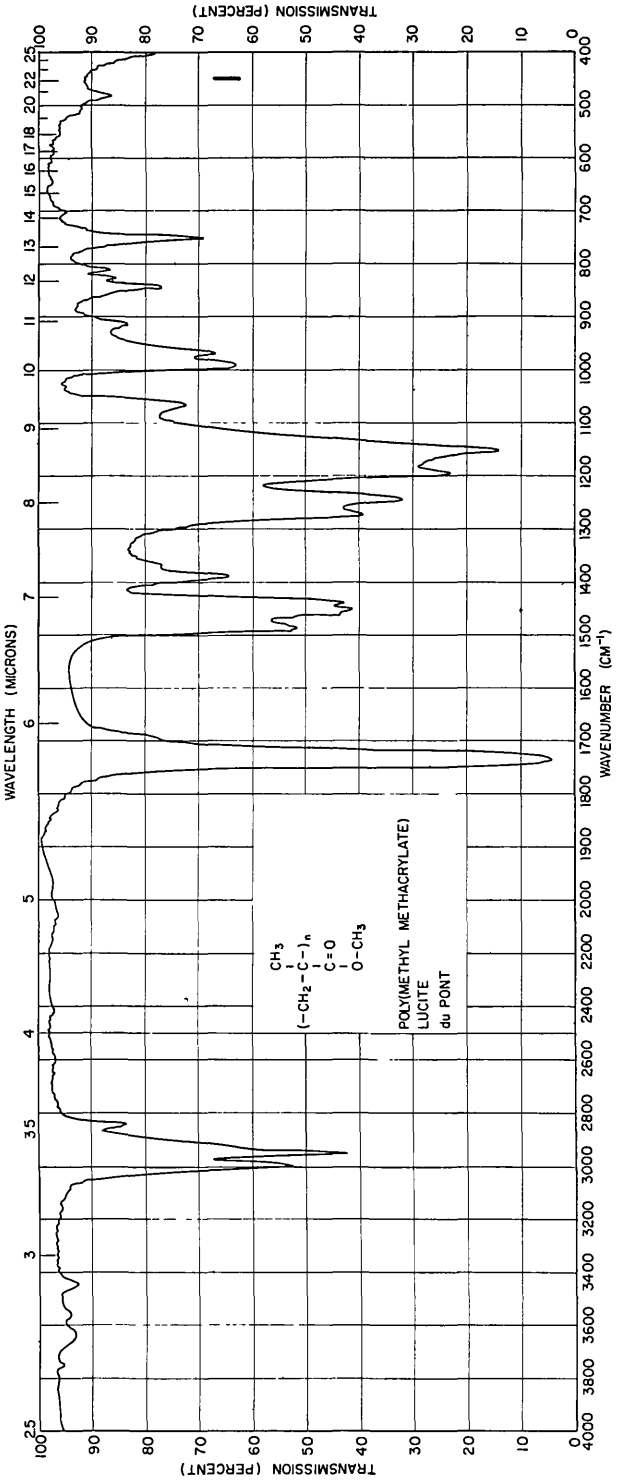
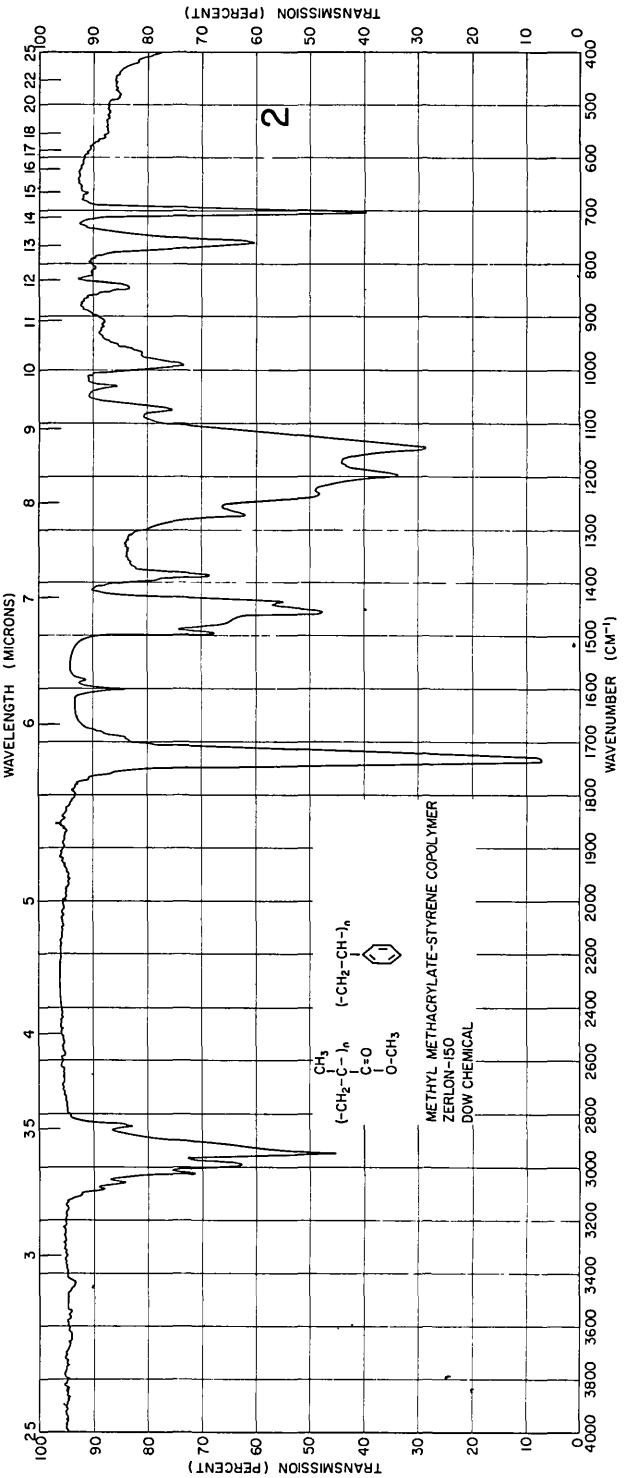
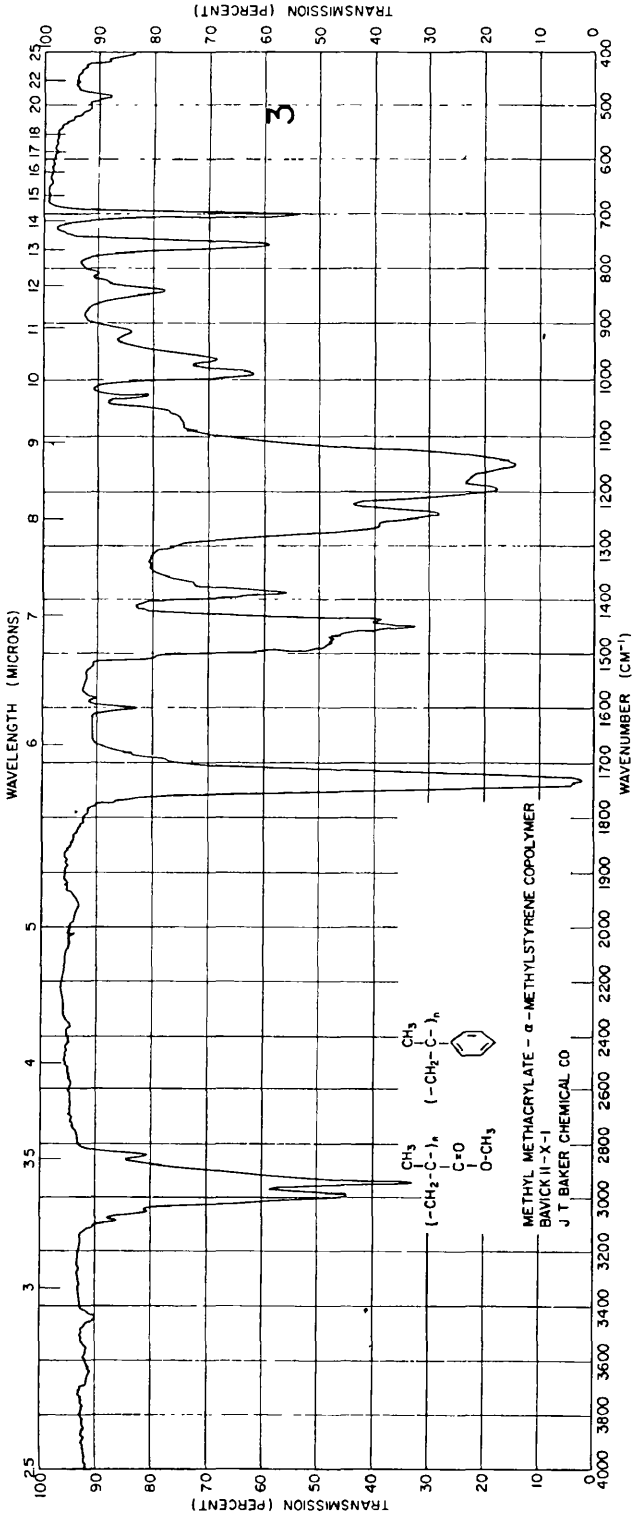
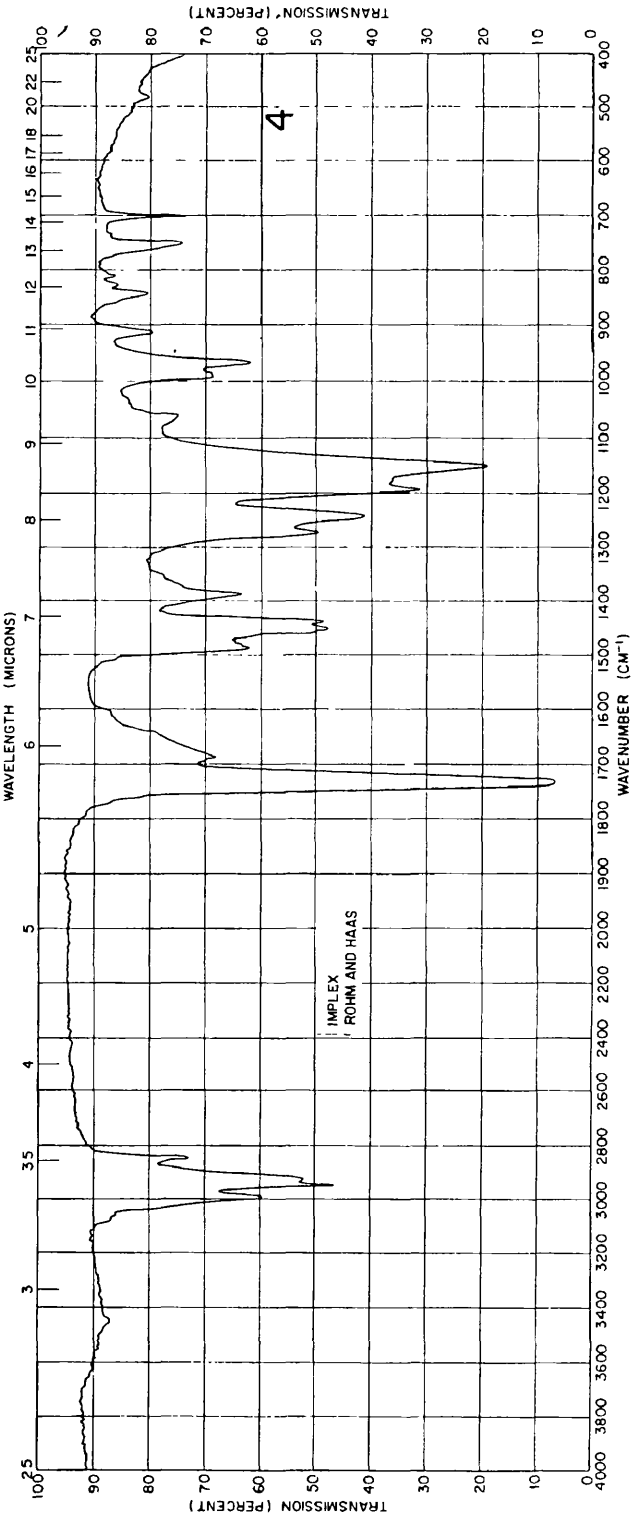


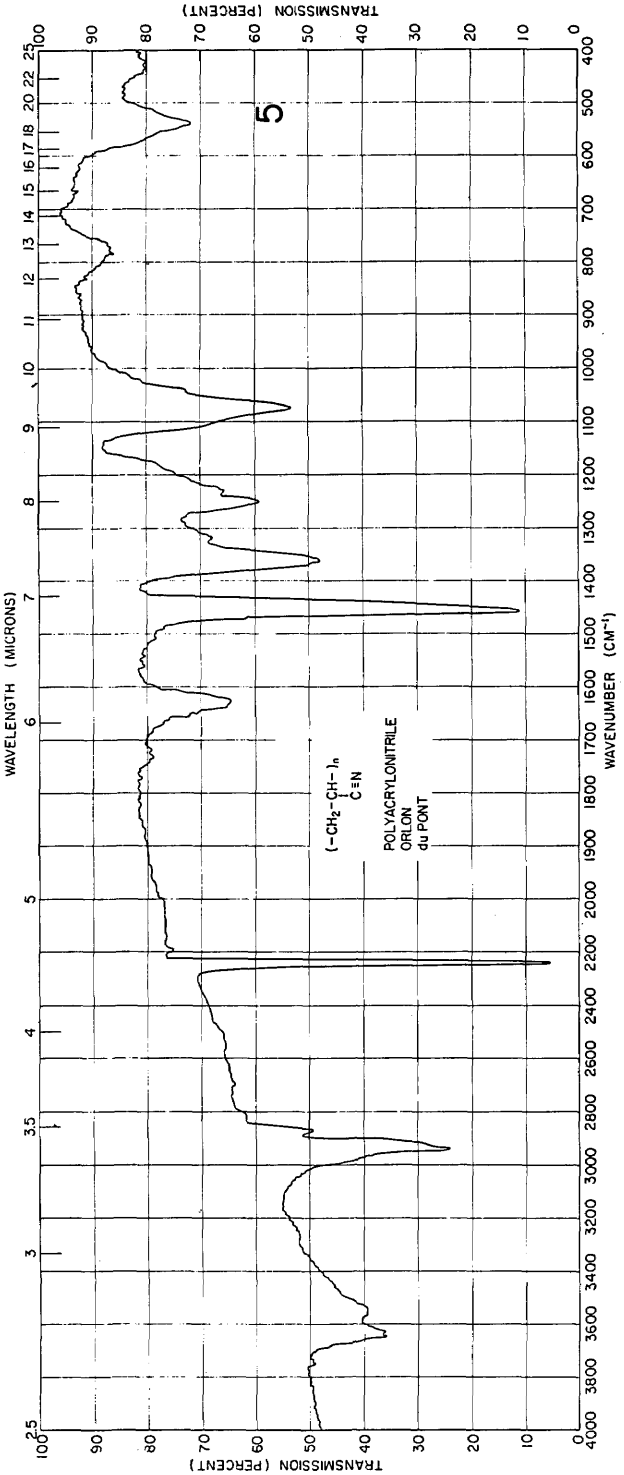
Fig. 5 — Procedure used in the identification of unknown plastics and resins. The much larger number of these materials makes identification by this method much more difficult than in past years.

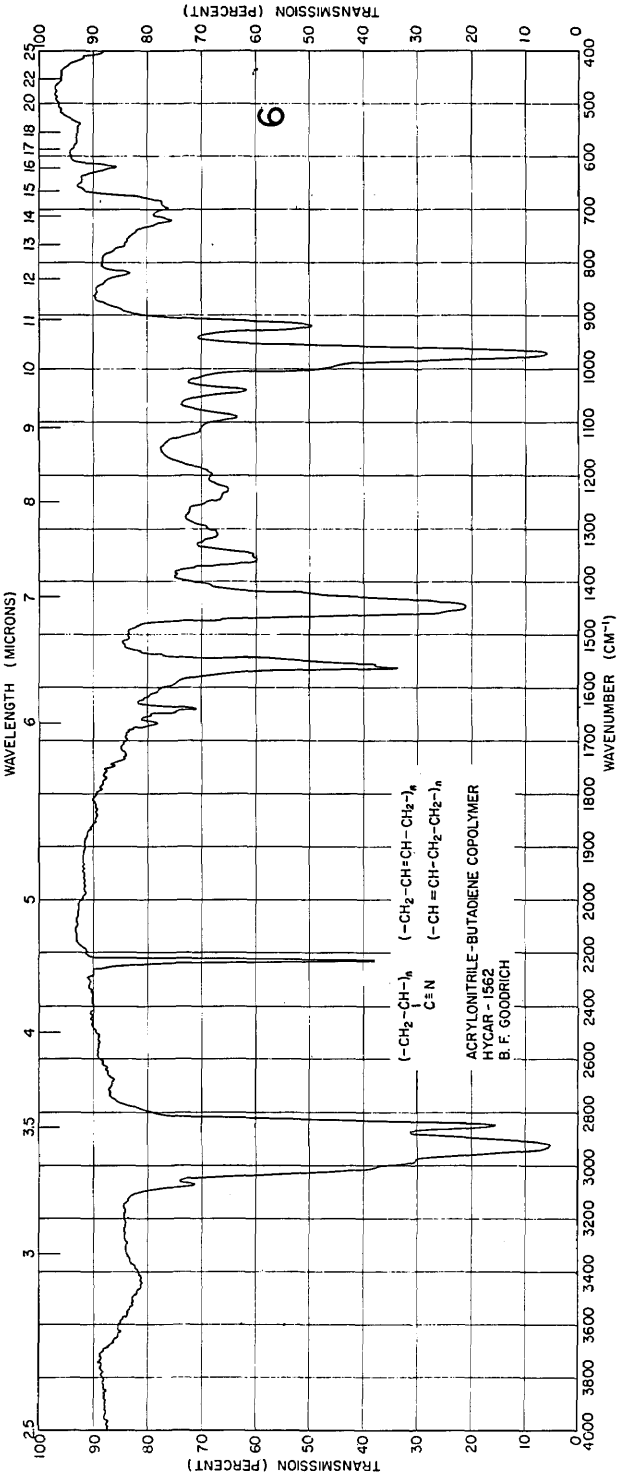

1
POLY(METHYL METHACRYLATE)
LUCITE
du PONT
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

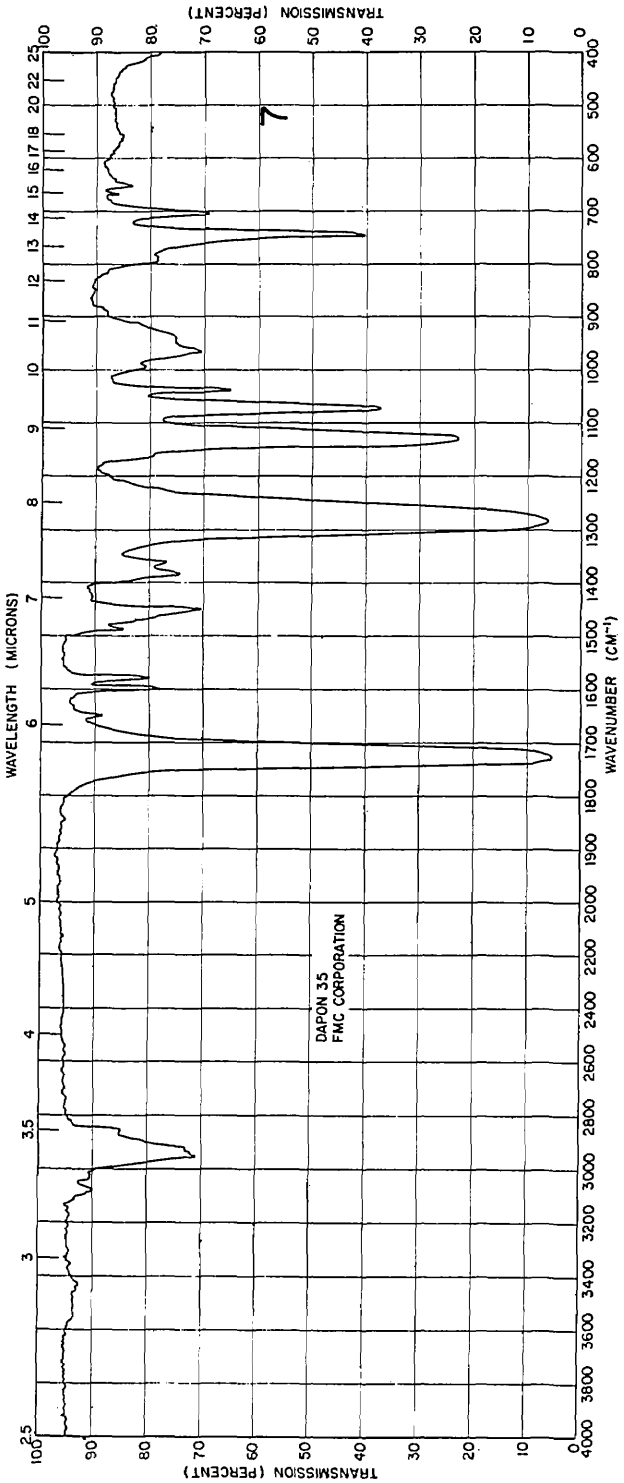

2
METHYL METHACRYLATE-STYRENE COPOLYMER
ZERLON-150
DOW CHEMICAL
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

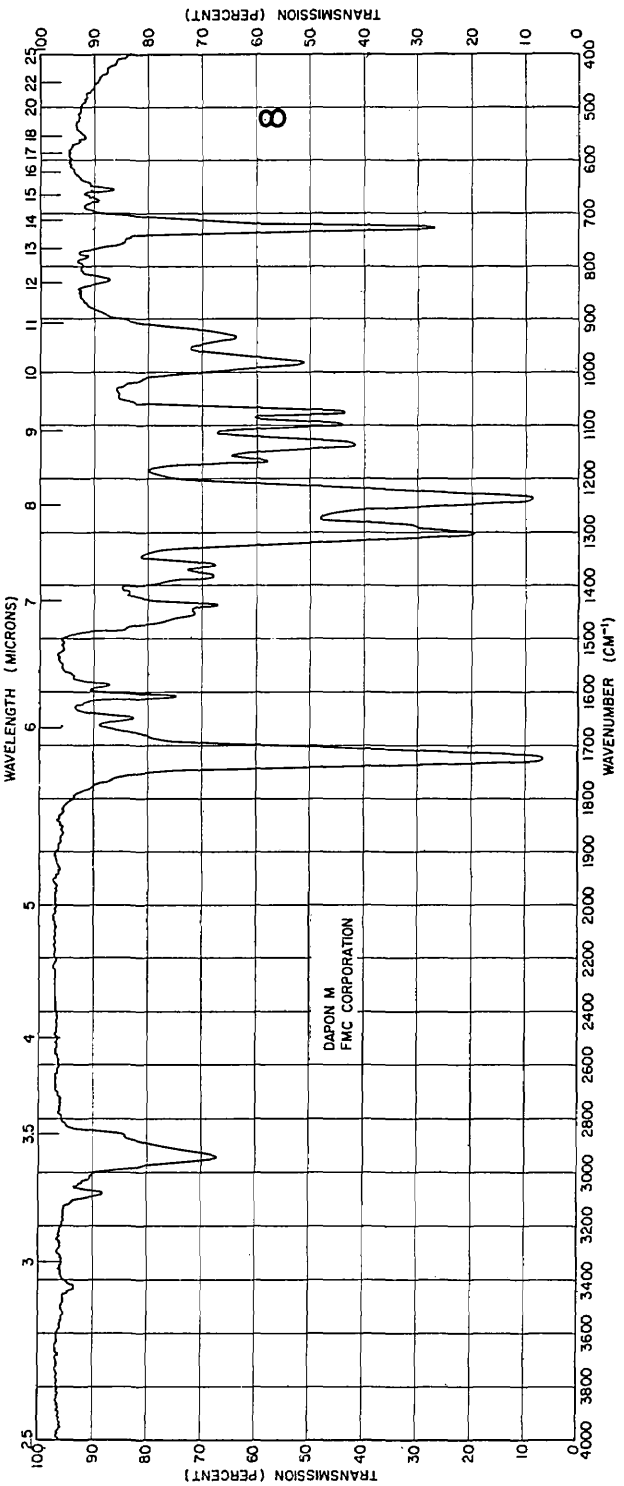

3
METHYL METHACRYLATE - α-METHYLSTYRENE COPOLYMER
BAVICK II-X-I
J T BAKER CHEMICAL CO
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

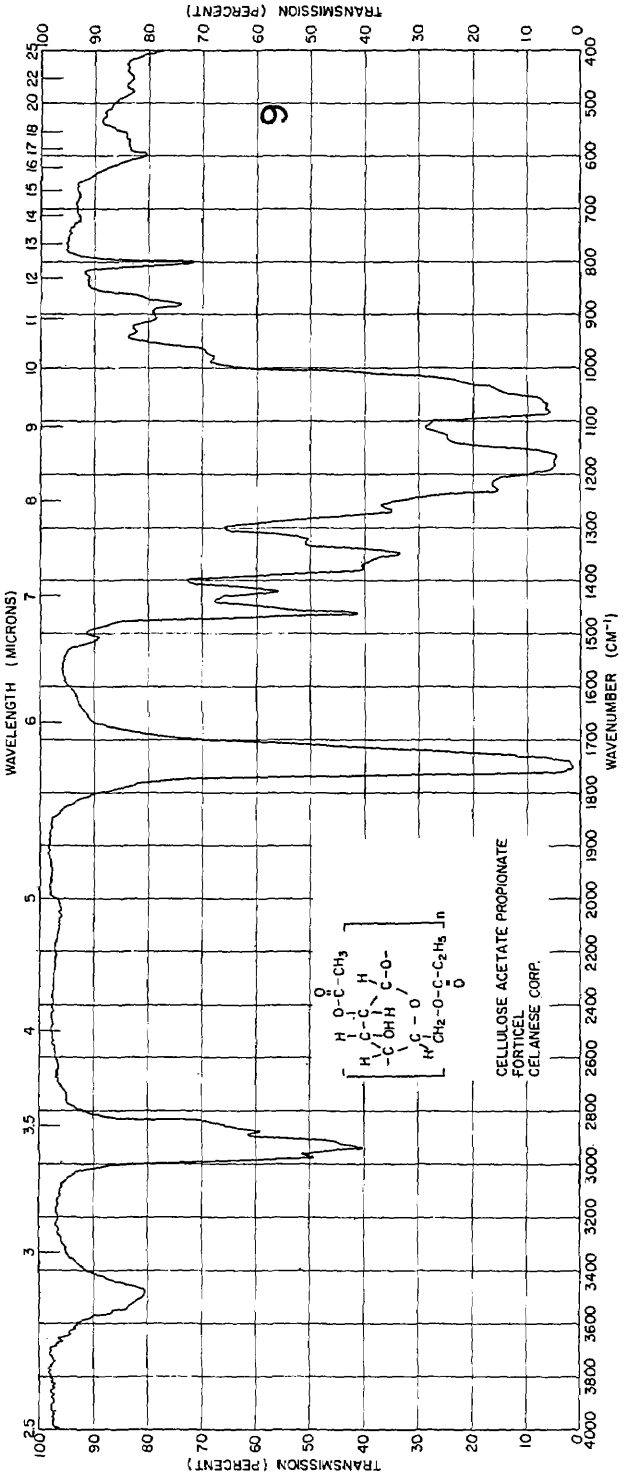

4
IMPLEX
ROHM AND HAAS
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

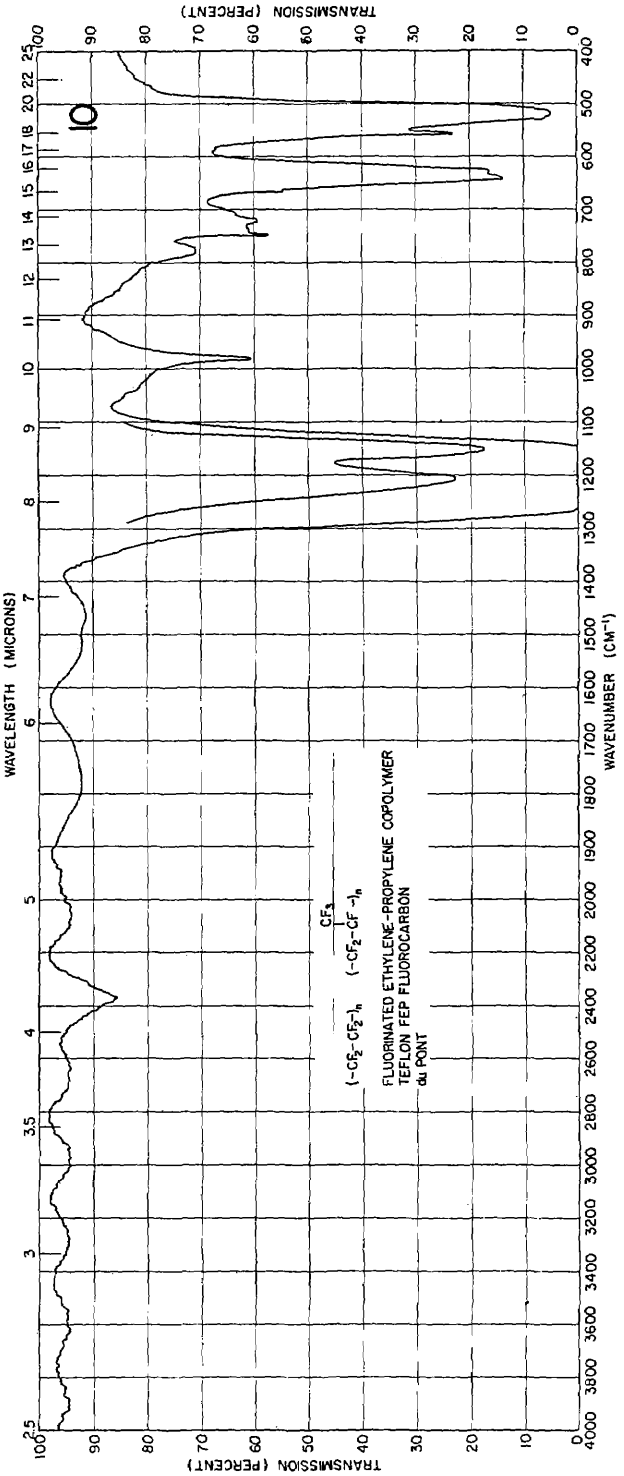

5
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
(-CH2-CH-)n
C≡N
POLYACRYLONITRILE
ORLON
du PONT

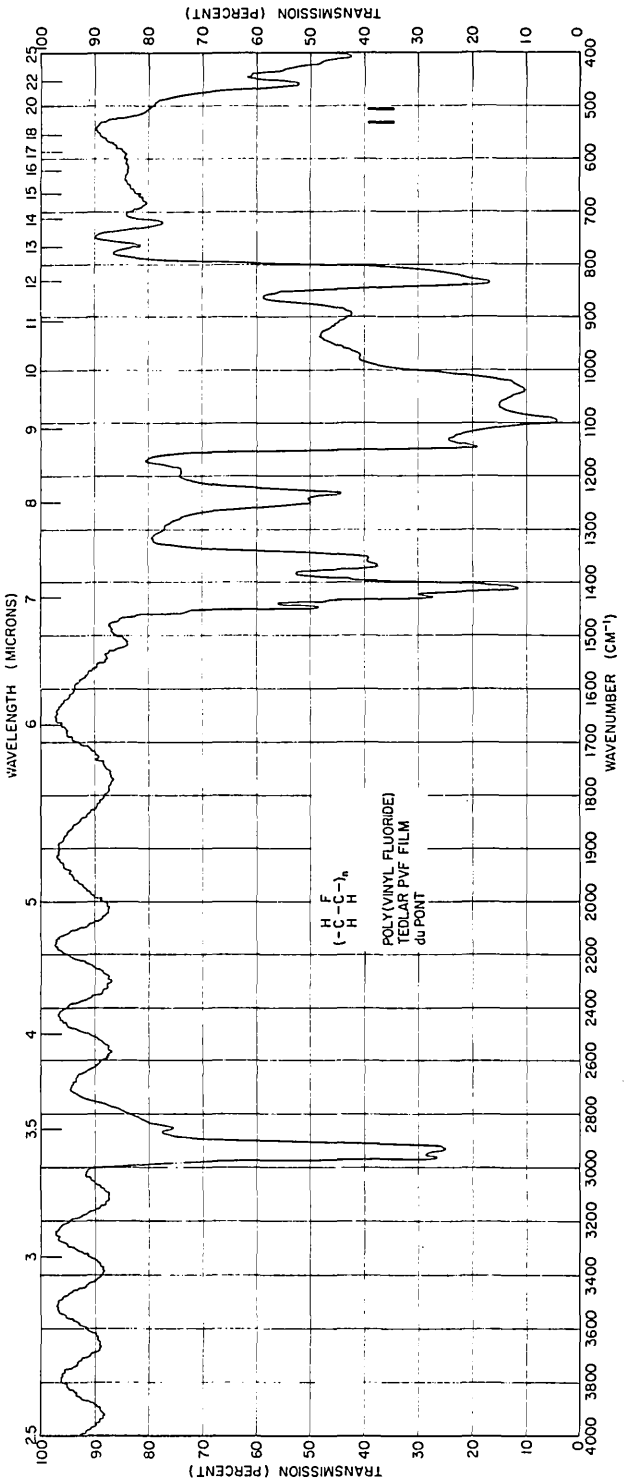

6
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
(-CH2-CH=CH-CH2-)n
(-CH=CH-CH2-CH2-)n
(-CH2-CH-)n
C≡N
ACRYLONITRILE-BUTADIENE COPOLYMER
HYCAR - 1562
B. F. GOODRICH

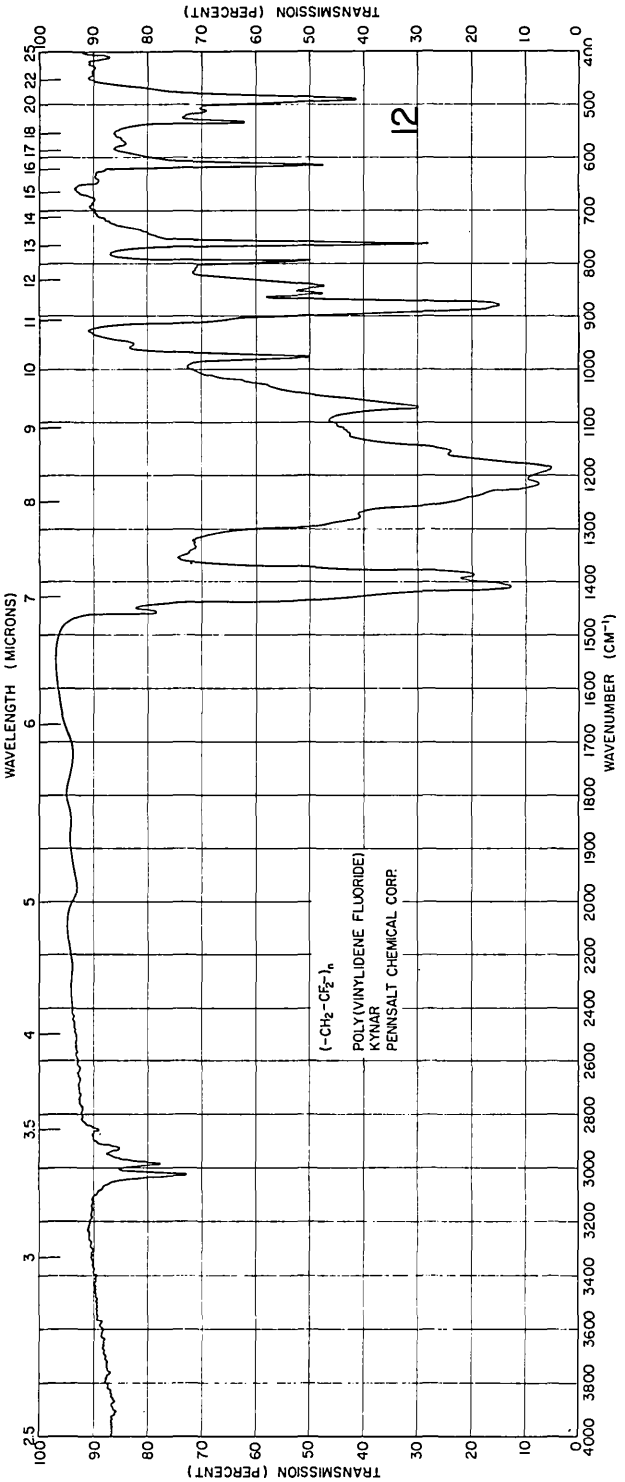

7
DAPON 35
FMC CORPORATION
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

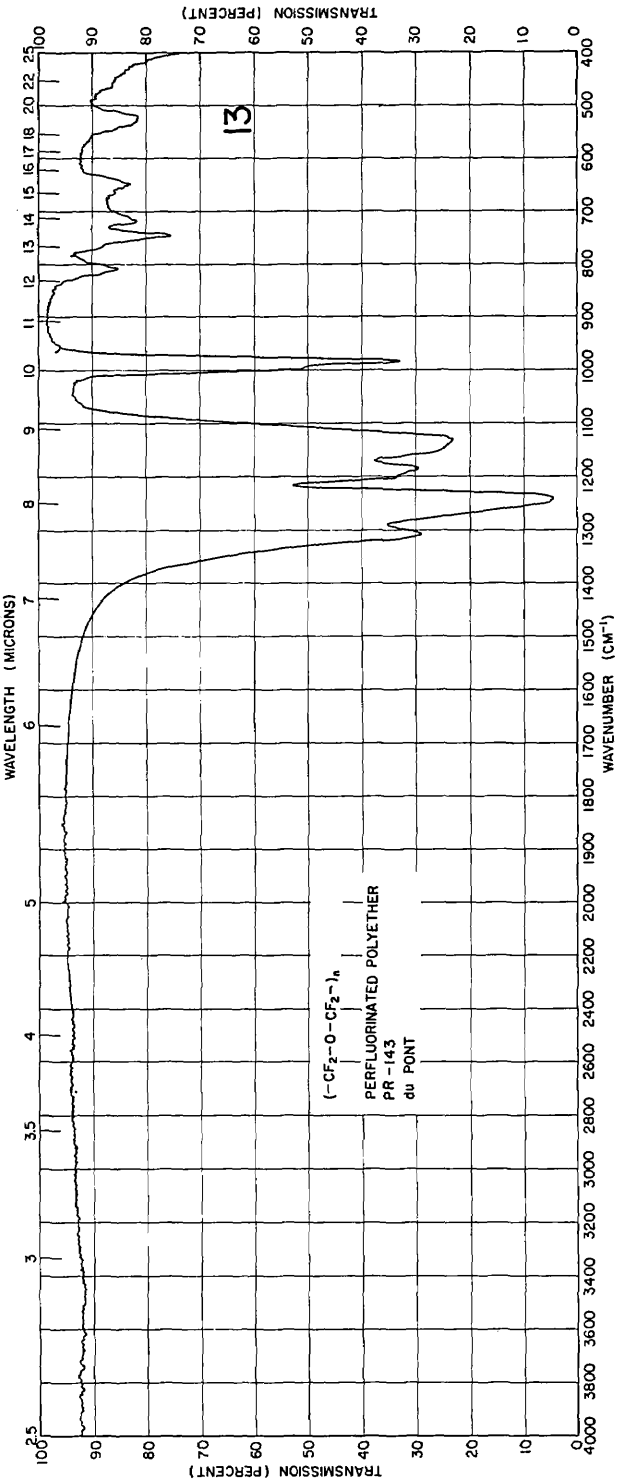

8
DAPON M
FMC CORPORATION
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

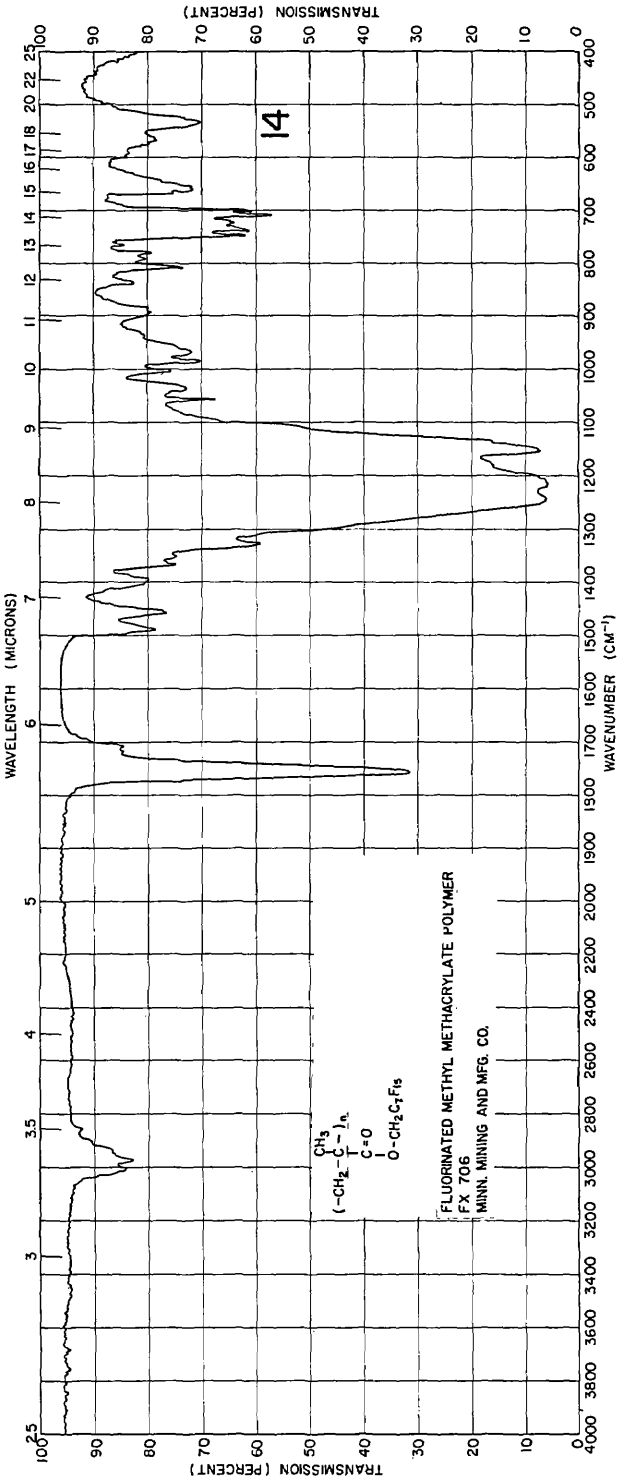

9
CELLULOSE ACETATE PROPIONATE
FORTICEL
CELANESE CORP.
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

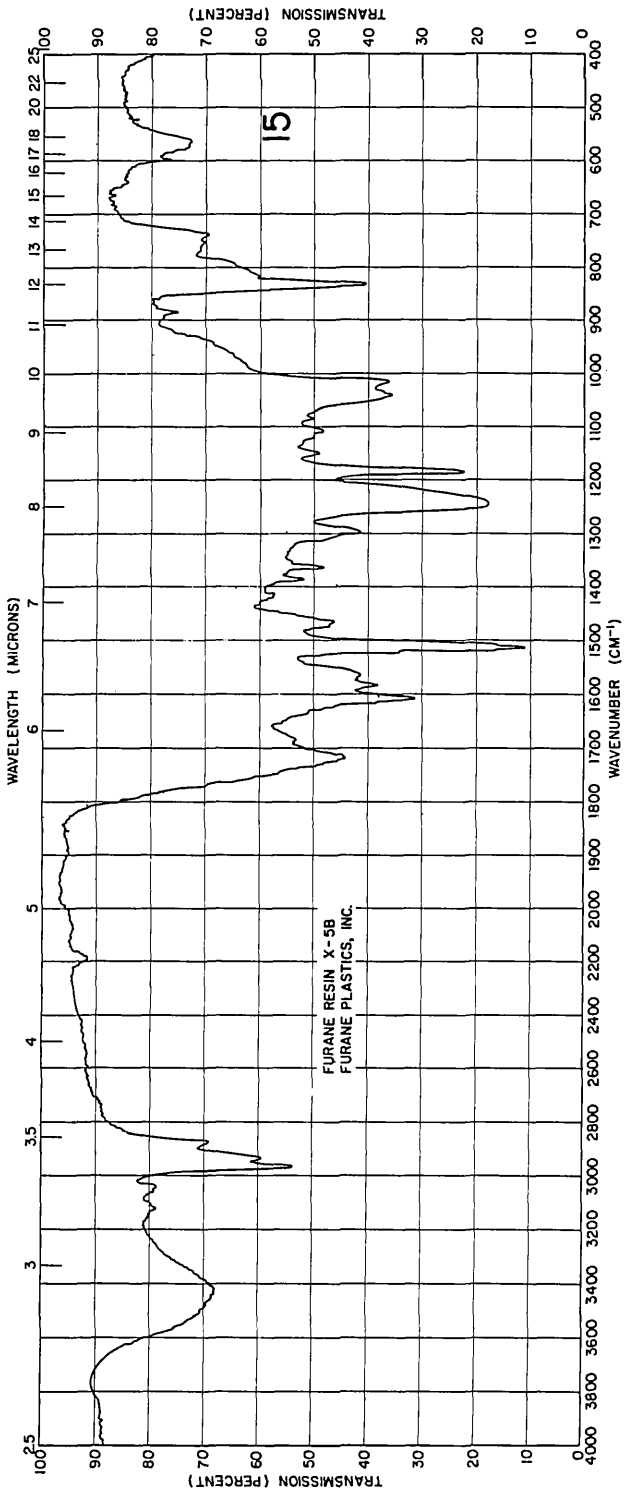

10
FLUORINATED ETHYLENE-PROPYLENE COPOLYMER
TEFLON FEP FLUOROCARBON
du PONT
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

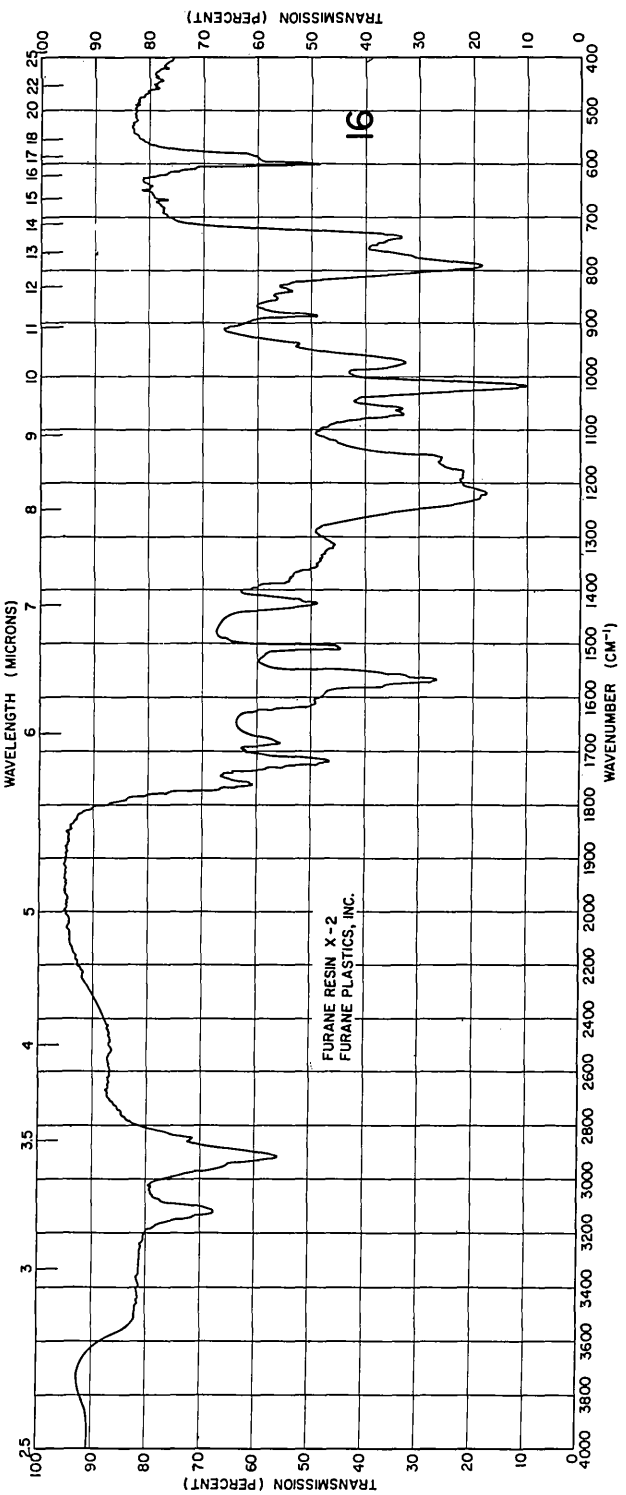

11
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
POLY(VINYL FLUORIDE)
TEDLAR PVF FILM
du PONT

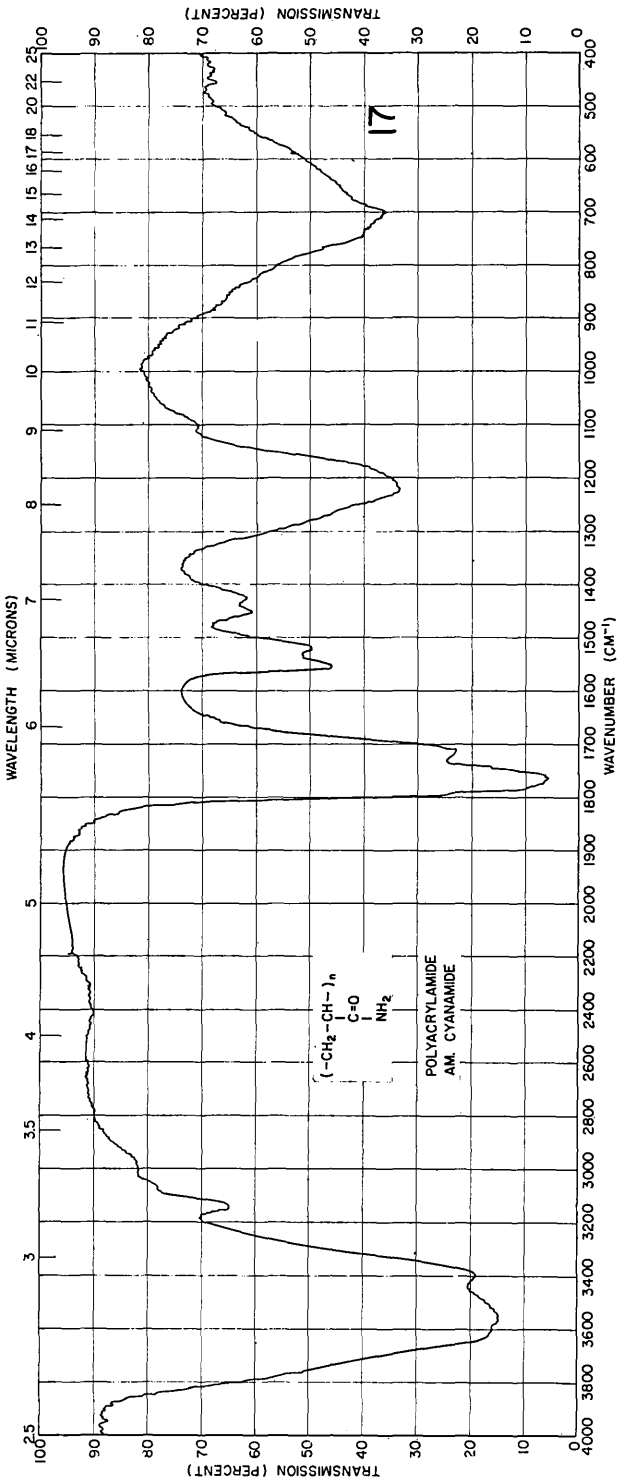

12
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
POLY(VINYLIDENE FLUORIDE)
KYNAR
PENNSALT CHEMICAL CORP.

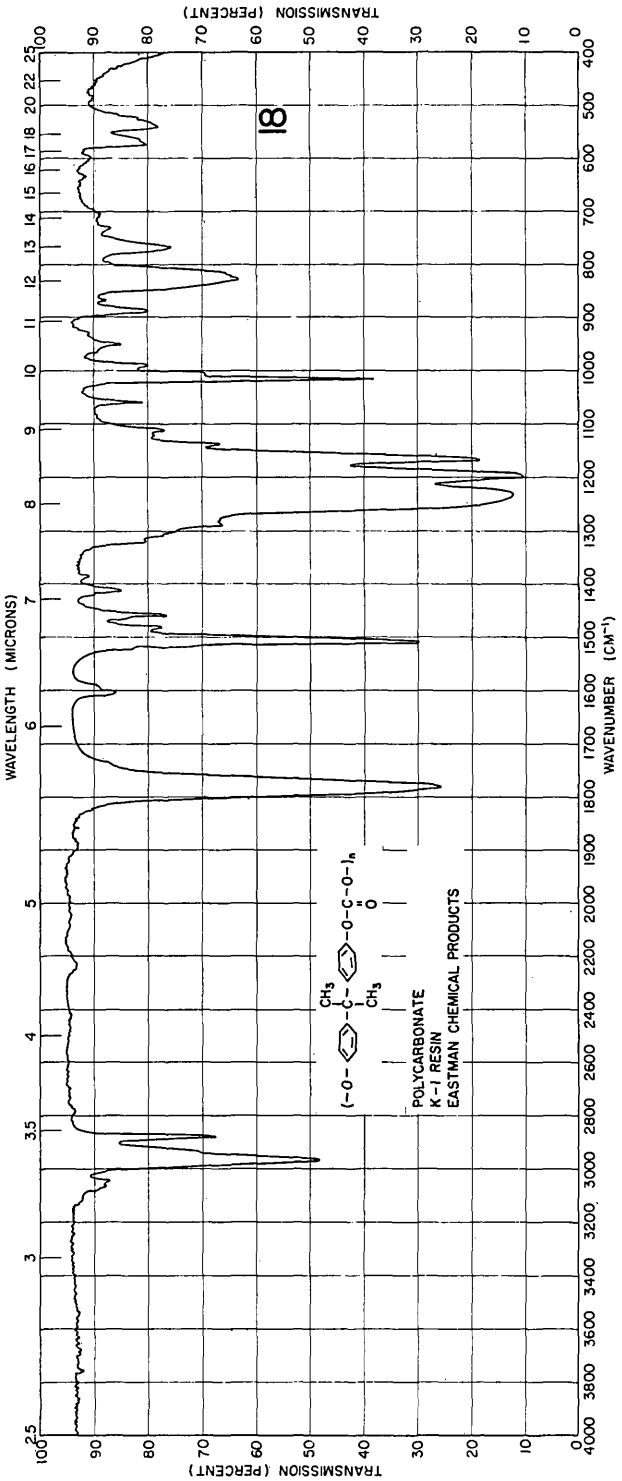

13
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
(-CF2-O-CF2-)n
PERFLUORINATED POLYETHER
PR-143
du PONT

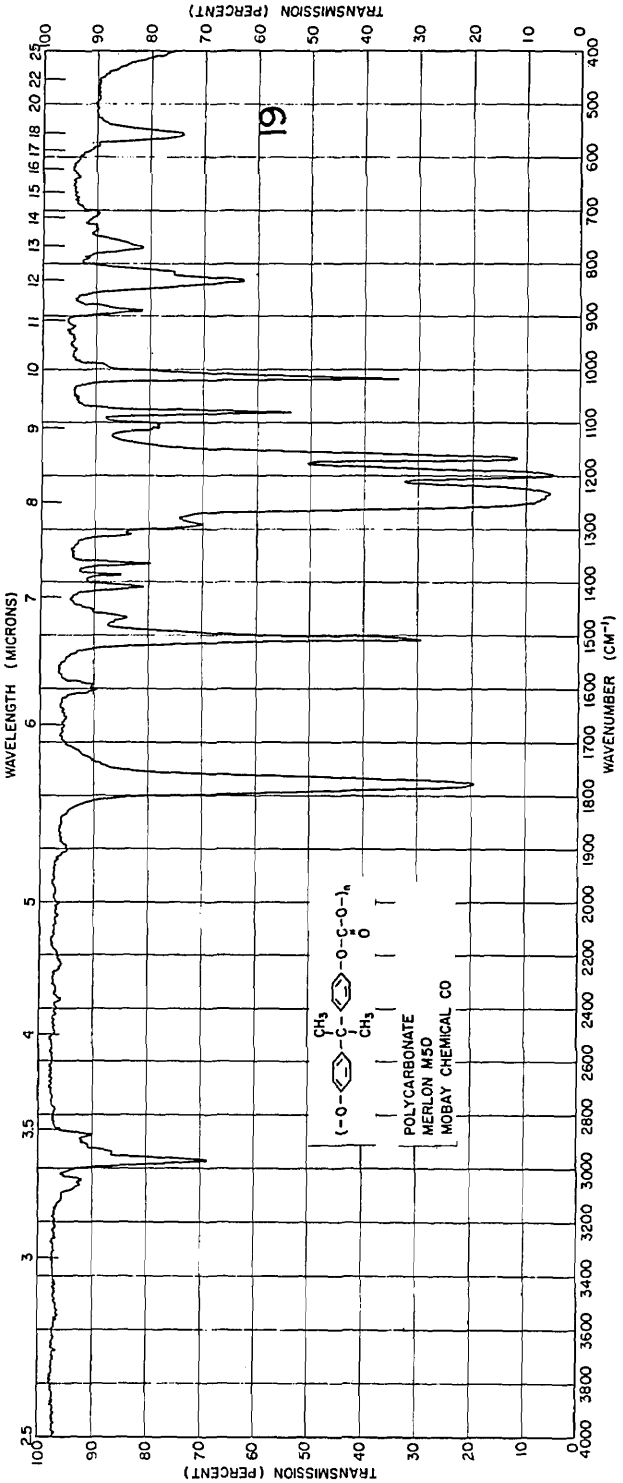

14
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
FLUORINATED METHYL METHACRYLATE POLYMER
FX 706
MINN. MINING AND MFG. CO.

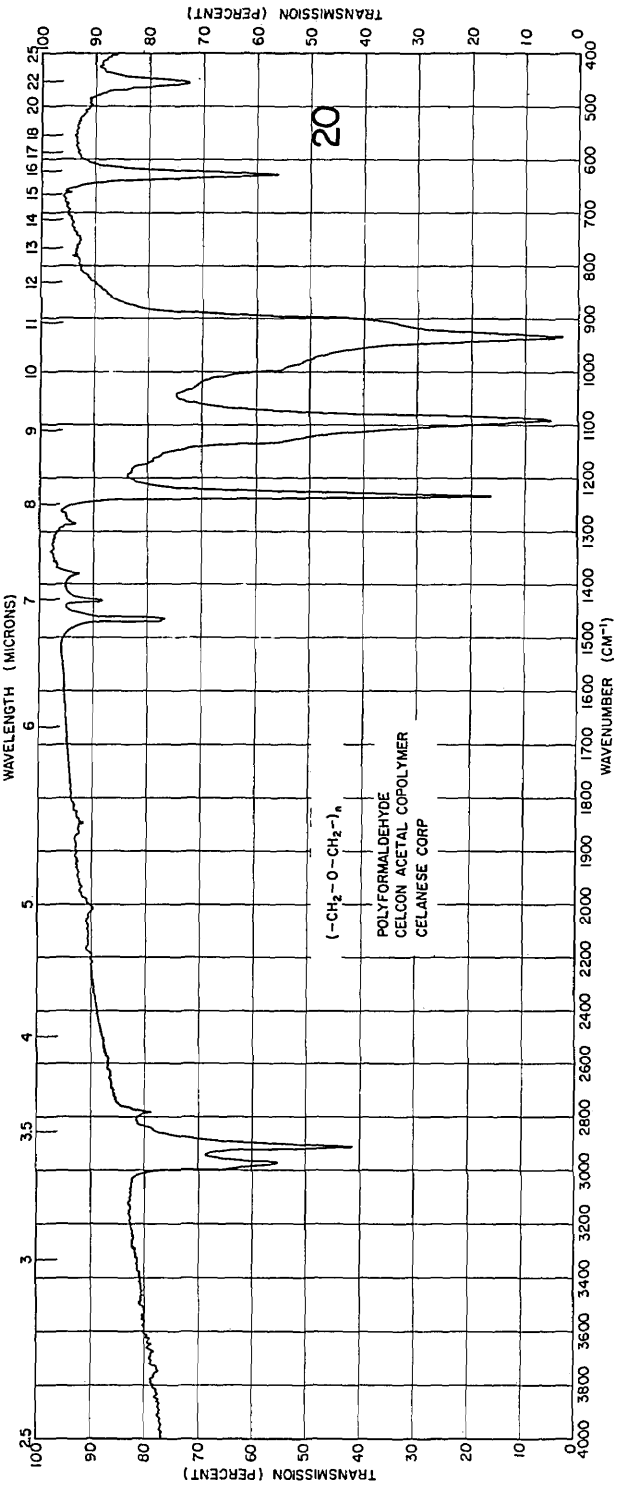

15
FURANE RESIN X-5B
FURANE PLASTICS, INC.
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

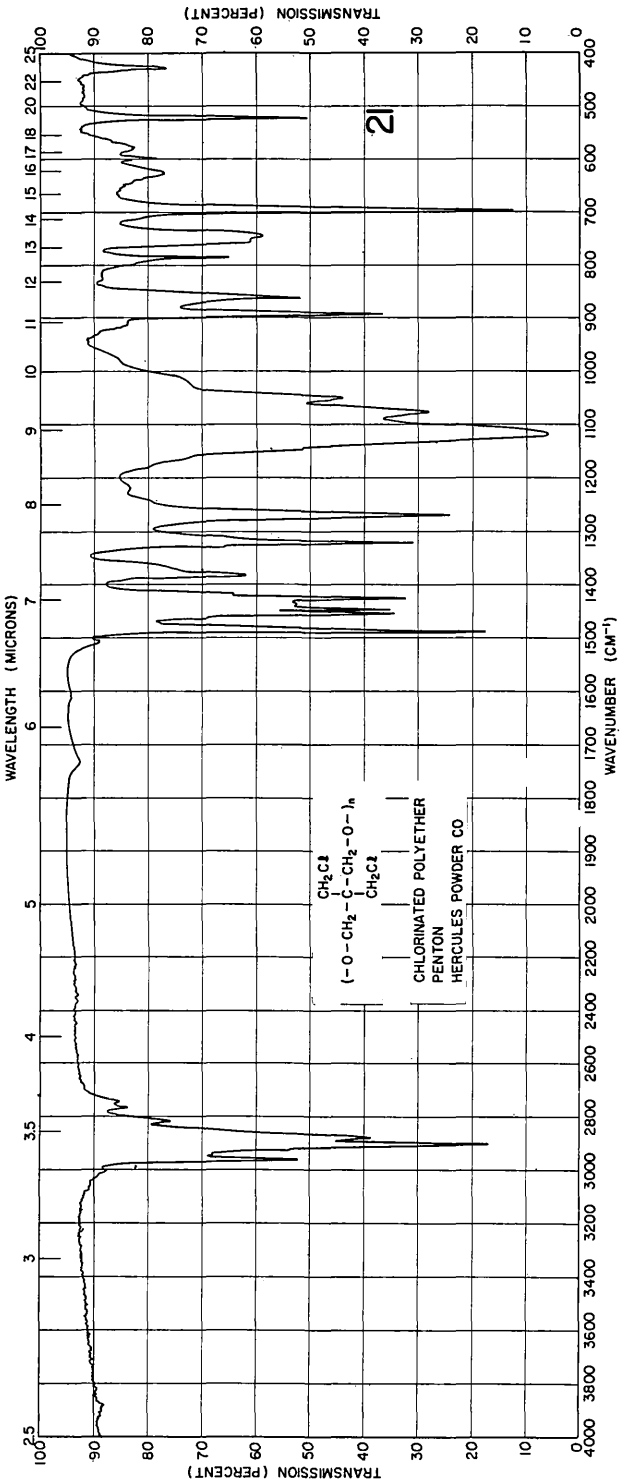

16
FURANE RESIN X-2
FURANE PLASTICS, INC.
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

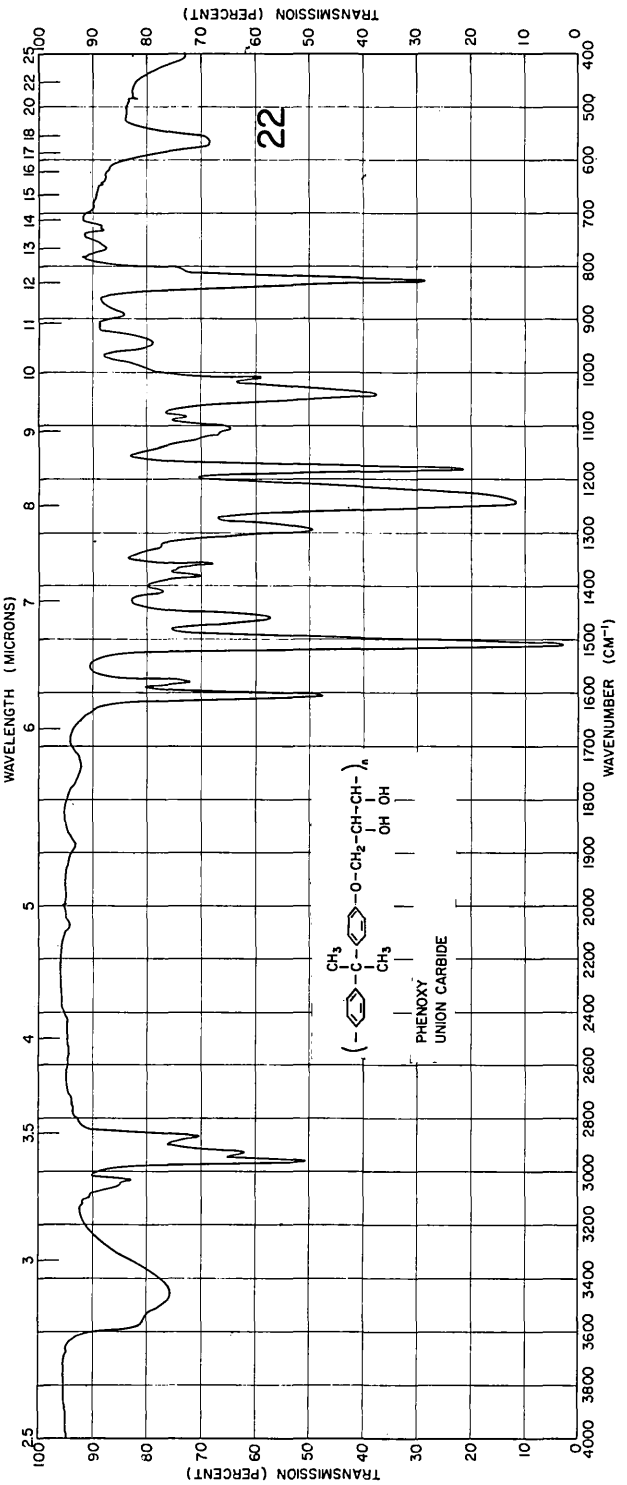

17
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
POLYACRYLAMIDE
AM. CYANAMIDE

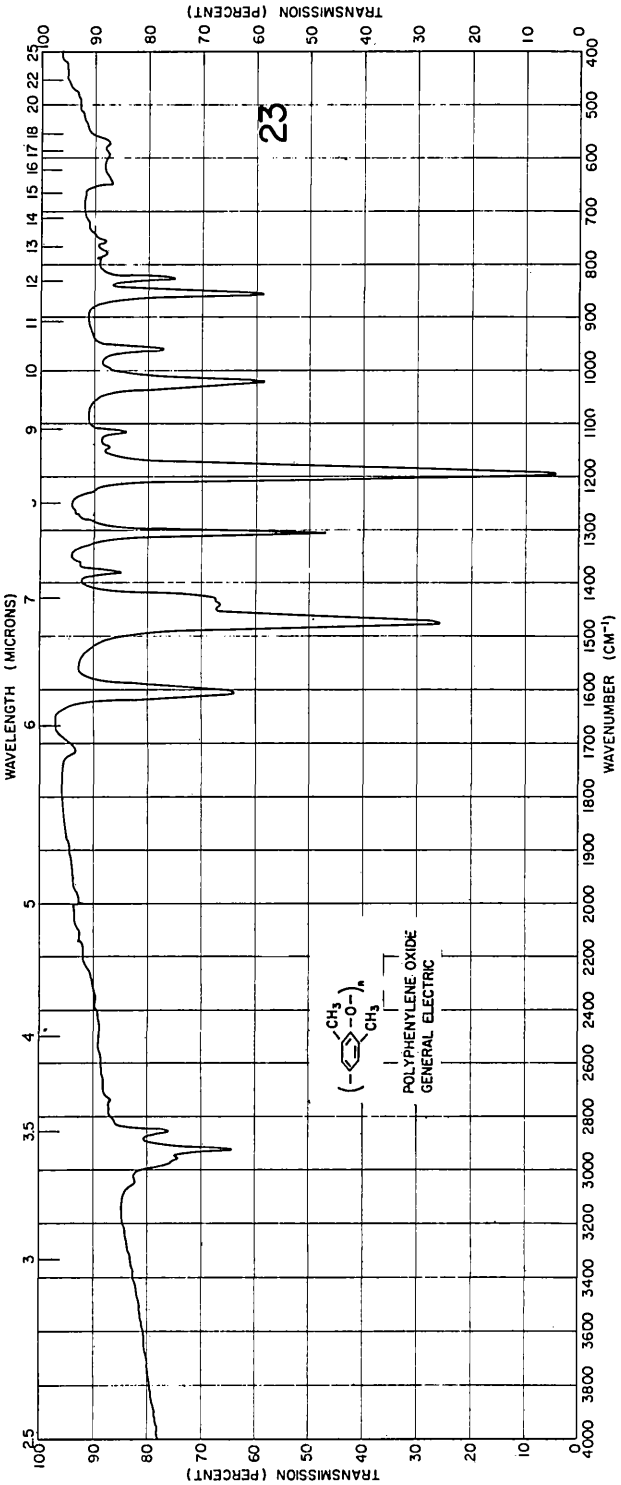

18
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
POLYCARBONATE
K-1 RESIN
EASTMAN CHEMICAL PRODUCTS

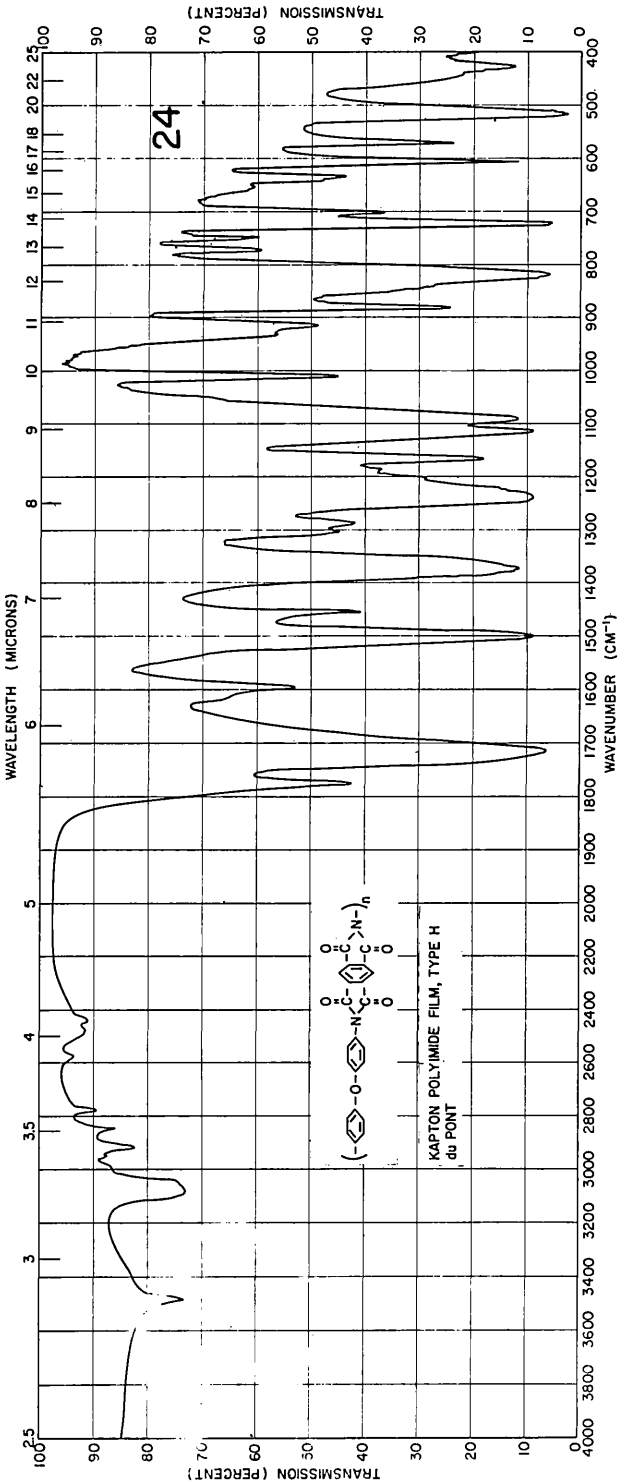

19
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
POLYCARBONATE
MERLON M50
MOBAY CHEMICAL CO

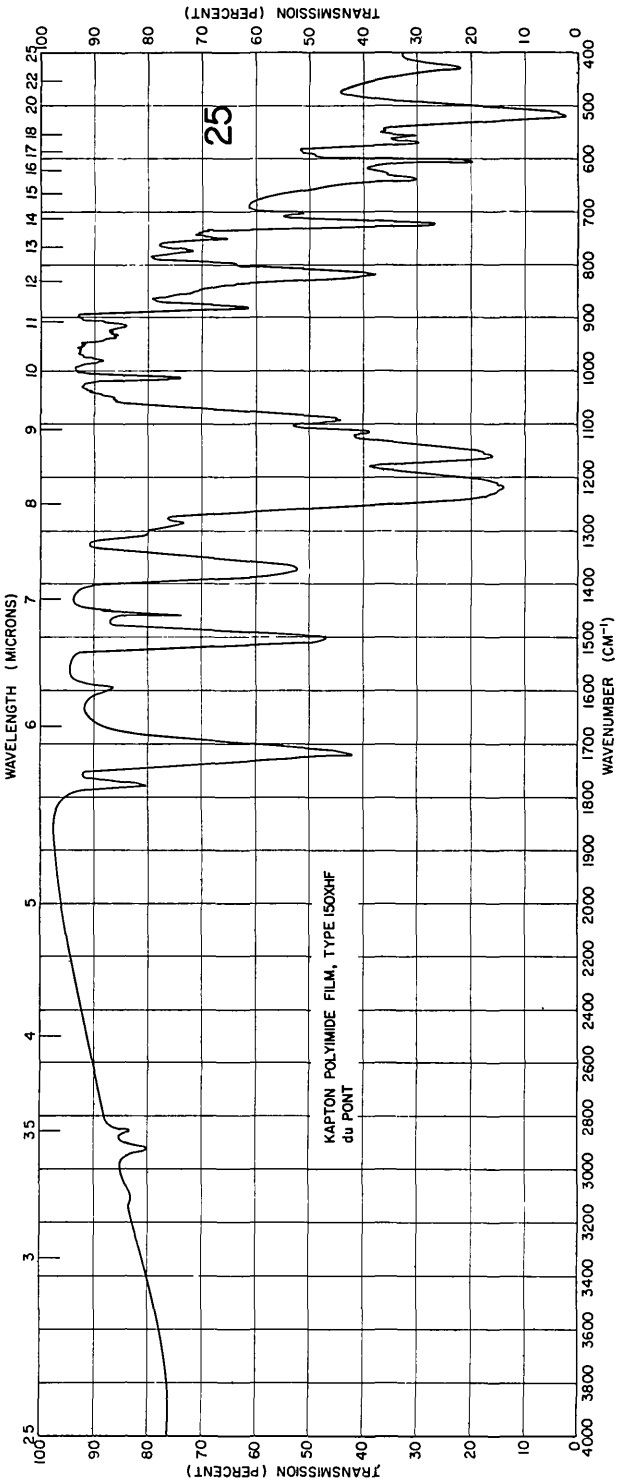

20
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
POLYFORMALDEHYDE
CELCON ACETAL COPOLYMER
CELANESE CORP

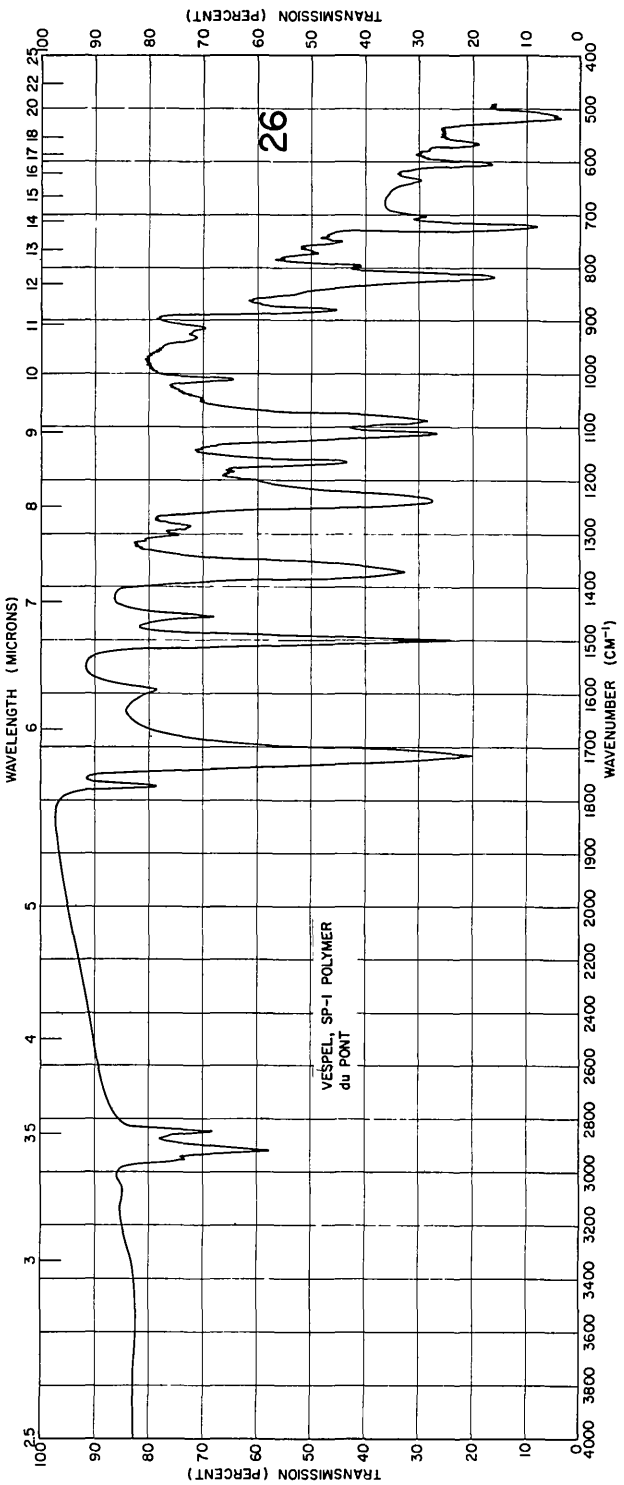

21
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
CHLORINATED POLYETHER
PENTON
HERCULES POWDER CO

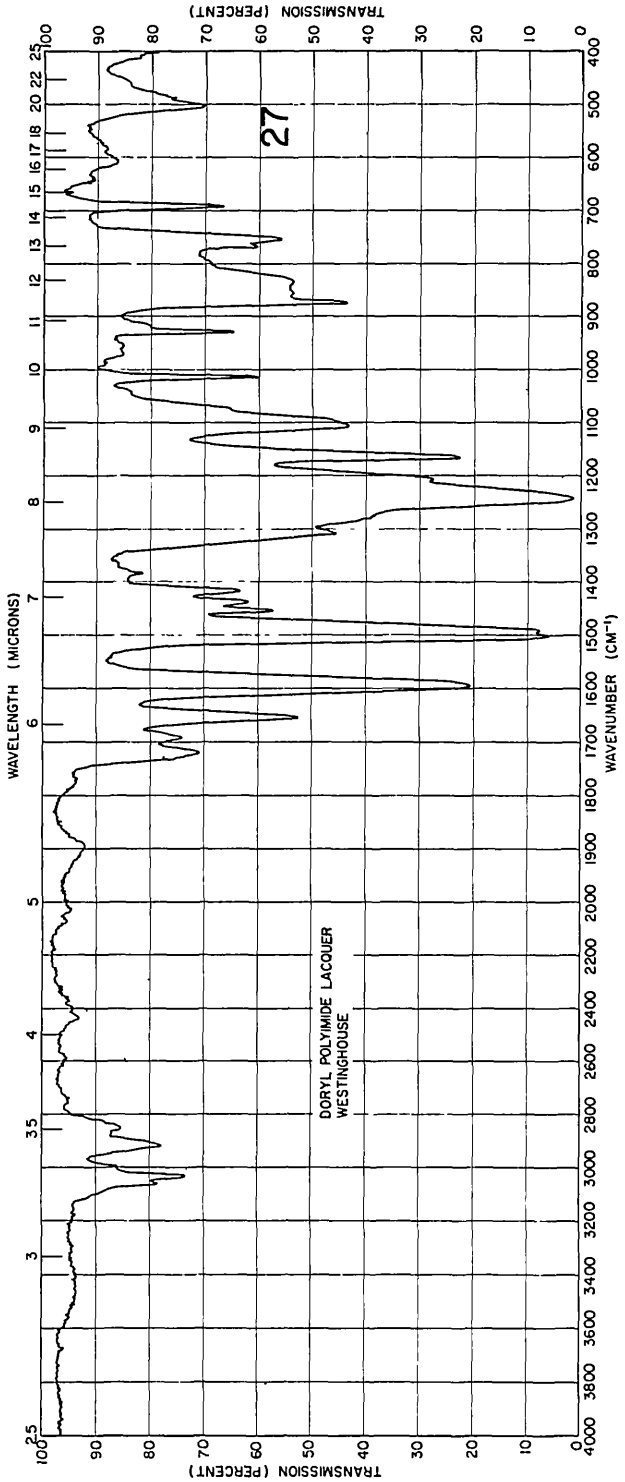

22
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
PHENOXY
UNION CARBIDE

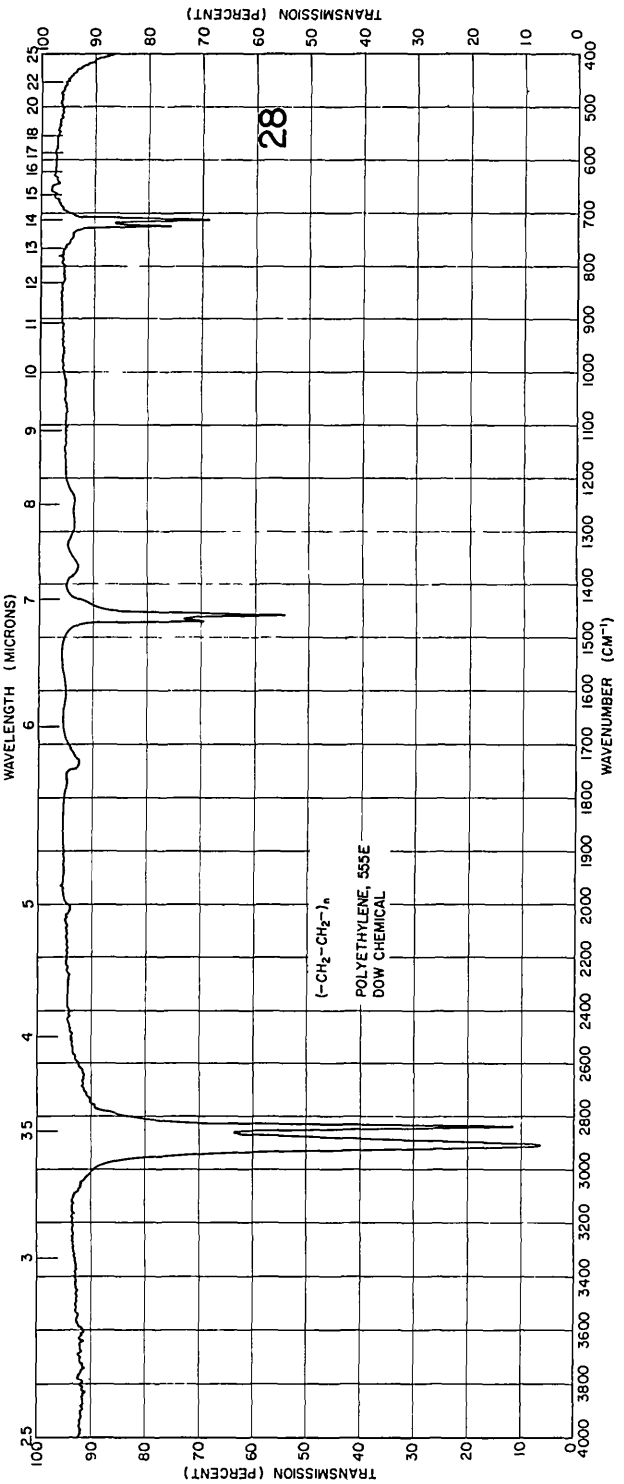

23
POLYPHENYLENE OXIDE
GENERAL ELECTRIC
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

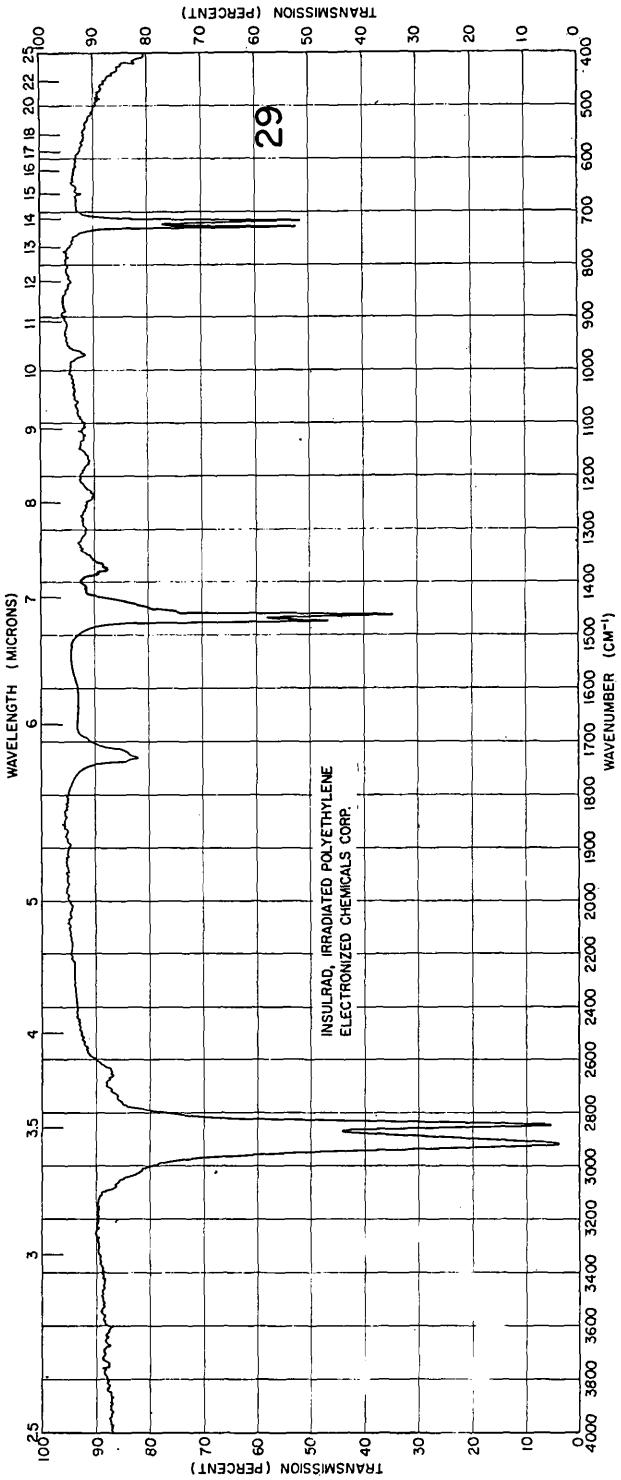

24
KAPTON POLYIMIDE FILM, TYPE H
du PONT
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

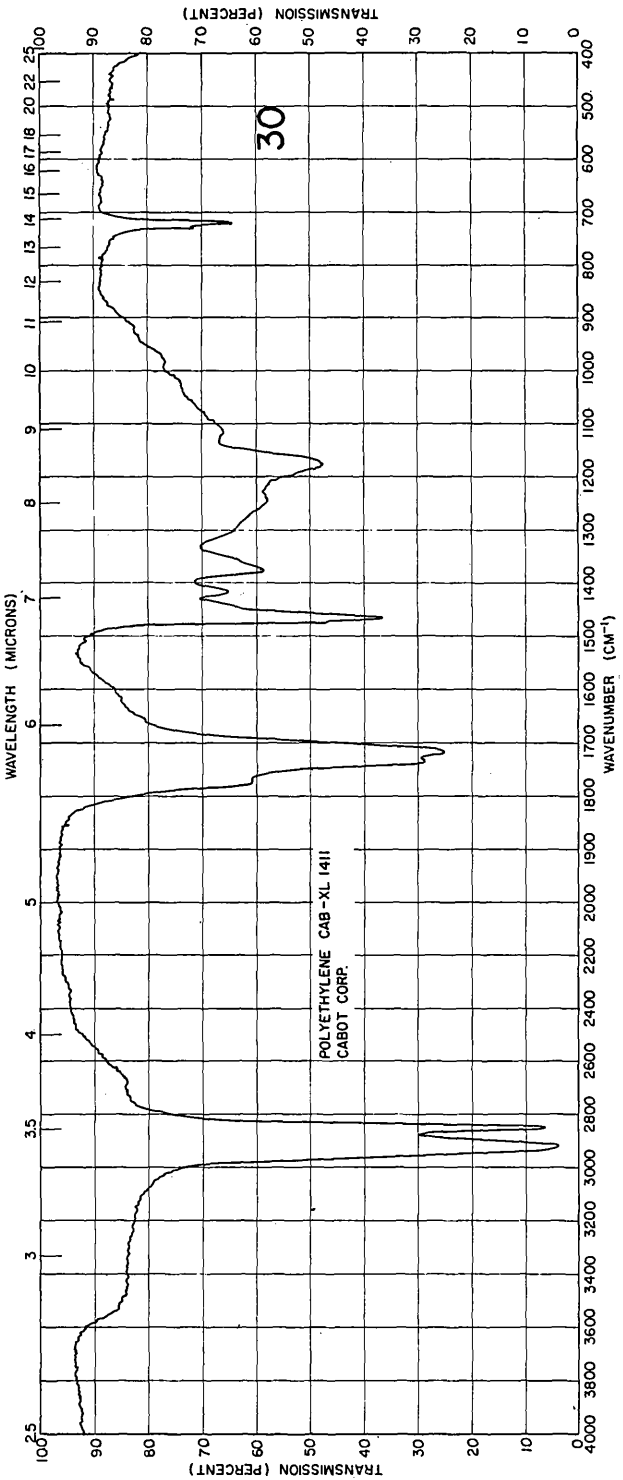

25
KAPTON POLYIMIDE FILM, TYPE 150XHF
du PONT
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

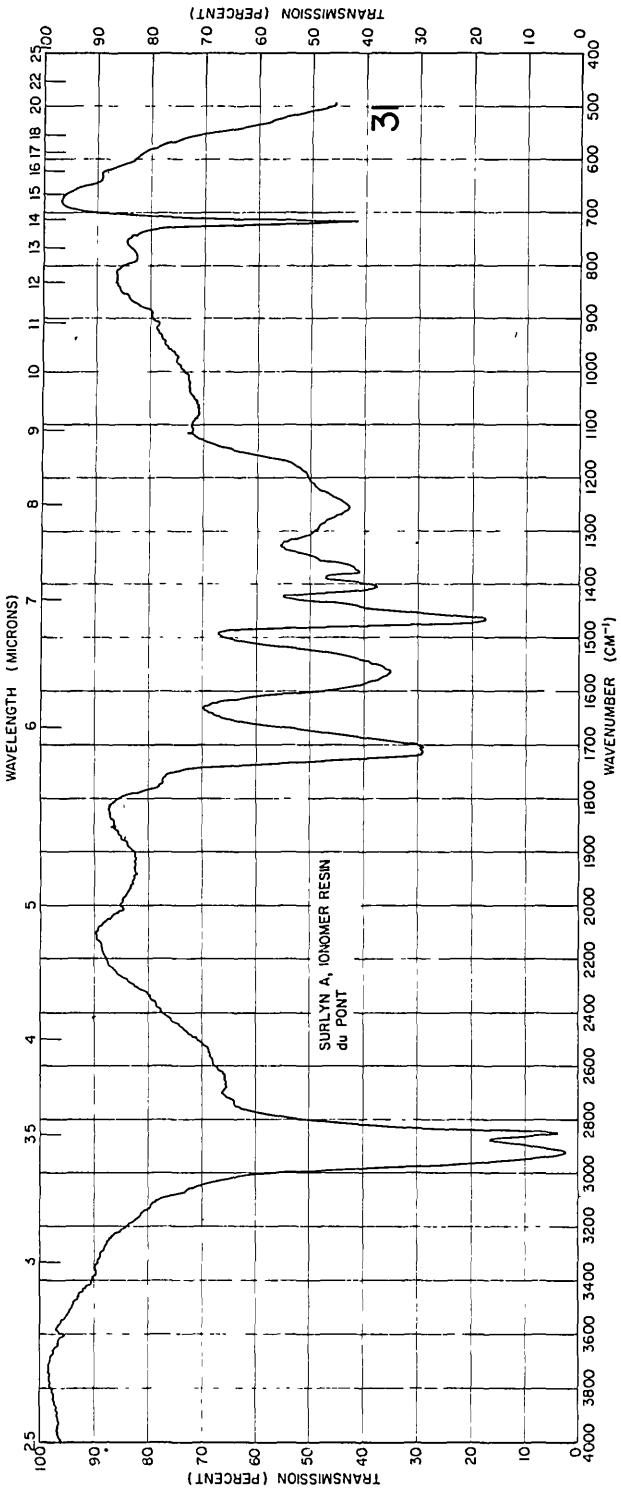

26
VESPEL, SP-1 POLYMER
du PONT
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

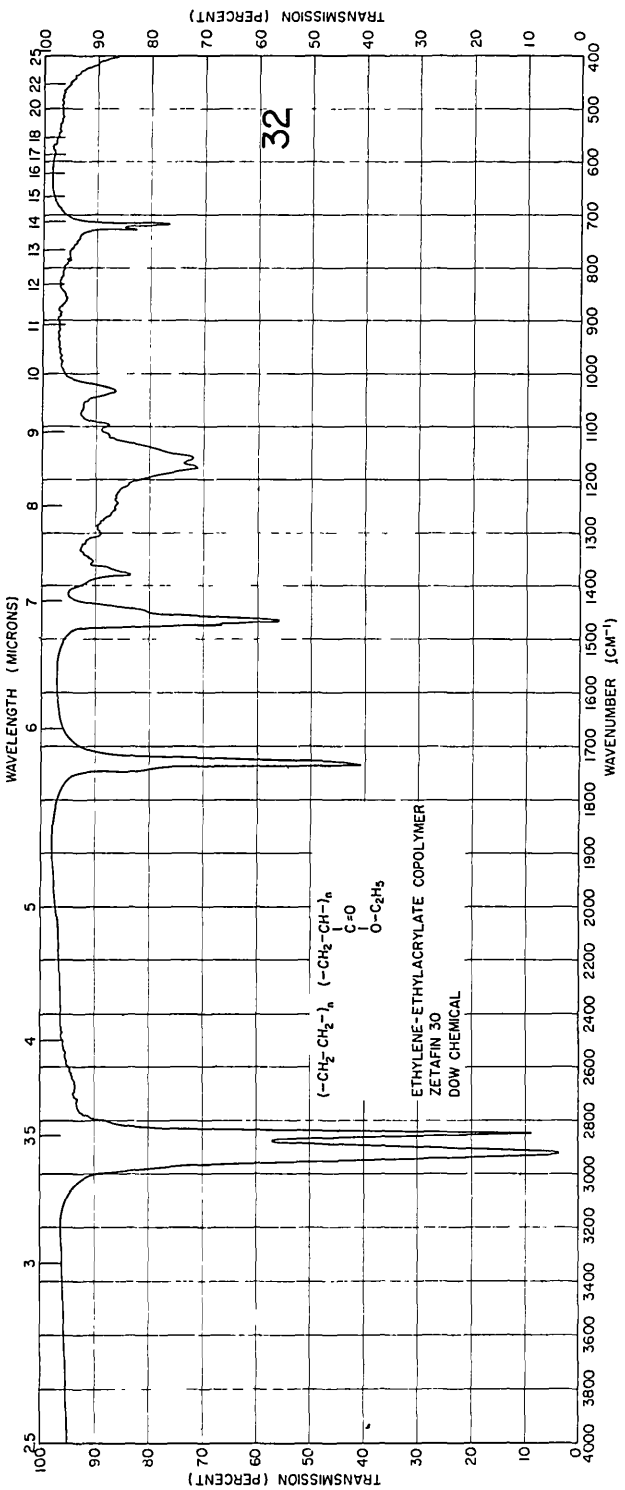

27
DORYL POLYIMIDE LACQUER
WESTINGHOUSE
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

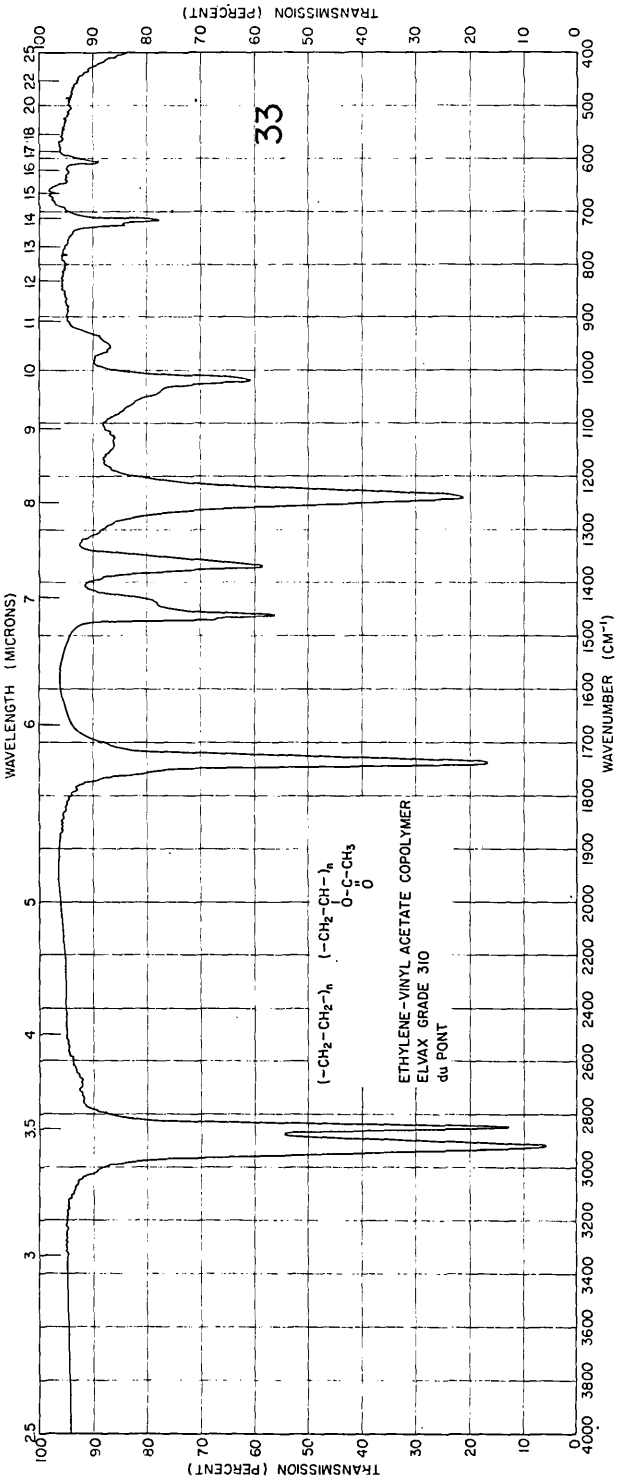

28
(-CH2-CH2-)n
POLYETHYLENE, 555E
DOW CHEMICAL
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

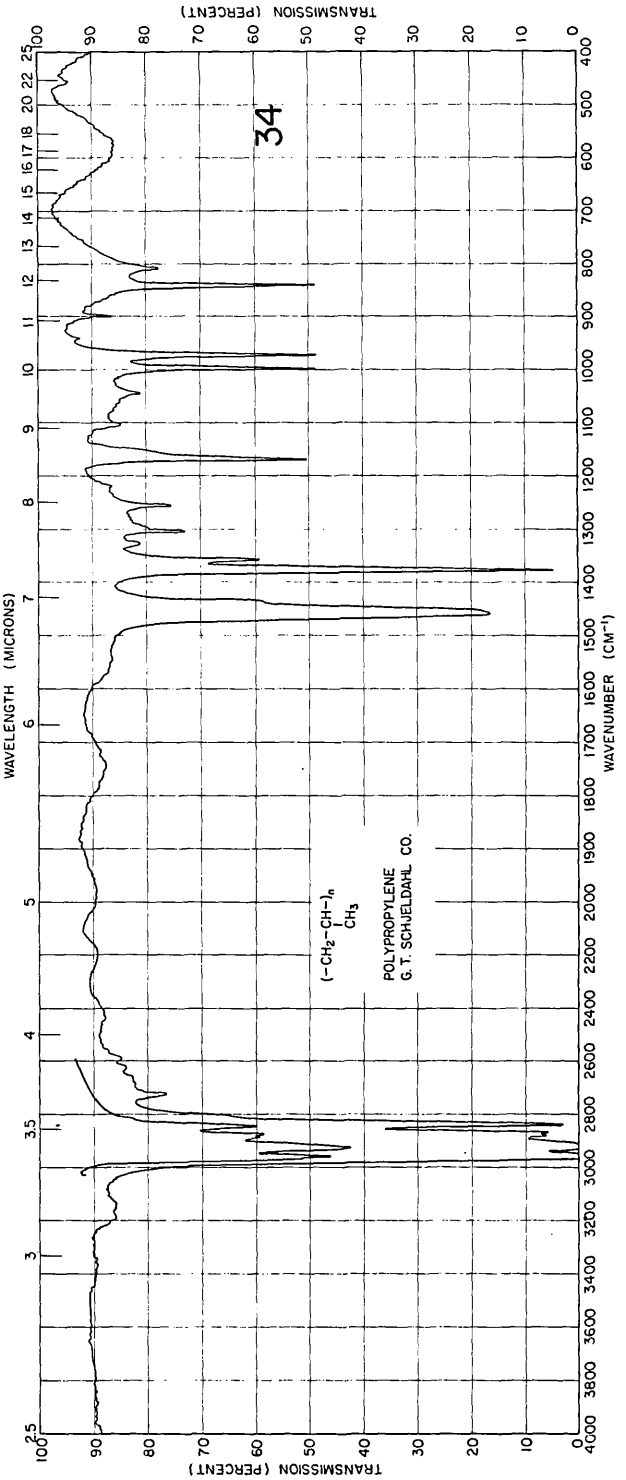

29
INSULRAD, IRRADIATED POLYETHYLENE
ELECTRONIZED CHEMICALS CORP.
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

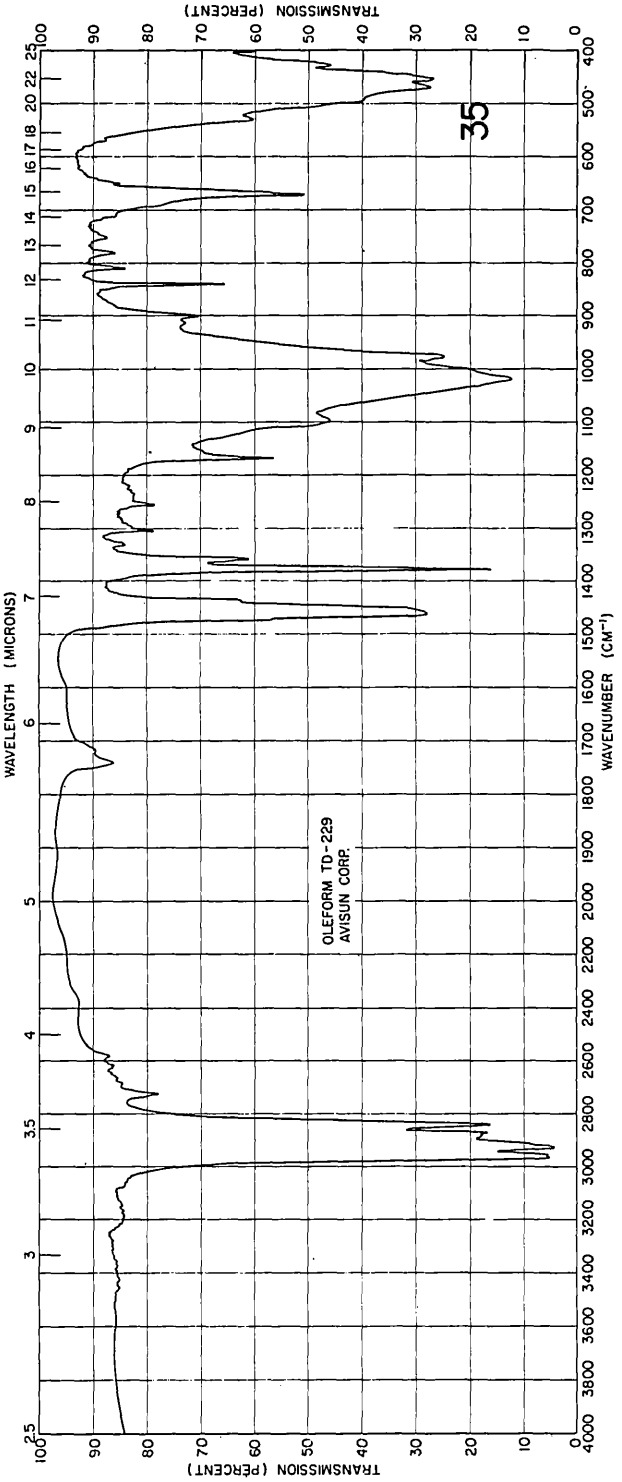

30
POLYETHYLENE CAB-XL 1411
CABOT CORP.
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

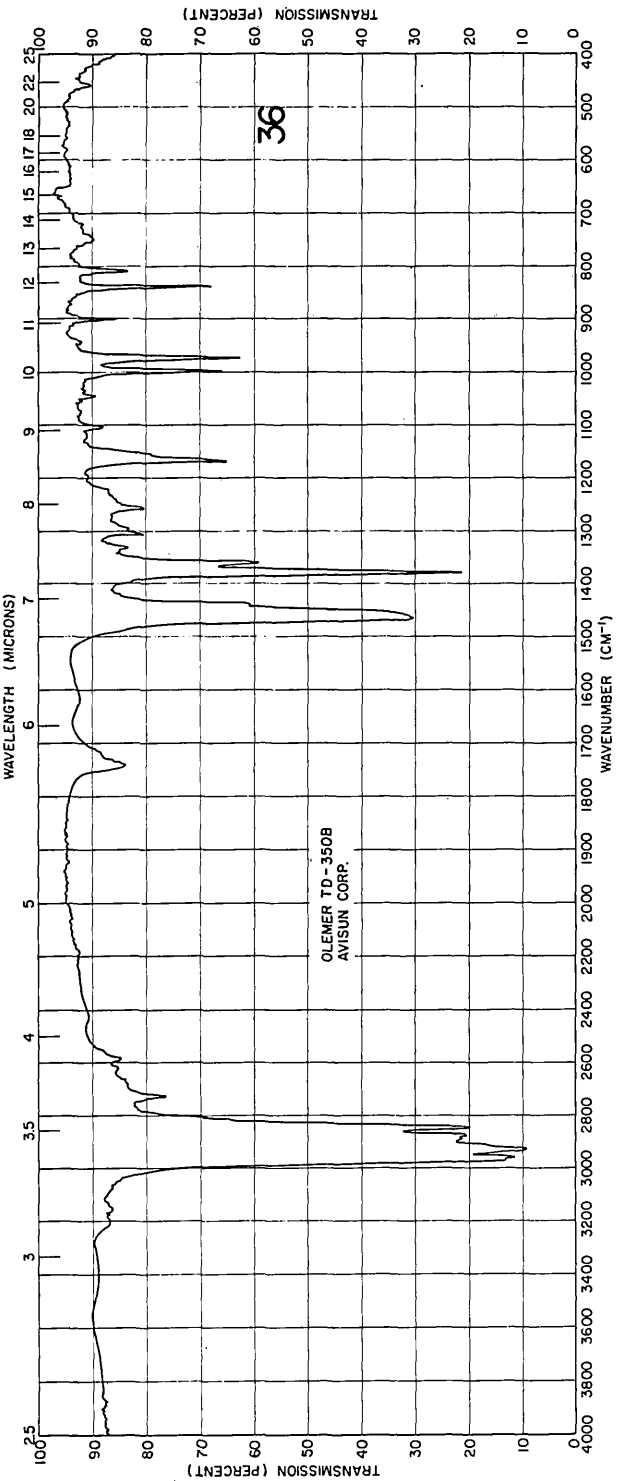

31
SURLYN A, IONOMER RESIN
du PONT
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

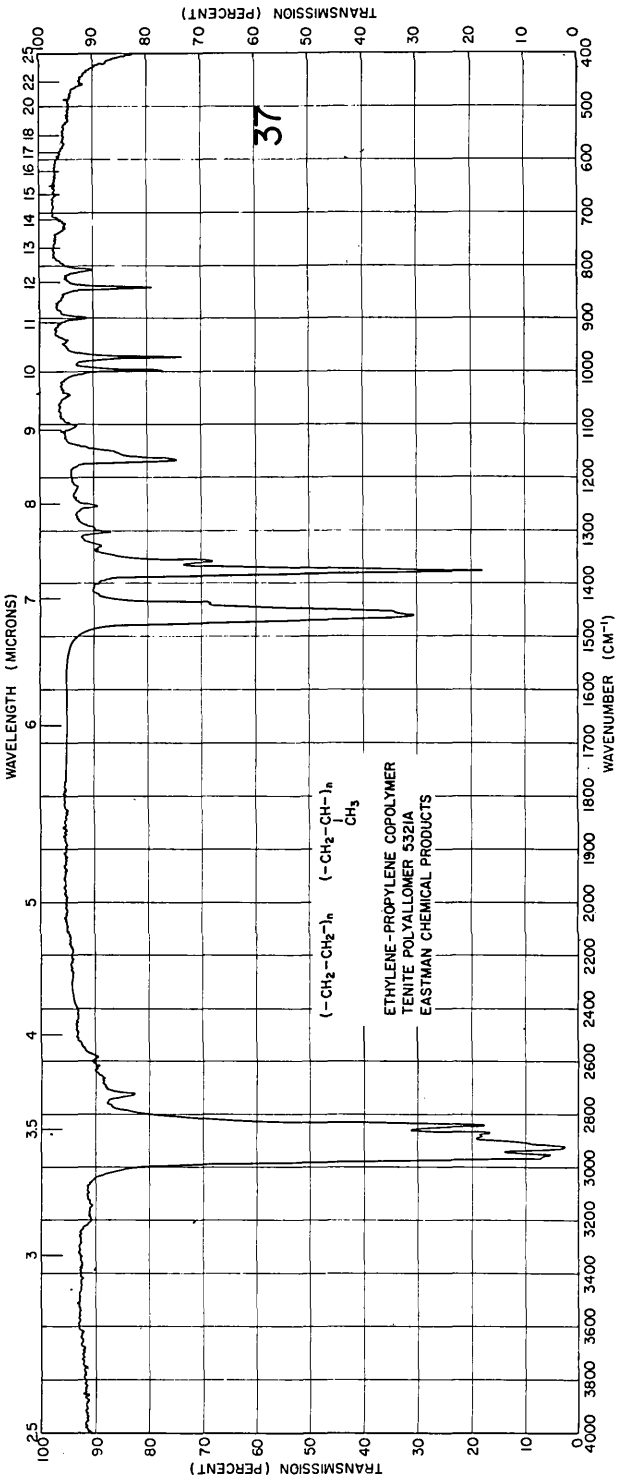

32
ETHYLENE-ETHYLACRYLATE COPOLYMER
ZETAFIN 30
DOW CHEMICAL
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

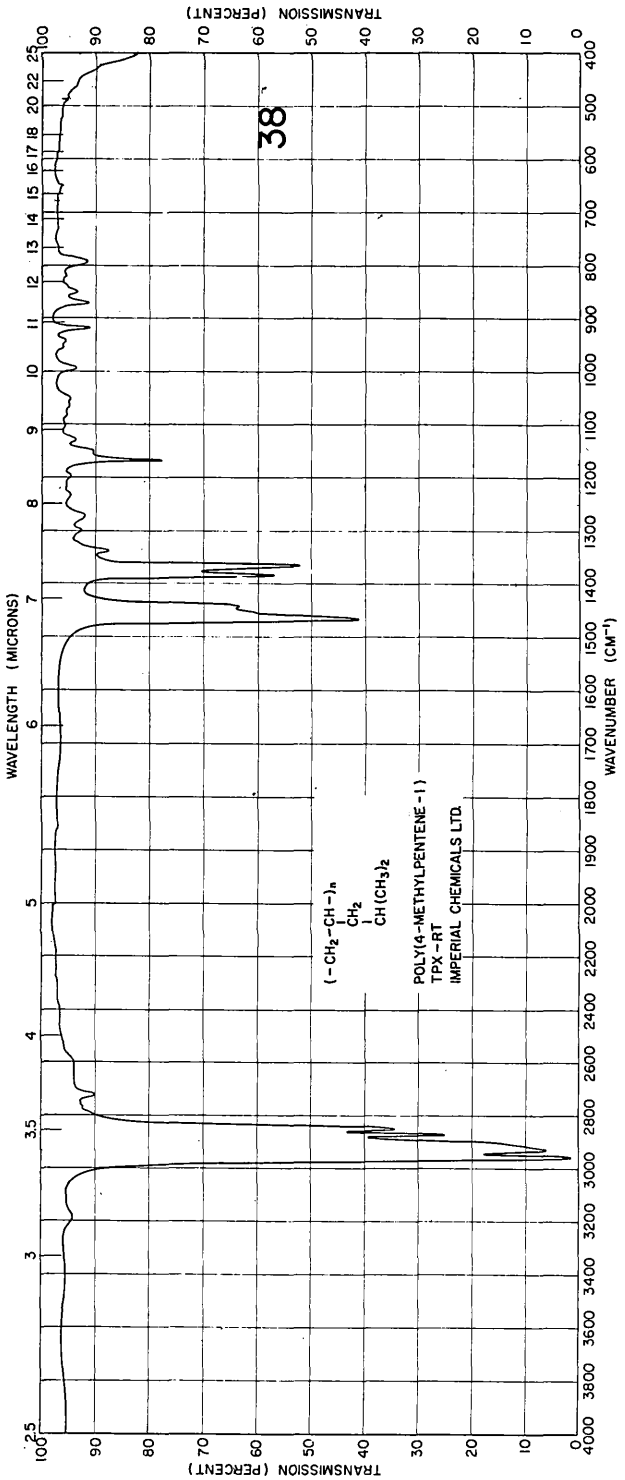

33
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
(-CH2-CH2-)n (-CH2-CH-)n
O-C-CH3
O
ETHYLENE-VINYL ACETATE COPOLYMER
ELVAX GRADE 310
du PONT

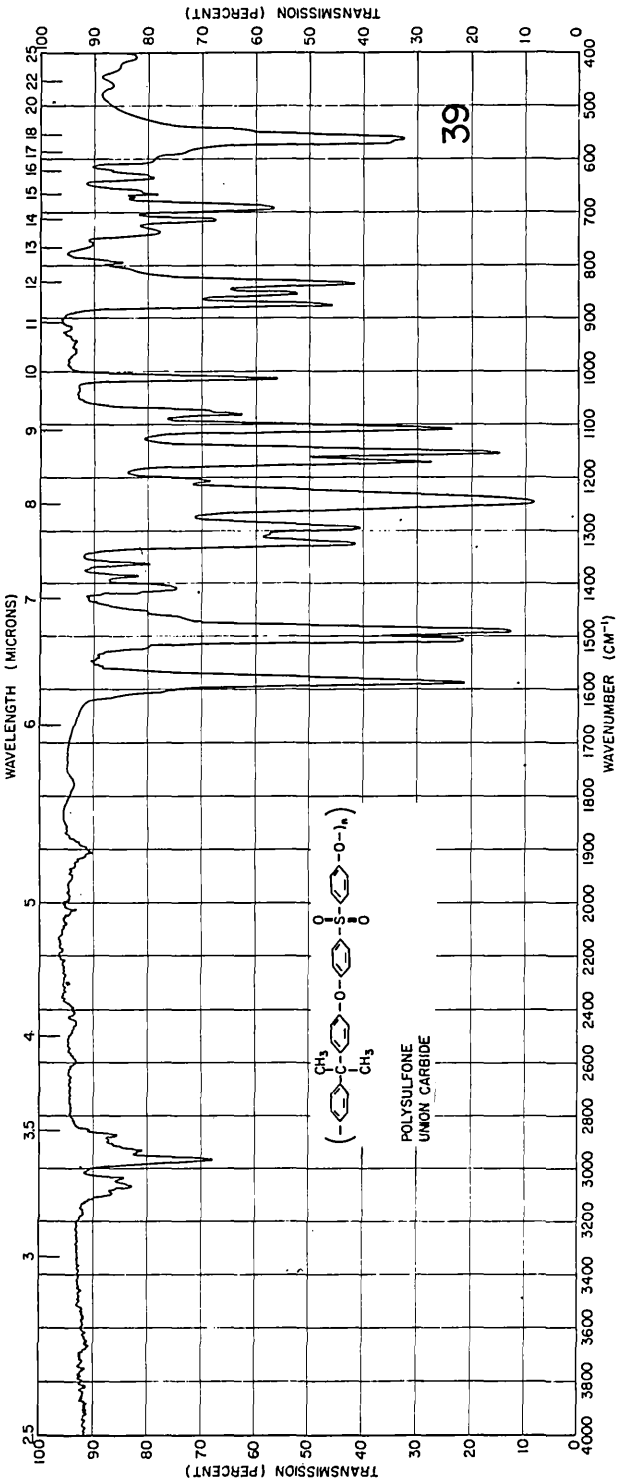

34
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
(-CH2-CH-)n
CH3
POLYPROPYLENE
G. T. SCHUELDAHL CO.

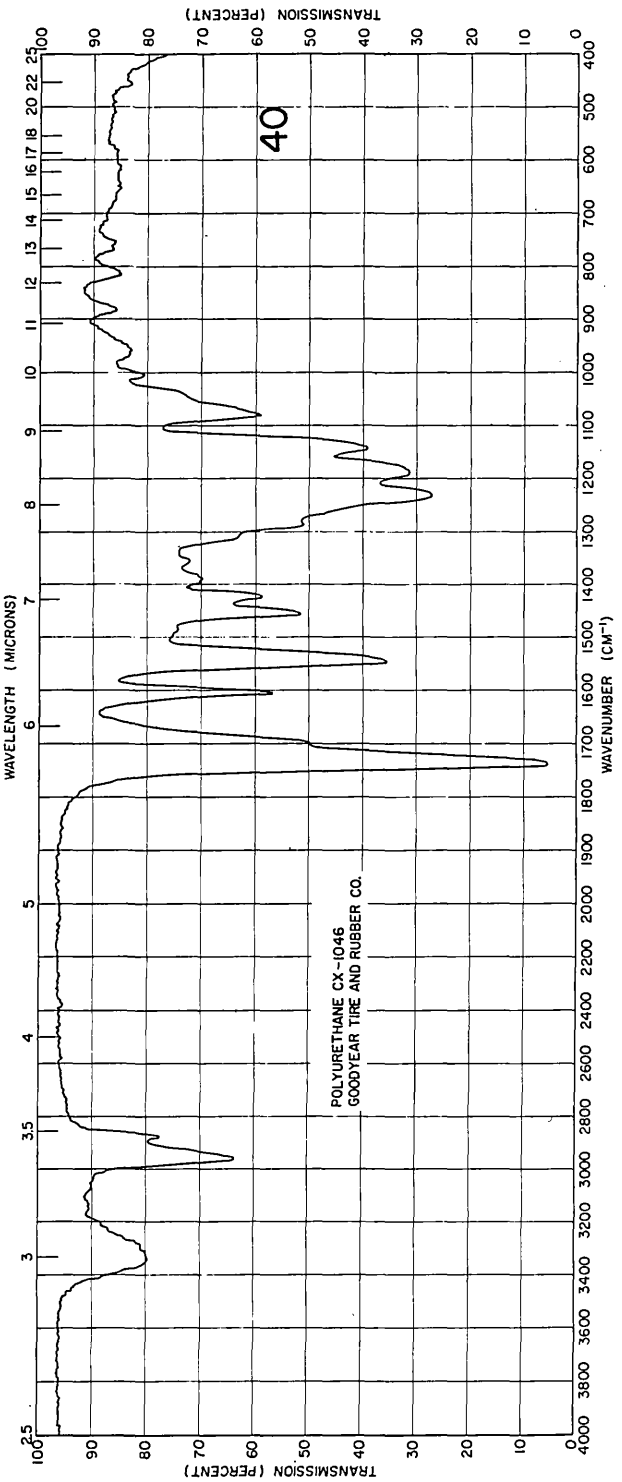

35
OLEFORM TD-229
AVISUN CORP.
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

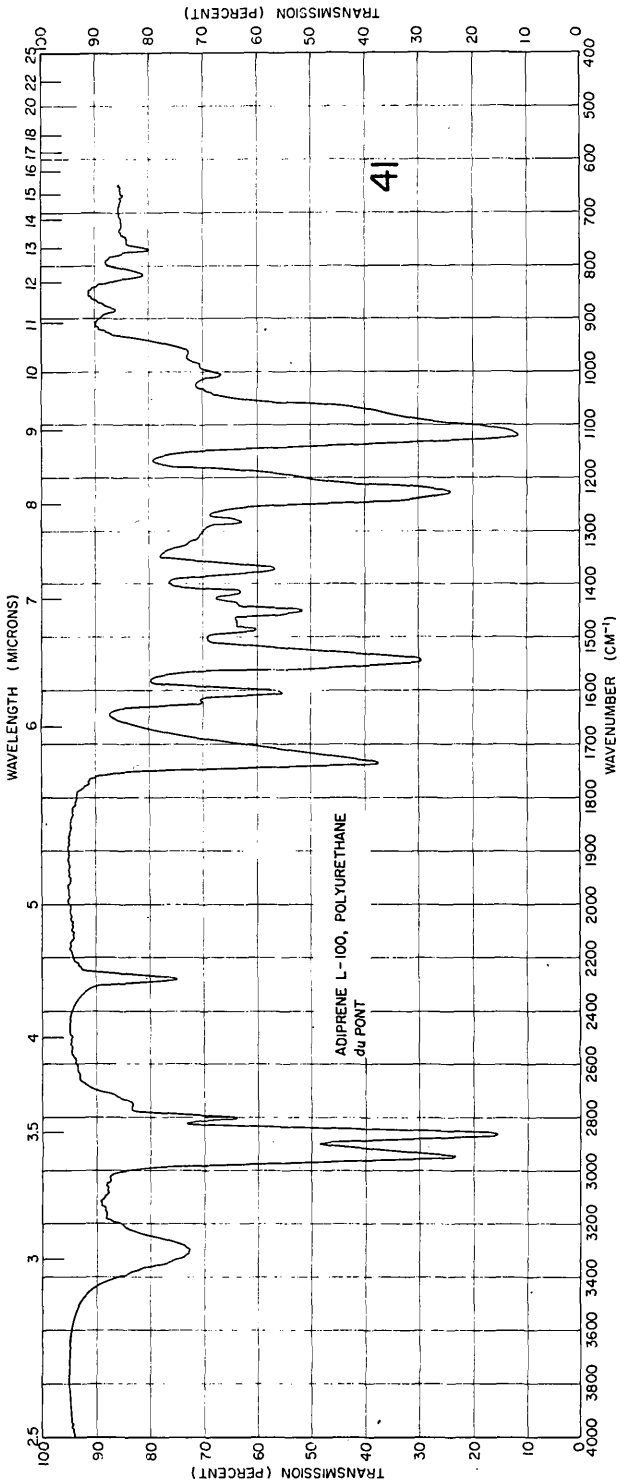

36
OLEMER TD-350B
AVISUN CORP.
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

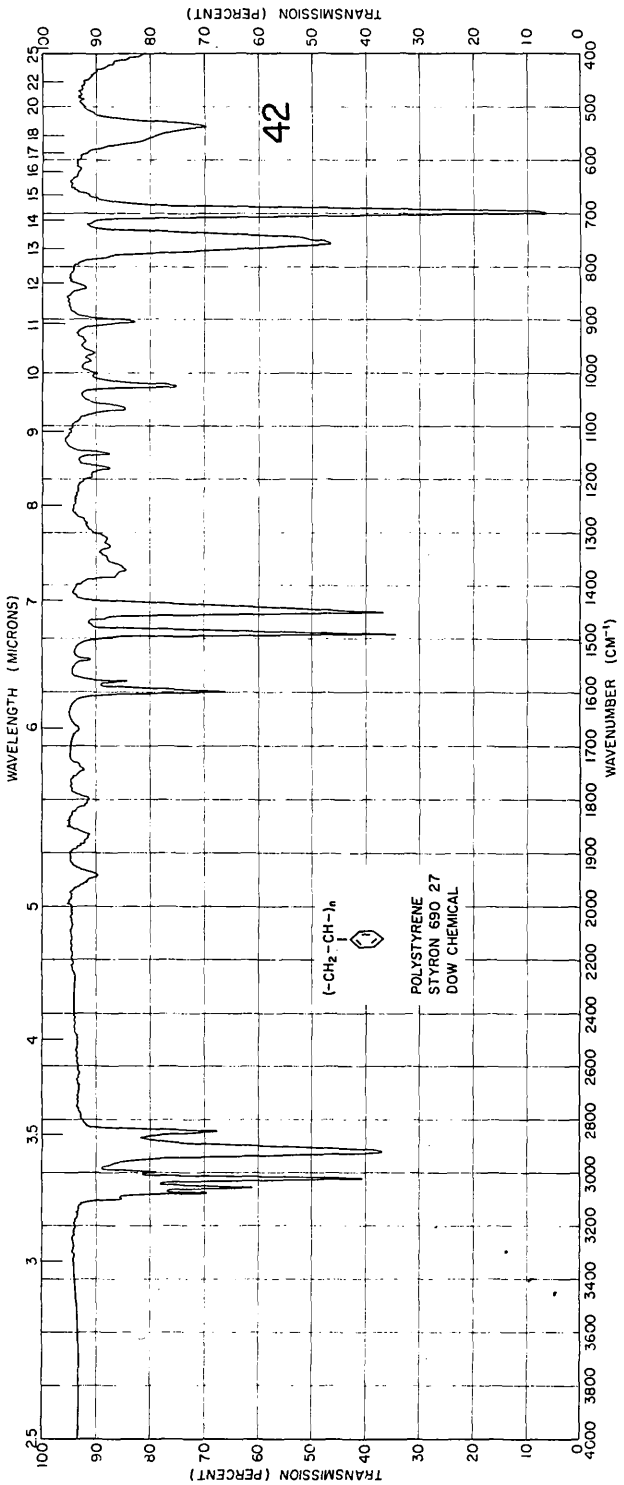

37
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
(-CH2-CH2-)n (-CH2-CH-)n
CH3
ETHYLENE-PROPYLENE COPOLYMER
TENITE POLYALLOMER 5321A
EASTMAN CHEMICAL PRODUCTS

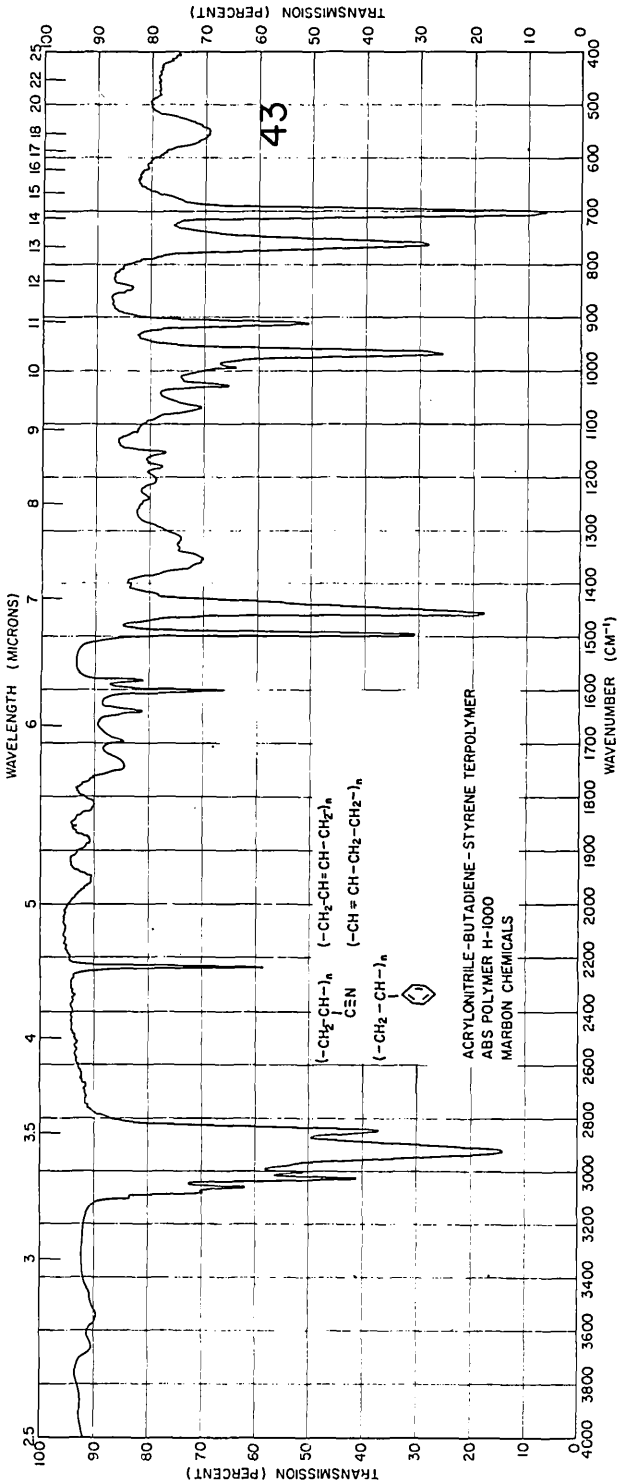

38
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
(-CH2-CH-)n
CH2
CH(CH3)2
POLY(4-METHYLPENTENE-1)
TPX-RT
IMPERIAL CHEMICALS LTD.

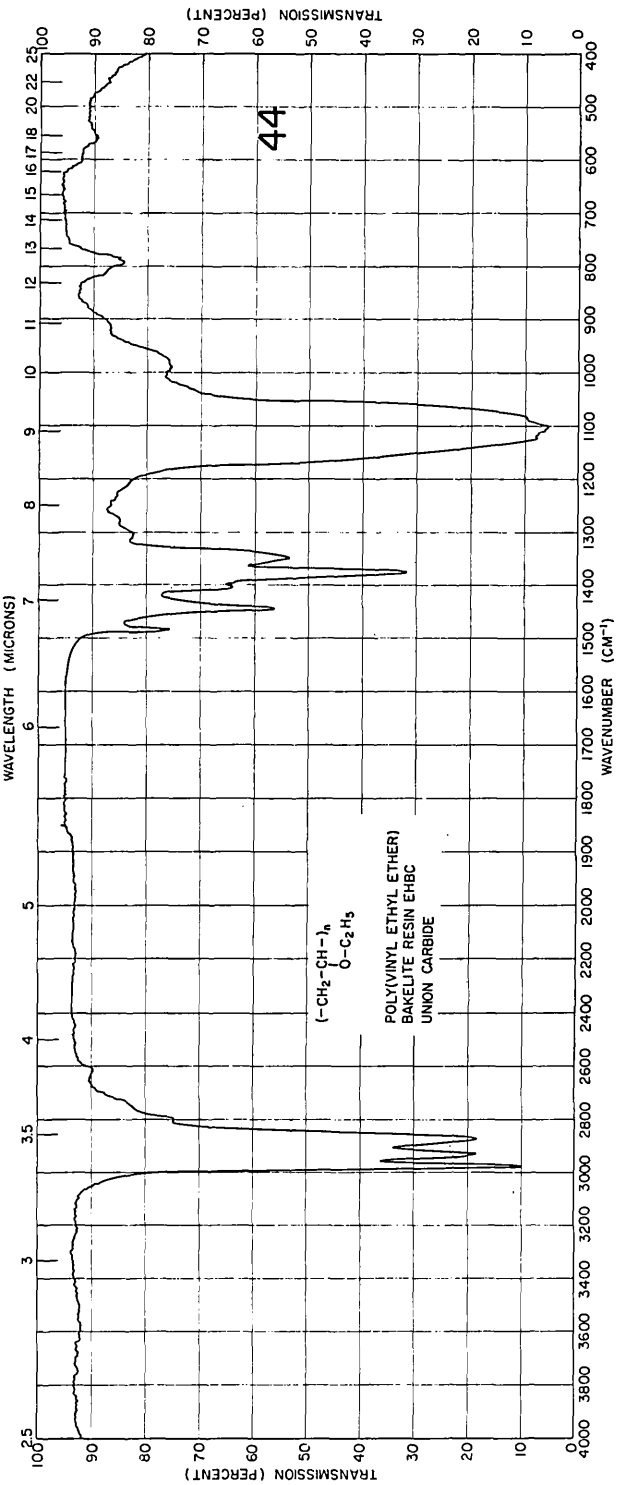

39
POLYSULFONE
UNION CARBIDE
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

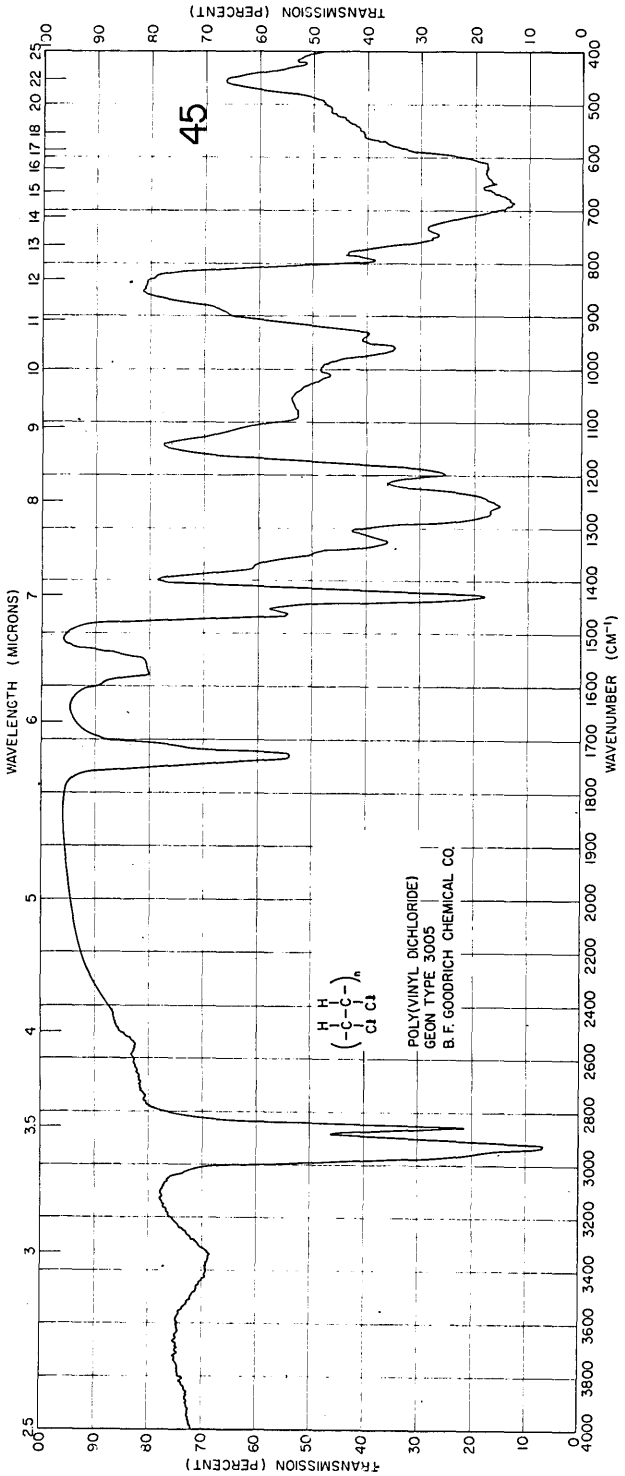

40
POLYURETHANE CX-1046
GOODYEAR TIRE AND RUBBER CO.
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)

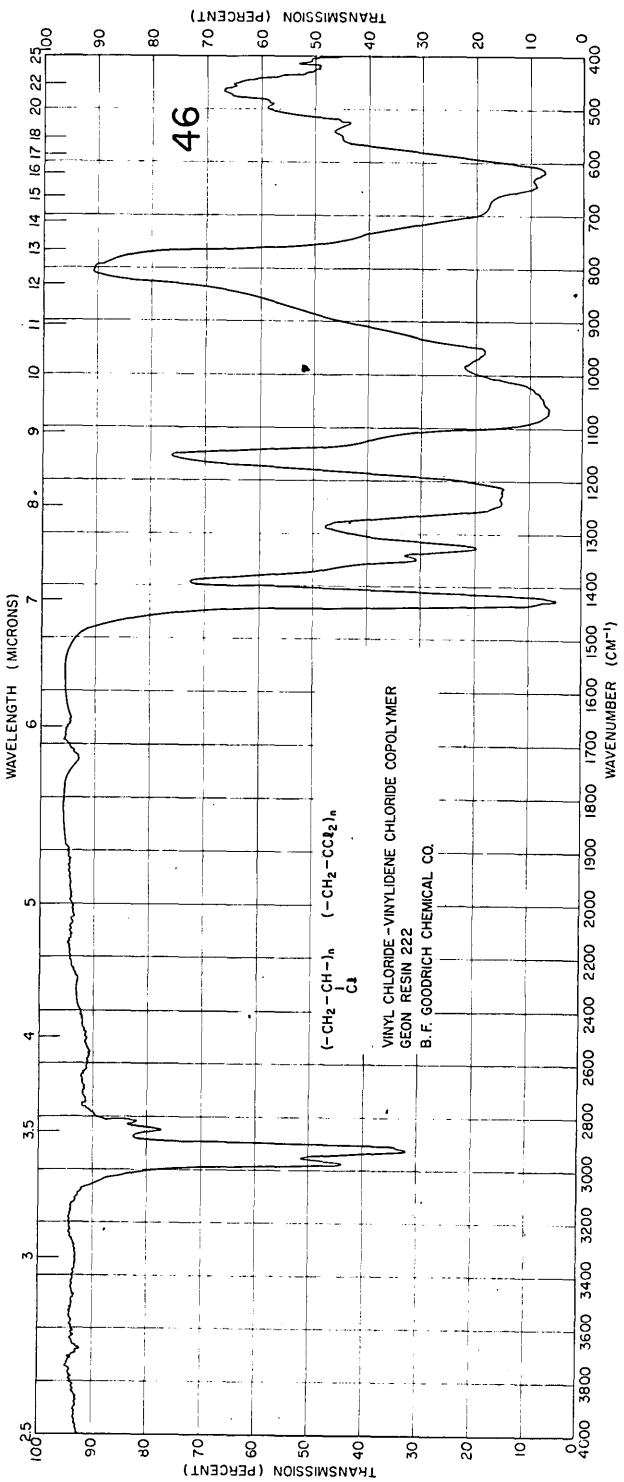

41
ADIPRENE L-100, POLYURETHANE
du PONT
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)


42
(-CH2-CH-)n
POLYSTYRENE
STYRON 690 27
DOW CHEMICAL
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)


43
TRANSMISSION (PERCENT)
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
(-CH2-CH=CH-CH2-)n
(-CH=CH-CH2-CH2-)n
(-CH2-CH-)n
CEN
(-CH2-CH-)n
ACRYLONITRILE-BUTADIENE-STYRENE TERPOLYMER
ABS POLYMER H-1000
MARBON CHEMICALS


44
TRANSMISSION (PERCENT)
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
(-CH2-CH-)n
O-C2H5
POLY(VINYL ETHYL ETHER)
BAKELITE RESIN EHBC
UNION CARBIDE


45
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
POLY(VINYL DICHLORIDE)
GEON TYPE 3005
B. F. GOODRICH CHEMICAL CO.


46
WAVELENGTH (MICRONS)
WAVENUMBER (CM⁻¹)
TRANSMISSION (PERCENT)
VINYL CHLORIDE-VINYLIDENE CHLORIDE COPOLYMER
GEON RESIN 222
B. F. GOODRICH CHEMICAL CO.

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* U.S. Naval Research Laboratory Washington, D.C. 20390	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

INFRARED SPECTRA OF PLASTICS AND RESINS
Part 2—Materials Developed Since 1954

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

An interim report on one phase of the problem.

5. AUTHOR(S) *(Last name, first name, initial)*

Stimler, Suzanne S., and Kagarise, R.E.

6. REPORT DATE May 23, 1966	7a. TOTAL NO. OF PAGES 38	7b. NO. OF REFS 16

8a. CONTRACT OR GRANT NO. NRL Problem C07-01 b. PROJECT NO. RR 001-01-43-4803 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NRL Report 6392 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Dept. of the Navy (Office of Naval Research and Bureau of Ships) Washington, D.C.

13. ABSTRACT

Sixty-one polymeric materials, most of which have been developed since 1954, were studied. Infrared transmittance curves in the region from 4000 to 400 cm^{-1} are presented for 46 of these. Curves for the 15 remaining ones are not shown, but are compared to those in each group that are identical or similar to them. Where possible, the spectra are discussed briefly in terms of the structural groups present.

Methods based on infrared absorbance ratios are used to estimate the densities of some polyethylene polymers and some acrylonitrile-butadiene-styrene (ABS) terpolymers. In the case of polyethylene, these ratios can also be related to the crystalline content of the polymer.

The procedure for identification of unknown spectra given in "Infrared Spectra of Plastics and Resins," Part 1, NRL Report 4369, May 26, 1954, is extended to include the newer polymeric materials.

DD FORM 1 JAN 64 1473

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Absorption spectrum						
Density						
Infrared spectrophotometers						
Plastics						
Polymers						
Infrared spectroscopy						

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