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INFRARED CHARACTERIZED SPACECRAFT CONTAMINANTS AND RELATED COMPOUNDS

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16. Abstract

A brief overview of the discovery of the electromagnetic spectrum is introduced. Particular emphasis is presented on a small portion of the spectrum, namely, the infrared (IR). The limits of the IR region are discussed, together with an explanation of some of the shortcomings of obtaining data in this range.

An effort is made to display the similarities and differences in the interest taken by the chemist/spectroscopist and the space/spectroscopist in the IR spectrum. The chemist uses IR spectra to identify materials and contaminants associated with spacecraft fabrication and testing. The space scientist, using IR spectrometry, can determine atmospheric conditions around planets, stars, and galaxies. He could also determine the temperature profile of the Earth's atmosphere at different altitudes, or even the temperature profile of the Sun.

A discussion of the importance of detecting contamination of spacecraft explains the possible results of not taking corrective action. All space experiments contain some contaminants, to a lesser or greater degree; the responsible personnel involved must determine the level of toleration.

A collection of IR spectra of known spacecraft contaminants is presented as a guide for cognizant scientists and engineers.

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INTRODUCTION

Historically, it was first learned by Isaac Newton, just over 300 years ago, that white light is composed of many different colors. Much later, William Herschel discovered invisible radiation, located beyond the red end of the spectrum emanating from ordinary sunlight. Thus arose the term infrared (IR, infra means "below" from the Latin). After a number of years, the remainder of the invisible portion of the spectrum was discovered. In approximately the middle of the nineteenth century, James Maxwell proposed and tested the theory of electromagnetic radiation (waves).

The IR portion of the electromagnetic spectrum represents a relatively small fraction of the total known radiation span. This spectral range has been defined by some as encompassing the region of about 0.7 to 300 microns (μ).* In fact, the area of major interest within the IR is further restricted to approximately a 0.7- to 50-μ expanse.

There are some valid reasons for this fact. First, the instrumentation for producing and measuring long wavelength IR radiation has been limited because of technological inadequacies, developmental difficulties, and cost; secondly, spectral characteristic patterns are generally much more well-defined in the region up to about 50μ.

This report represents an effort to establish a link between two seemingly unrelated scientific disciplines so that one may complement the other. These disciplines are analytical chemistry and astronomy, using IR spectrophotometry as the common denominator. More specifically, the collection of IR spectra presented should alert the astronomer conducting aerospace experiments to possible contaminants and ultimately to more acceptable choices of fabrication materials. The spectra of materials exhibited represent those commonly used in aerospace technology, or contaminants frequently found in vacuum chamber tests and surface sampling of spacecraft hardware.

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*One must realize that no sharp demarcation exists between one type of radiation and its adjacent neighbor. Therefore, there is some latitude for opinion on the one side where the visible spectrum ends and the near IR begins, and, on the other hand, where the far IR ends and microwaves begin.

It has been well recognized for some 25 to 30 years that IR spectroscopy (in the 2.5- to 16-μ range) is a valuable and rapid tool for identifying most organic, and many inorganic, compounds. So, naturally, when it became apparent early in the space program that contamination would be a real and continuing threat to mechanical systems, as well as to scientific experiments, chemists realized the inherent value of IR spectroscopy as an analytical tool for problem areas.

There are some similarities, as well as differences, in the measuring equipment used by the chemist/spectroscopist and the aerospace astronomer. The chemist uses an IR spectrophotometer to record the spectra of materials of interest. The most fruitful range of the spectrum covered is 2.5 to 16μ (since the advent of gratings, wave numbers (cm^{-1}) are commonly used). However, many laboratories have extended their survey to 25μ (for potassium bromide (KBr) optics and detector) and in a few cases to 50μ (for cesium iodide (CsI) optics and detector). The astronomer and other space scientists use IR spectrophotometers and radiometers to make their measurements. Usually, the measurements made by these investigators are segmented into relatively narrow regions of the spectrum, depending on the investigation that is being conducted, such as: 0.2 to 6μ (includes some of the UV and visible range); 3 to 8μ; 8 to 12μ; 6 to 6.5μ; etc. In some of the more sophisticated experiments, many or all of the spectral ranges mentioned may be included.

The chemist spectroscopist usually surveys all parts of the spectrum to identify unknown entities. In doing this, he draws upon a knowledge of band wavelength (or frequency) correlation with functional chemical groups present in a compound. In a somewhat different vein, the IR aerospace scientist usually looks for one or more strong bands at a specific wavelength that may be characteristic of a compound(s) in which he may be interested. As an example, he may examine the 3-μ and 6- to 6.5-μ bands when searching for water; about 10μ when studying silicates; or 4.2 to 4.3μ when interested in CO_2 or CO. Understandably, the types of compounds sought in space experiments are limited in number and usually are comparatively simple in structure, thus enabling the investigator to rely on one or two bands as verification of existence.

The major concern regarding the problem of contamination is that many of the compounds for which the scientist is searching in space are also found to be contaminants of the spacecraft or that these contaminants may have IR bands in common with the compounds sought. Another type of problem occurs when contamination that absorbs IR radiation (as most contaminants do to some extent) accumulates on thermal control surfaces or thermal radiators of the spacecraft, thereby raising the temperature and compromising the success of the experiment. The possible detriments in contamination situations such as these are definitely not hypothetical, but are known to have occurred on some occasions in testing and flight. When the occurrence is in testing of an unmanned, nonrecoverable spacecraft, usually some corrective action can be taken before launch to alleviate or eliminate the problem. If, however, the contamination appears after launch, the experiment may suffer irreparable damage unless it has specific design features incorporated to accommodate this phenomenon.

Some thought has been devoted to the task of categorizing the spectra presented in this document into specific groups based on their chemical types, uses, frequency of occurrence, or some other appropriate association. It is believed that the best arrangement of the spectra is to list them by general chemical type and to state after each its most common functional use. Even after about 10 years of collecting data, we are discovering compounds from time to time that we have not seen before or that we are not completely able to identify. Therefore, the compounds presented are intended to serve as a sampling, not as a complete listing of all that have been found or of all possibilities.

SPECTRA OF THE COMPOUNDS

The spectra presented were produced on a Perkin-Elmer Model 621 Infrared Grating Spectrophotometer, using the ordinary survey scan parameters. Most of the samples were introduced as a thin film on or between KBr disks. However, some were obtained using attenuated total reflectance (ATR) presentation techniques.

The first group of spectra presented in table 1 and illustrated in figures 1.1 to 1.17 consists of silicones (polysiloxanes). The types of silicones shown consist of dimethyl, methylphenyl, and fluorosilicones.

Table 2 contains spectra of common hydrocarbons, illustrated in figures 2.1 to 2.14. Some of the hydrocarbons contain fillers or other additives. Without these additives, the spectra of the hydrocarbons are among the most simple of the contaminants usually observed. This is particularly true of the frequently encountered saturated, aliphatic, straight-chained hydrocarbons.

Table 3 is composed of a class of compounds called esters, illustrated in figures 3.1 to 3.25. These compounds are found in a very large percentage of the contamination samples examined. Some of the reasons for this fact are their multitudinous uses, great volatility (of many types). and ease of extractability. One might understandably wonder why these compounds are found so frequently if they can be potentially harmful, that is, why do we allow them to be included on materials lists? As a matter of fact, many of the most frequently found contaminants cannot be explained by examination of material lists. Esters (particularly phthalates) are so ubiquitous that they are transferred from the air, packaging, manufacturing and test equipment, or even from impure cleaning solvents. Note that several materials with different nomenclature and uses are actually the same compound chemically.

The compounds listed in table 4 and illustrated in figures 4.1 to 4.11 are the ones which are less likely to be encountered in samples. The spectra in figures 4.1 and 4.2 are actually the same compound, polyphenyl ether. This compound has a low volatility and is usually trapped in the systems where it is employed. The spectra in figures 4.3 through 4.7 represent fluorocarbon lubricants which are becoming more commonly used but are still not the most frequently encountered. The Arochlor products, polychlorinated biphenyls, sometimes referred to as PCB's, are almost completely banned from general use because of environmental considerations, but still have been identified on a few occasions.

Table 1
Silicones

Figure number	Identification	Use(s)
1.1	DC 200 oil	lubricant, heat transfer medium
1.2	RTV-11	encapsulant, molding compound
1.3	Dow Corning high vacuum grease	lubricant
1.4	GE SF-96 oil	lubricant and heat transfer medium
1.5	GE SF-1147 oil	lubricant
1.6	3M #70 electrical tape adhesive	electrical tape
1.7	3M #61 electrical tape adhesive	electrical tape
1.8	GE Versilube F-50 oil	lubricant
1.9	DC F-6-1105 oil	controlled volatility lubricant
1.10	DC 710 oil	lubricant
1.11	DC 560 oil	adhesive and encapsulant
1.12	DC 510 oil	damping fluid
1.13	DC 704 oil	diffusion pump fluid
1.14	DC 705 oil	diffusion pump fluid
1.15	GE G-300 grease	lubricant, heat sink
1.16	DC FS-1265 oil	lubricant
1.17	DC FS-1281 grease	lubricant

Table 2
Hydrocarbons

Figure number	Identification	Use(s)
2.1	Vac Torr oil	mechanical pump fluid
2.2	Duo Seal oil	mechanical pump fluid
2.3	Sunvis 931	mechanical pump fluid
2.4	Sunvis 951	mechanical pump fluid
2.5	Apiezon C oil	controlled volatility lubricant
2.6	Apiezon H grease	controlled volatility lubricant
2.7	Apiezon T grease	controlled volatility lubricant
2.8	Apiezon L grease	controlled volatility lubricant
2.9	KG-80 oil	lubricant
2.10	SRG-30 oil	lubricant
2.11	Andok-C	lubricant
2.12	3M #53 tape adhesive	electrical tape
2.13	3M #56 tape adhesive	electrical tape
2.14	Mobil #28 grease	lubricant

Table 3
Esters

Figure number	Identification	Use(s)
3.1	Dibutyl phthalate	plasticizer, lubricant
3.2	Di-2-ethyl hexyl phthalate	plasticizer, lubricant
3.3	Octoil	plasticizer, lubricant
3.4	Di-n-octyl phthalate	pump fluid, plasticizer, lubricant
3.5	Di-tridecyl phthalate	pump fluid, plasticizer, lubricant
3.6	P-10 oil	lubricant
3.7	Di-2-ethyl hexyl sebacate	plasticizer, lubricant
3.8	Windsor Lube L245X	lubricant
3.9	Octoil-S	pump fluid
3.10	Butyl Stearate	plasticizer
3.11	NPT-4 oil	lubricant
3.12	Braycote KK-949B	lubricant
3.13	Anderol 401D	lubricant
3.14	Bis-2-ethyl hexyl adipate	lubricant
3.15	Dibutyl tin dilaurate	curing agent
3.16	Eastman 910	adhesive
3.17	Aéroshell 17 grease	lubricant
3.18	Beacon 325 grease	lubricant
3.19	3M #850 tape adhesive	thermal control
3.20	3M #852 tape adhesive	thermal control
3.21	3M #848 tape adhesive	thermal control
3.22	3M X-1205 tape adhesive	electrical tape
3.23	Tricresyl phosphate (TCP)	plasticizer, fire retardant
3.24	Tris-2, 3-dibromopropyl phosphate	plasticizer, fire retardant
3.25	Tris-B-chloroethyl phosphate	plasticizer, fire retardant

Table 4
Miscellaneous

Figure number	Identification	Use(s)
4.1	Convalex 10	pump fluid
4.2	Santovac 5	pump fluid
4.3	Kel-F (#90) grease	lubricant
4.4	Krytox 240 AB grease	lubricant
4.5	Krytox 143 AB oil	lubricant
4.6	Krytox 143 AZ oil	lubricant
4.7	Krytox 143 AX oil	lubricant
4.8	Arochlor 1254	plasticizer, heat transfer medium
4.9	Arochlor 1260	plasticizer, heat transfer medium
4.10	Arochlor 1262	plasticizer, heat transfer medium
4.11	Arochlor 5460	plasticizer, heat transfer medium

CONCLUSIONS

For many years, IR spectroscopy has been a valuable tool for the identification of spacecraft contaminants. A knowledge of the correct identity of a contaminant could ultimately lead the alert investigator to the source.

ACKNOWLEDGMENT

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Goddard Space Flight Center
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Greenbelt, Maryland February 1977

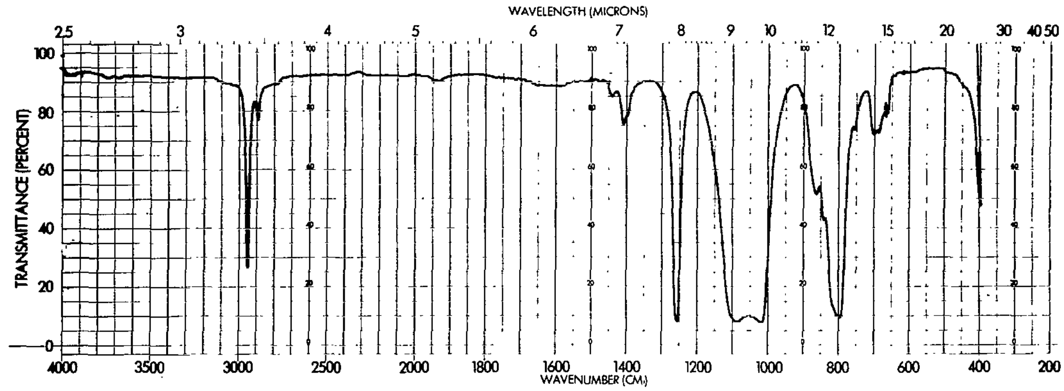


Figure 1.1. DC 200 oil.

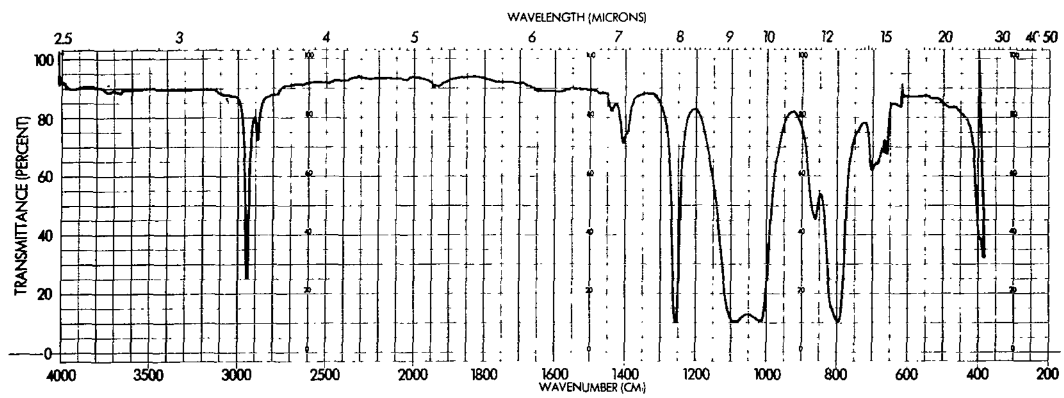


Figure 1.2. RTV-11.

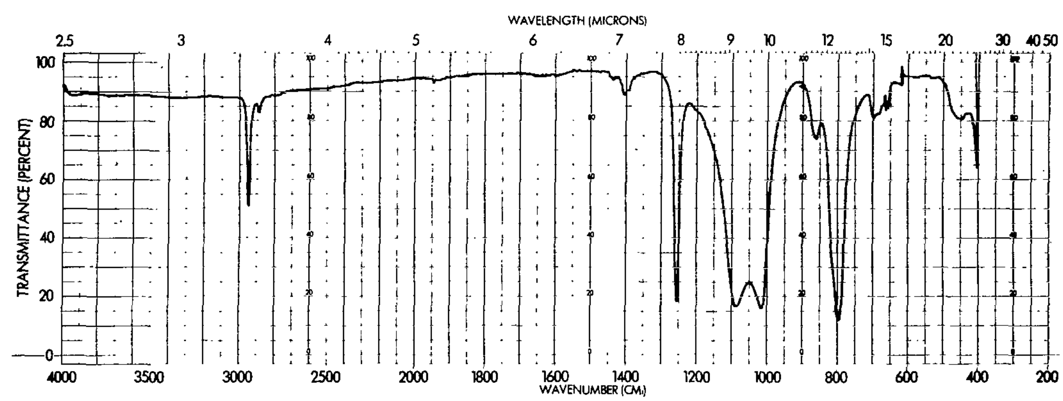


Figure 1.3. Dow Corning high vacuum grease.

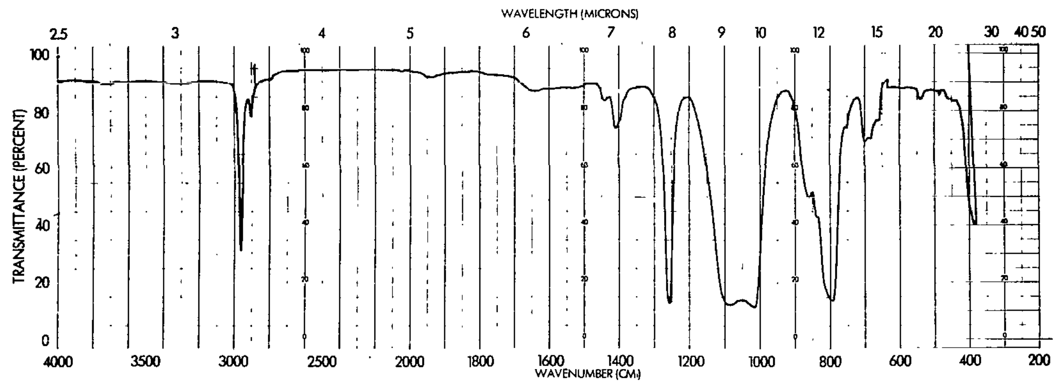


Figure 1.4. GE SF-96 oil.

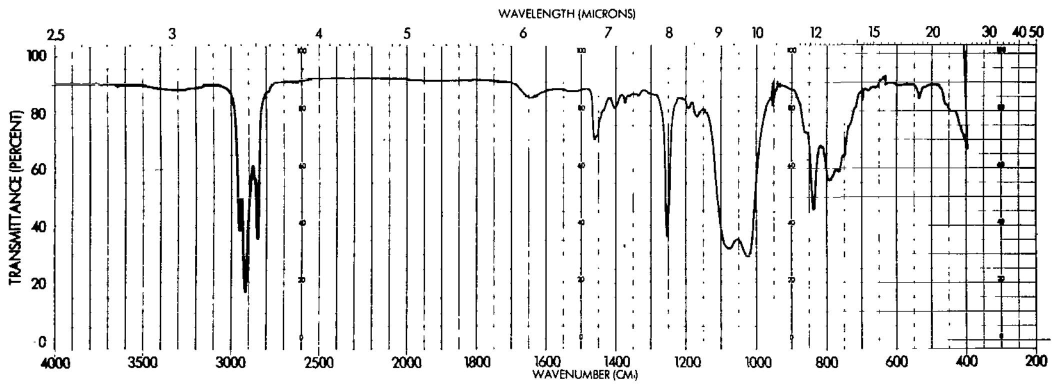


Figure 1.5. GE SF-1147 oil.

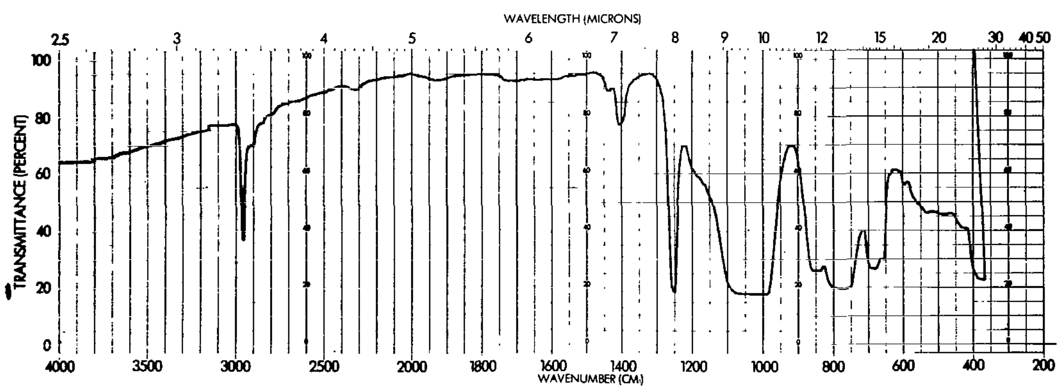


Figure 1.6. 3M #70 electrical tape adhesive.

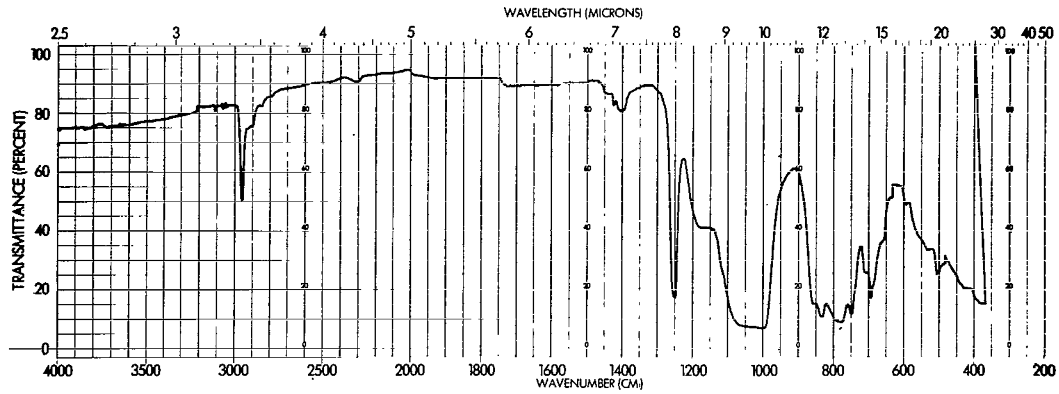
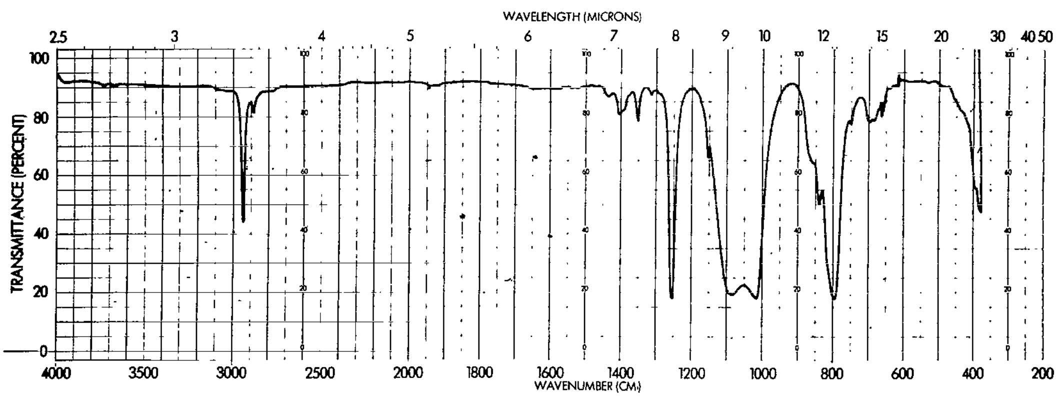


Figure 1.7. 3M #61 electrical tape adhesive.



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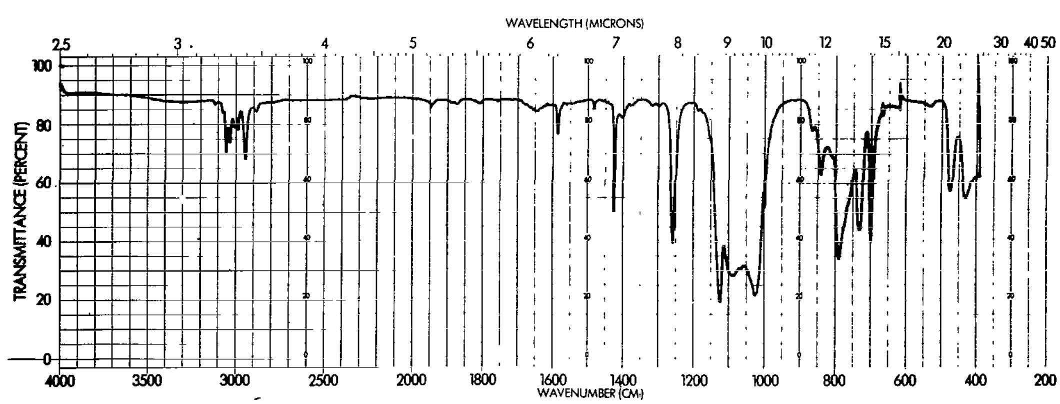
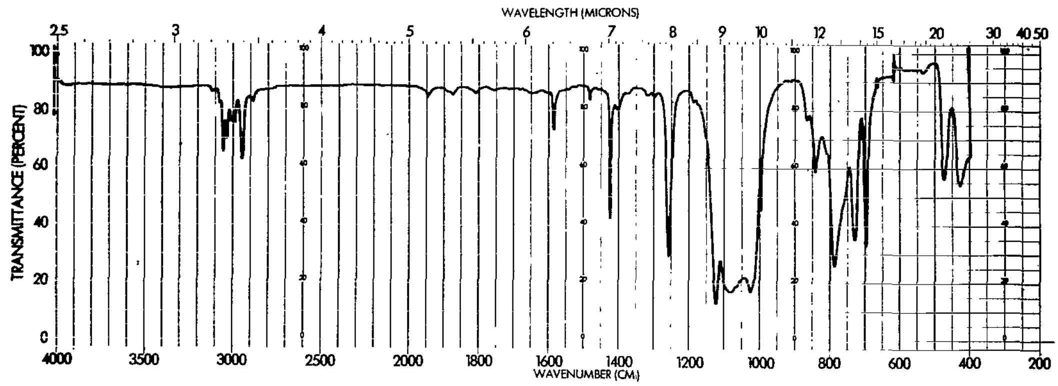


Figure 1.9. DC F-6-1105 oil.



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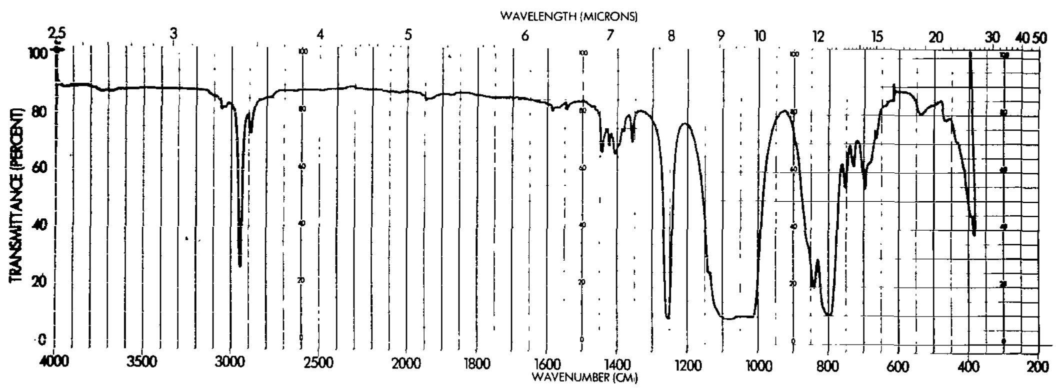

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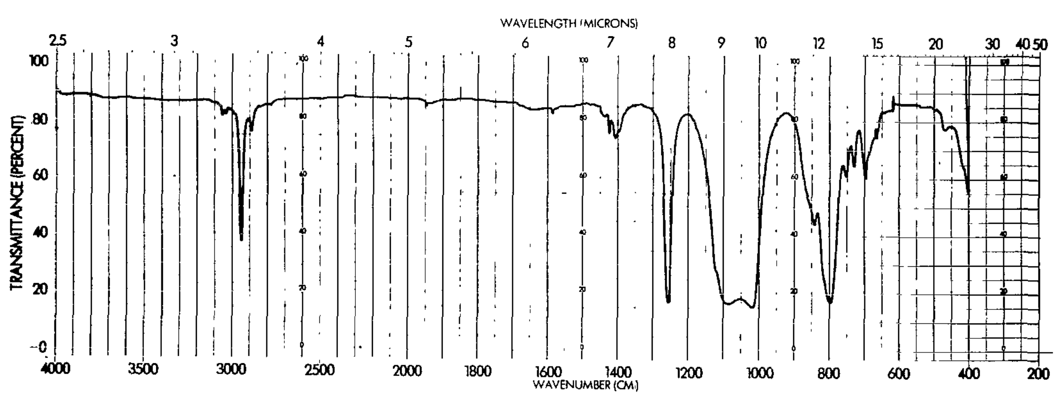

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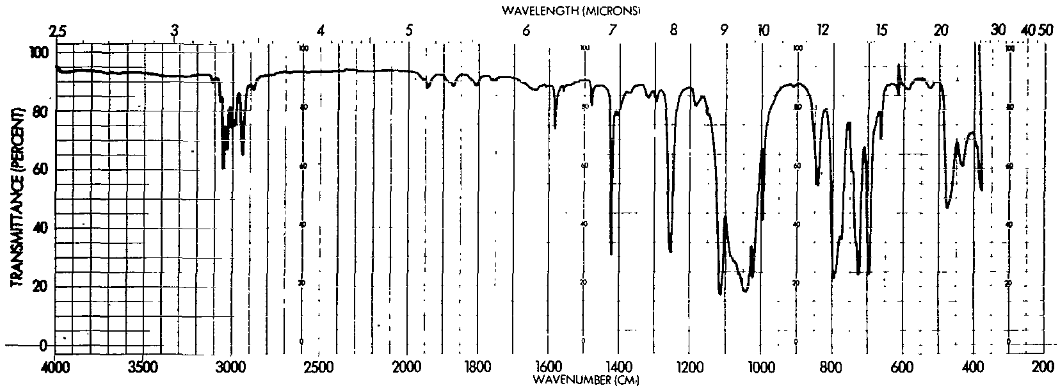

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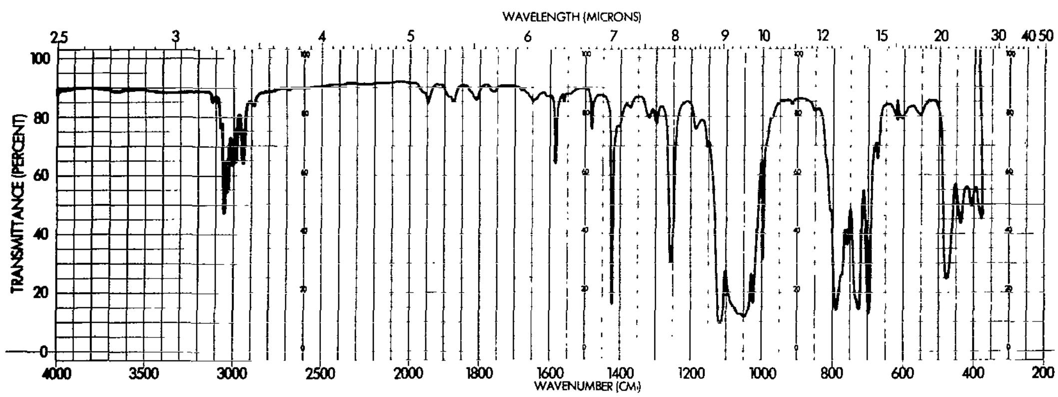

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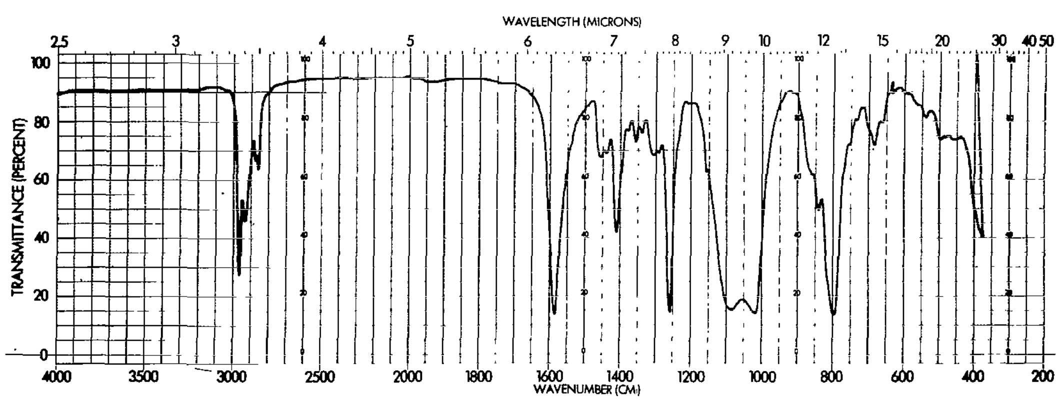


Figure 1.15. GE G-300 grease.

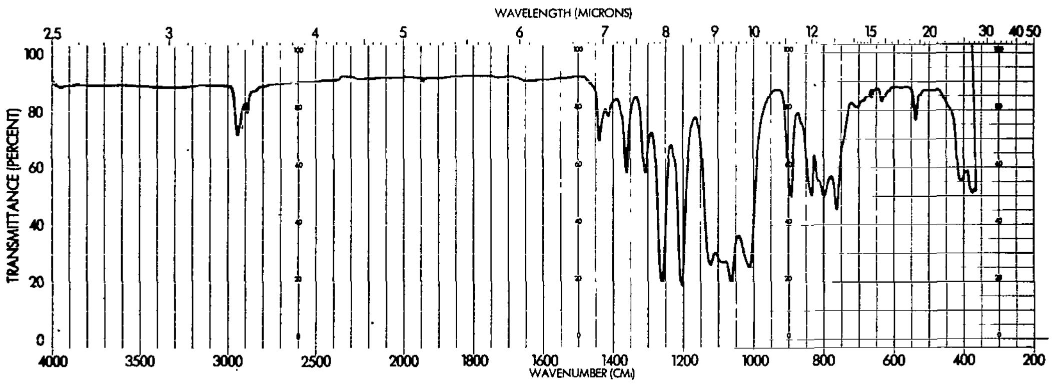
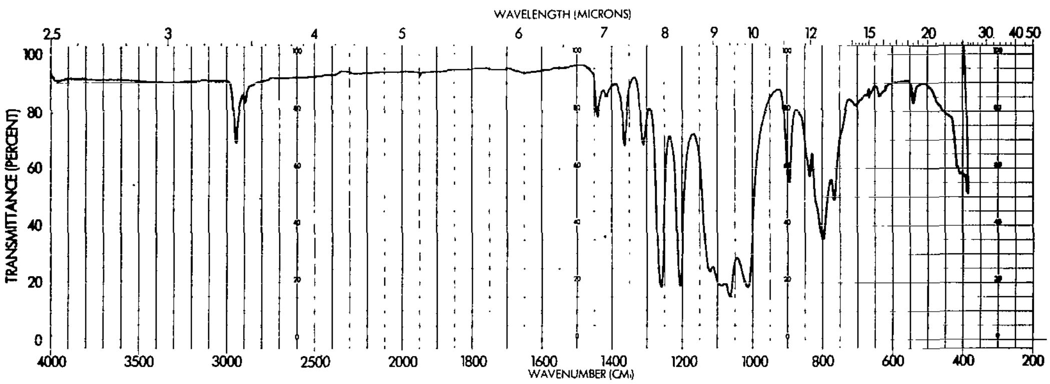


Figure 1.16. DC FS-1265 oil.



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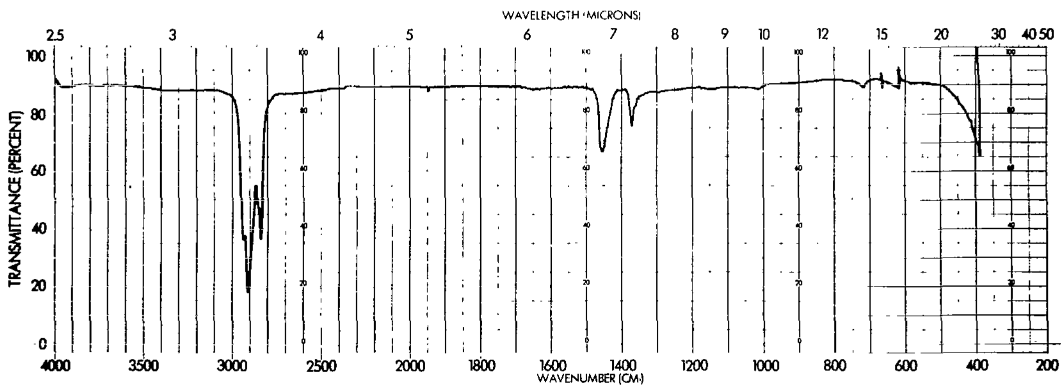

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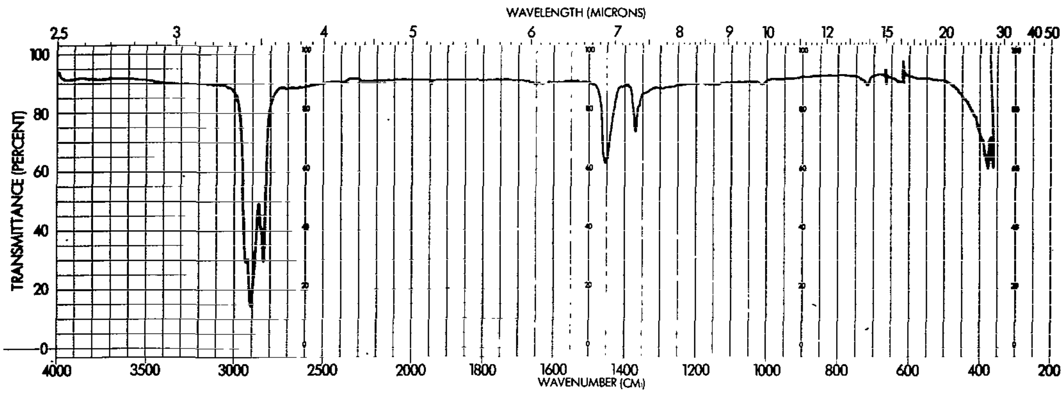

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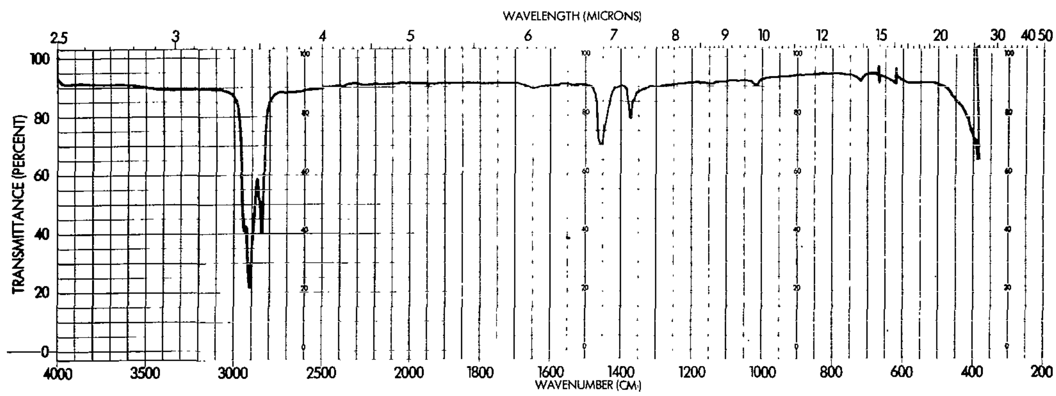
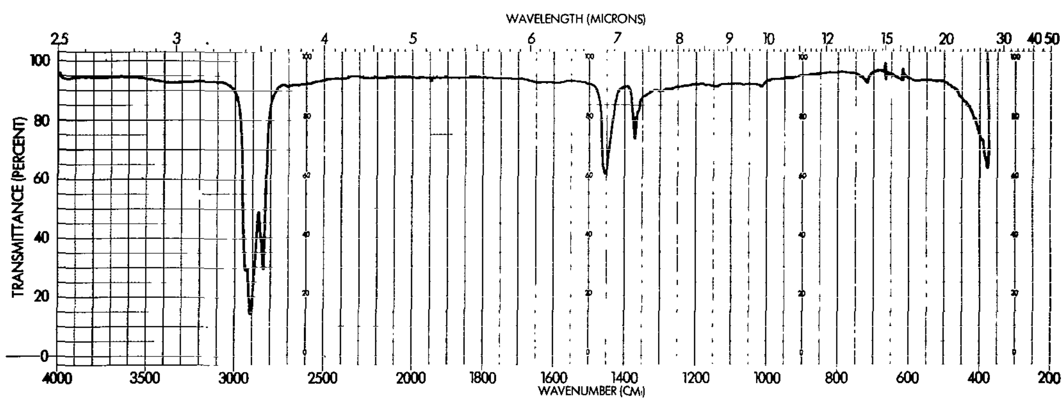


Figure 2.3. Sunvis 931.



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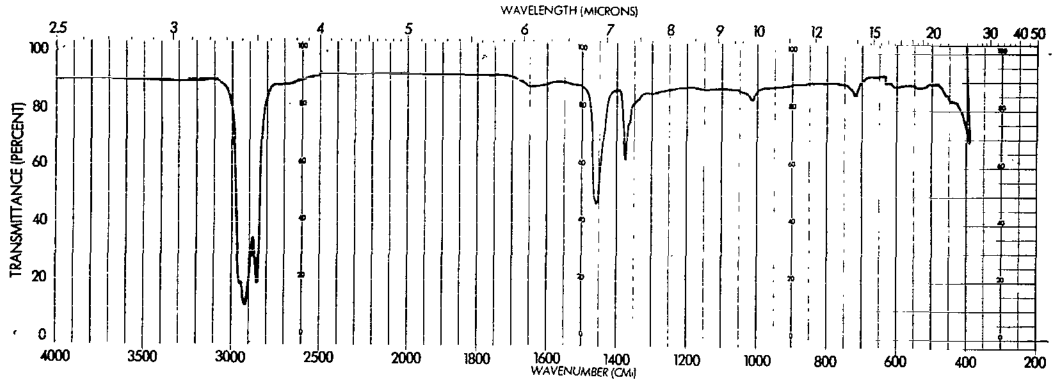

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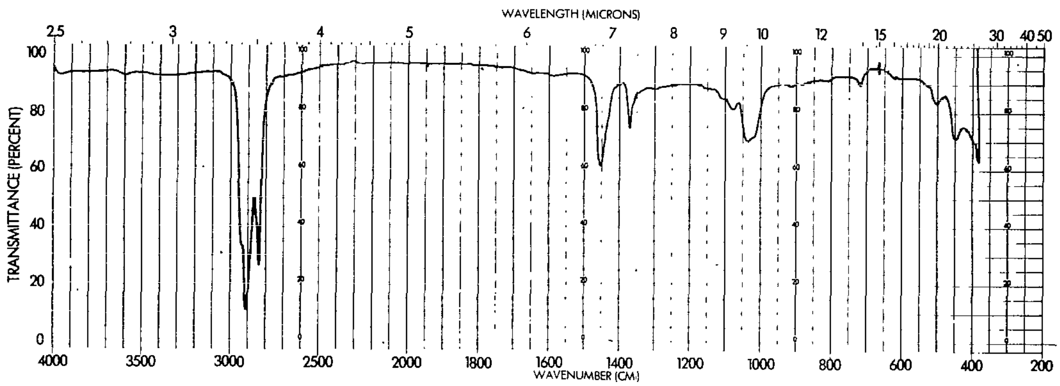

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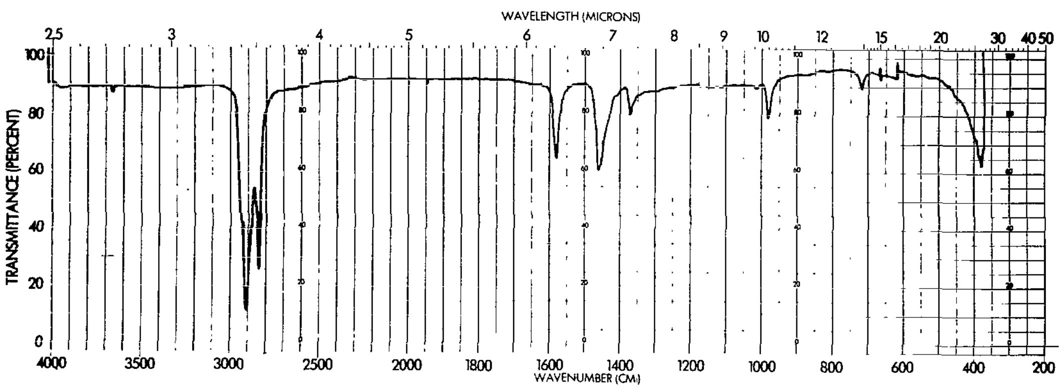

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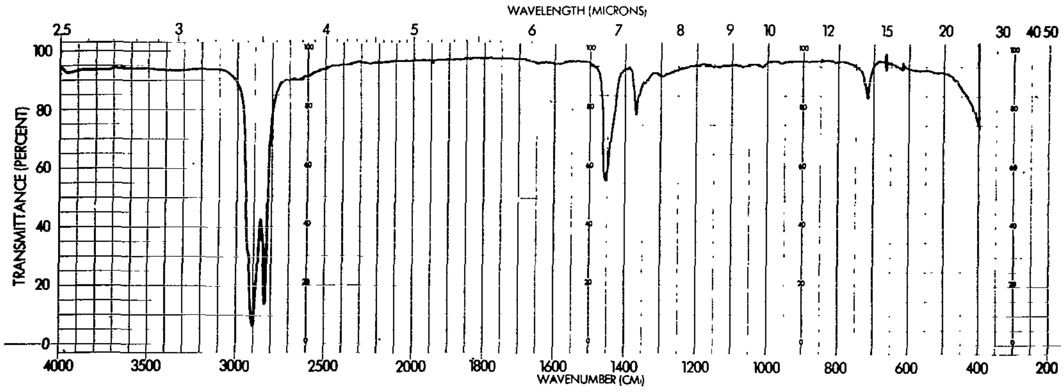

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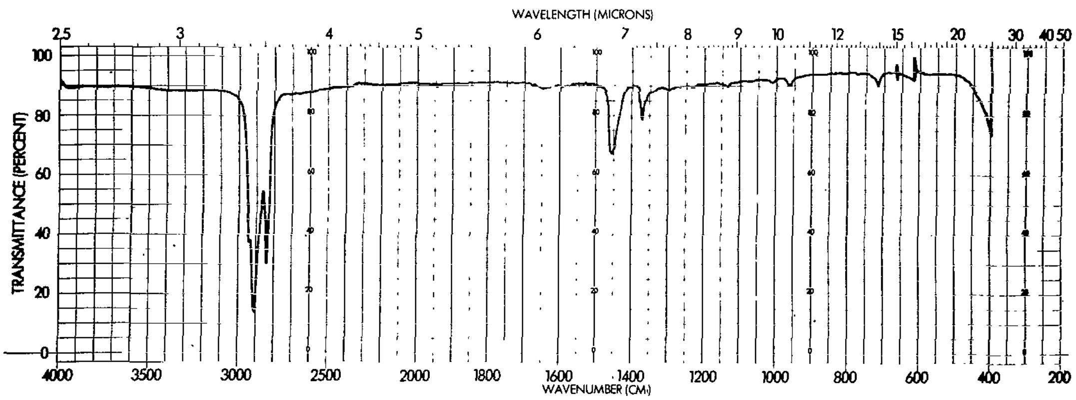

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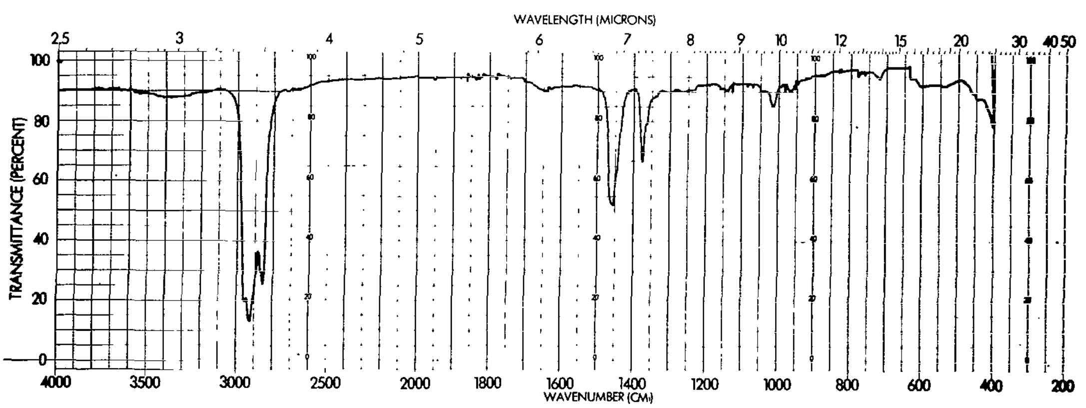

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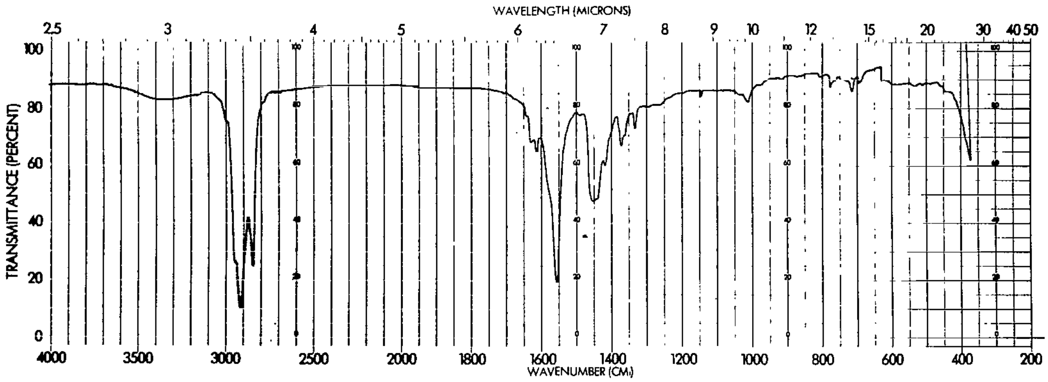

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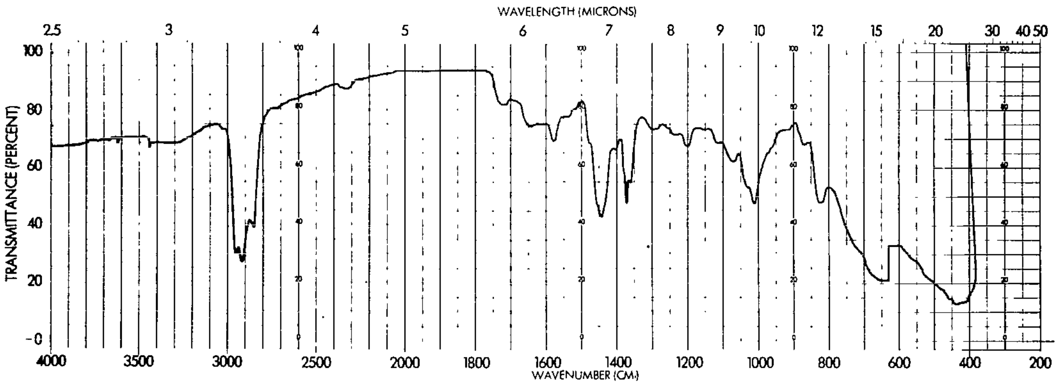
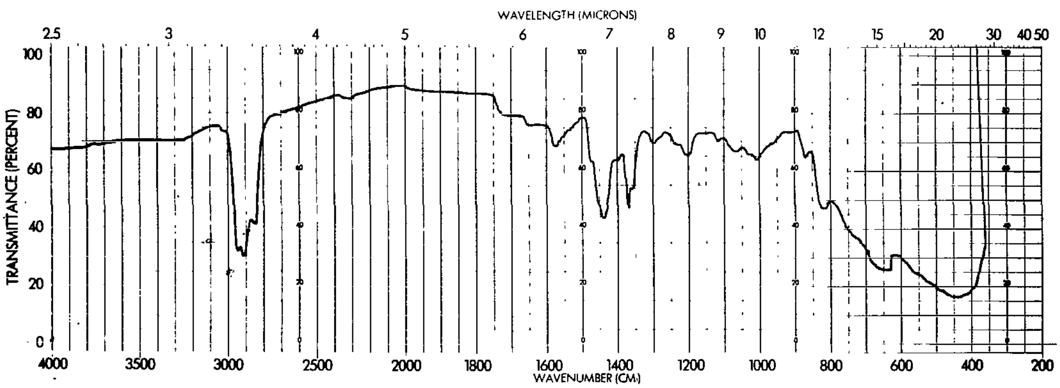


Figure 2.12. 3M #53 tape adhesive.



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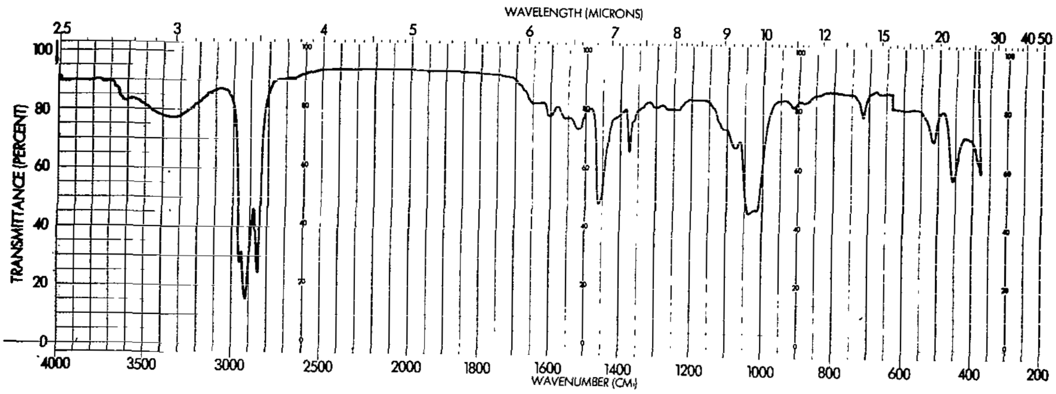

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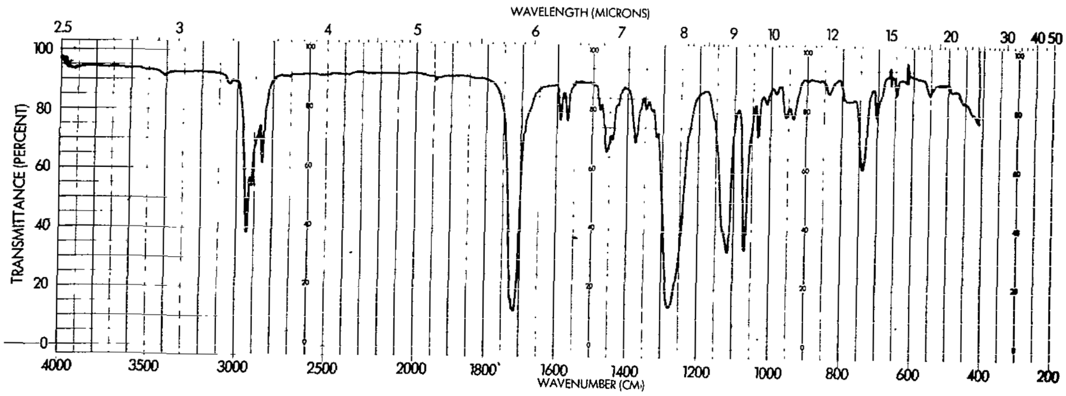
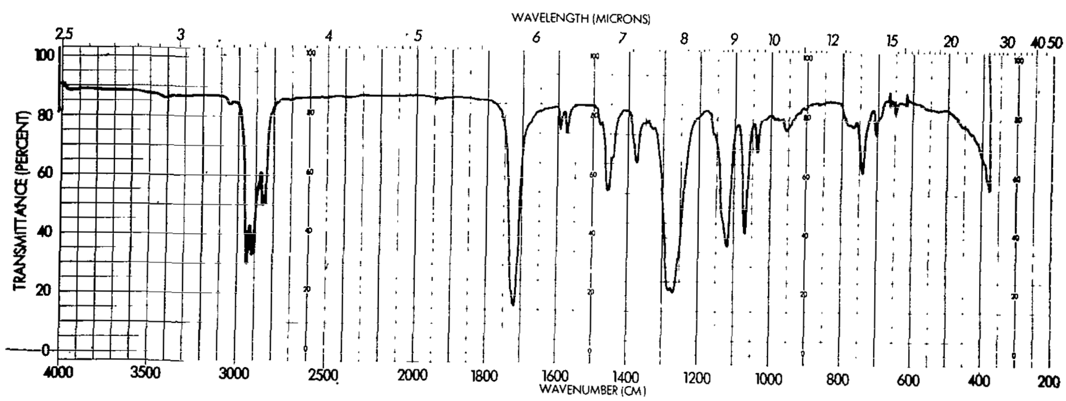


Figure 3.1. Dibutyl phthalate.



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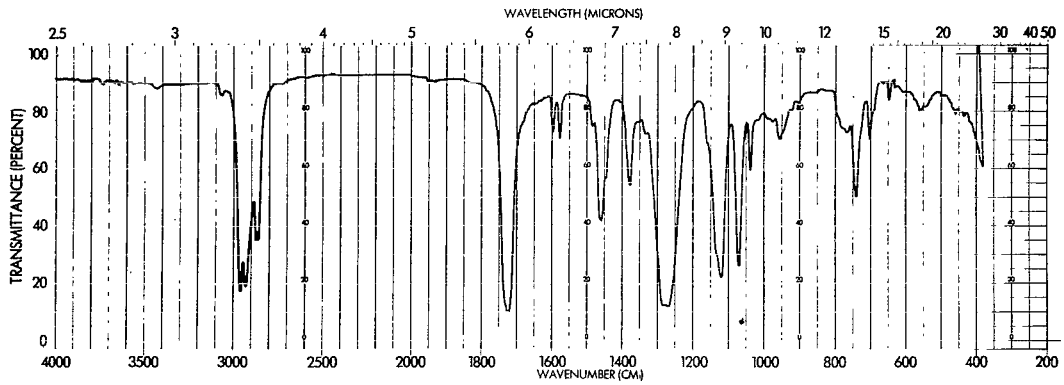

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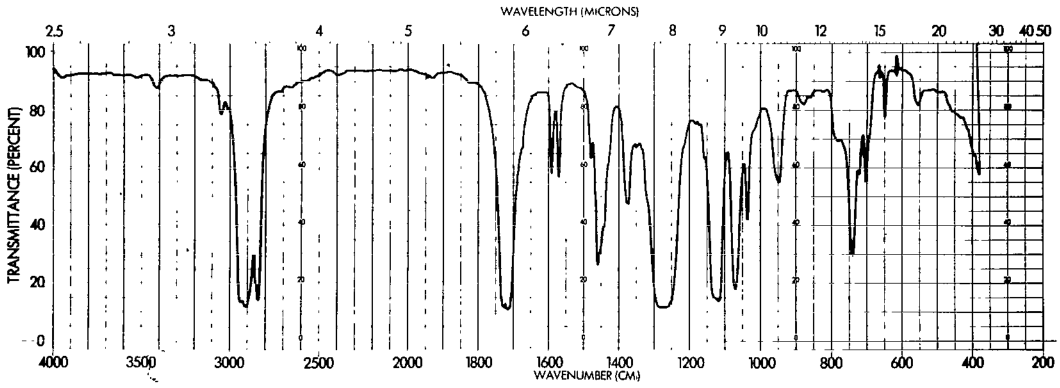

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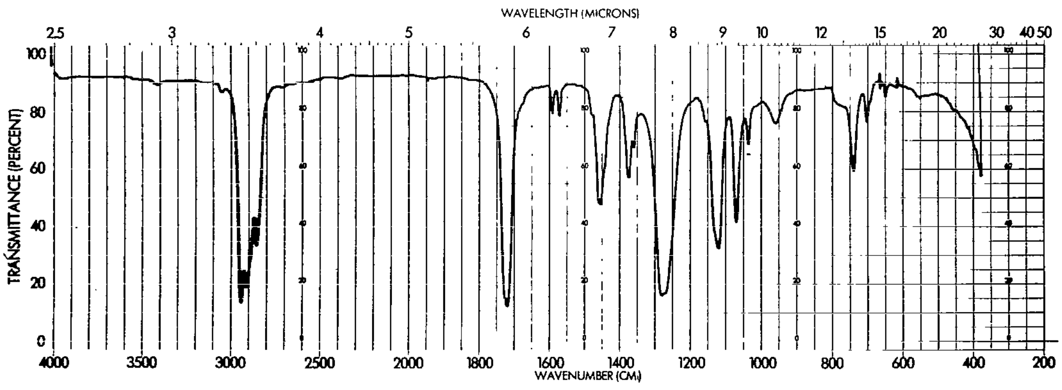

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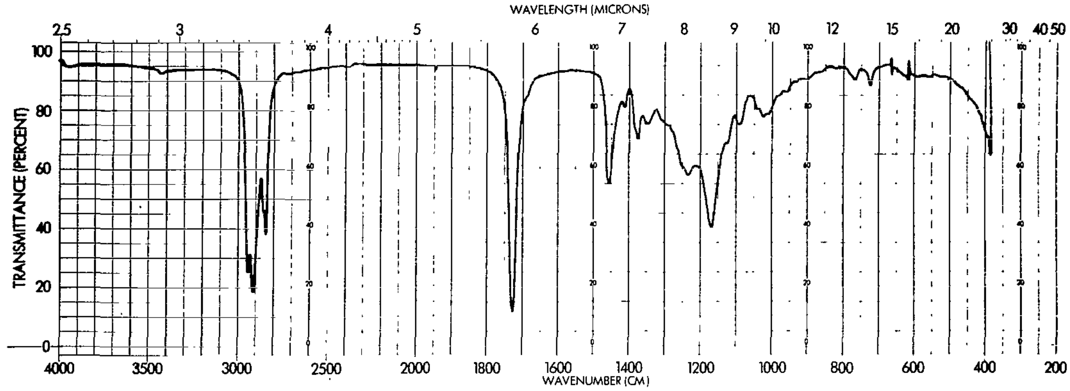

Figure 3.6. P-10 oil.

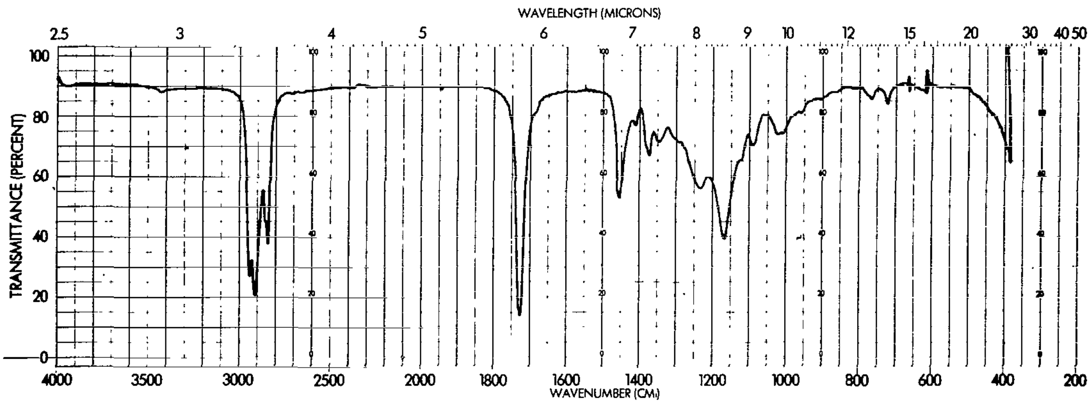

Figure 3.7. Di-2-ethyl hexyl sebacate.

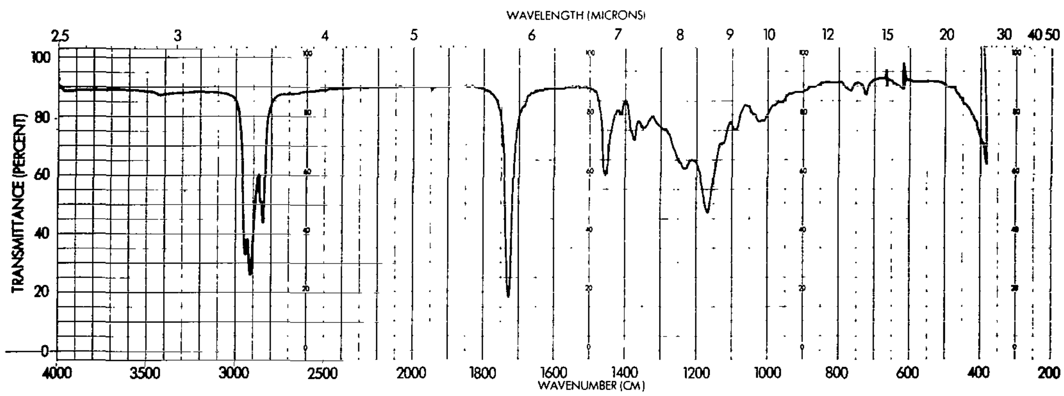

Figure 3.8. Windsor Lube L245X.

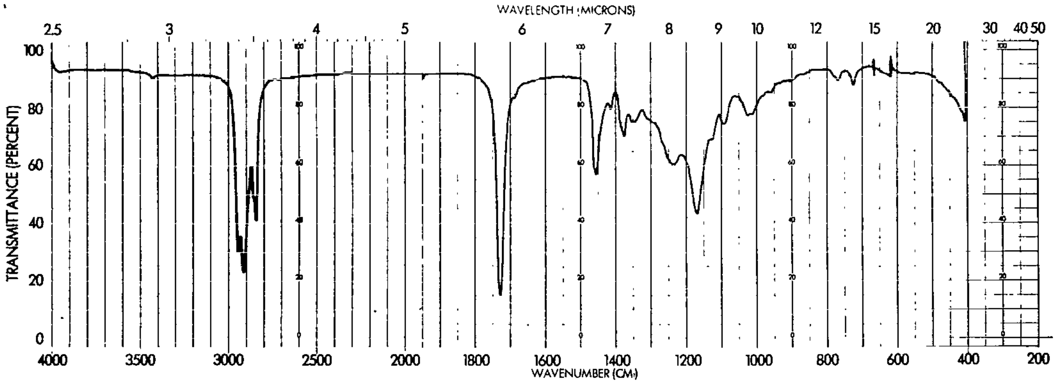

Figure 3.9. Octoil-S.

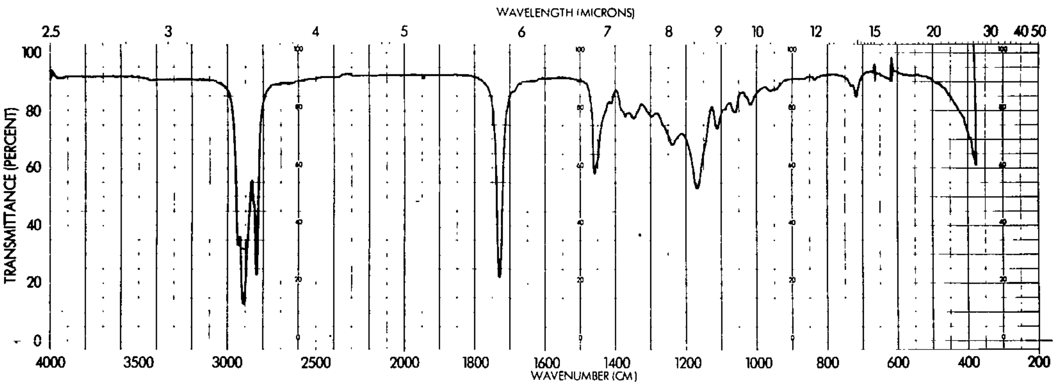

Figure 3.10. Butyl stearate.

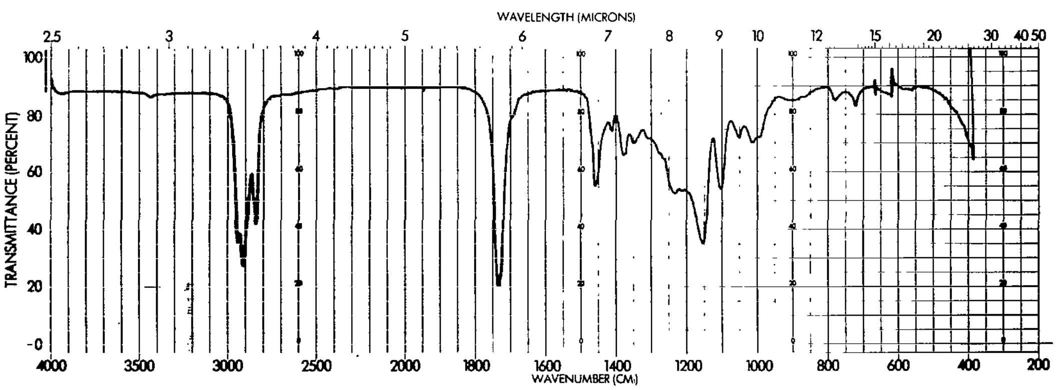

Figure 3.11. NPT-4 oil.

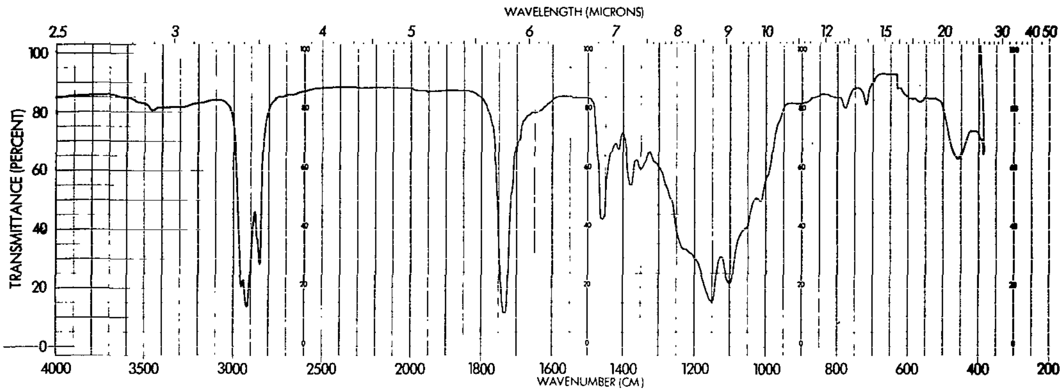

Figure 3.12. Braycote KK-949B.

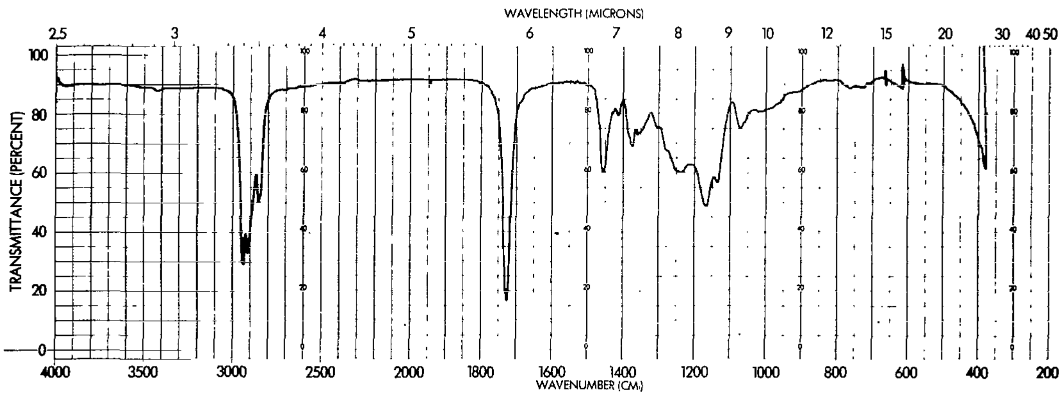

Figure 3.13. Anderol 401D.

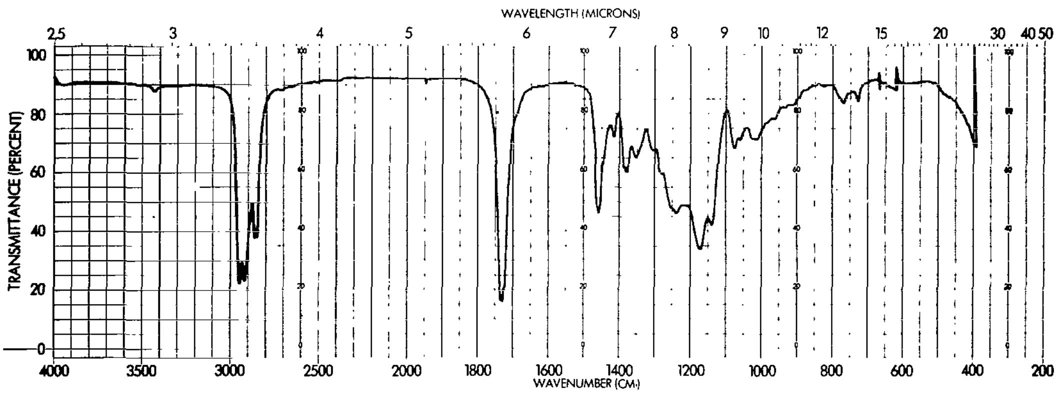

Figure 3.14. Bis 2-ethyl hexyl adipate.

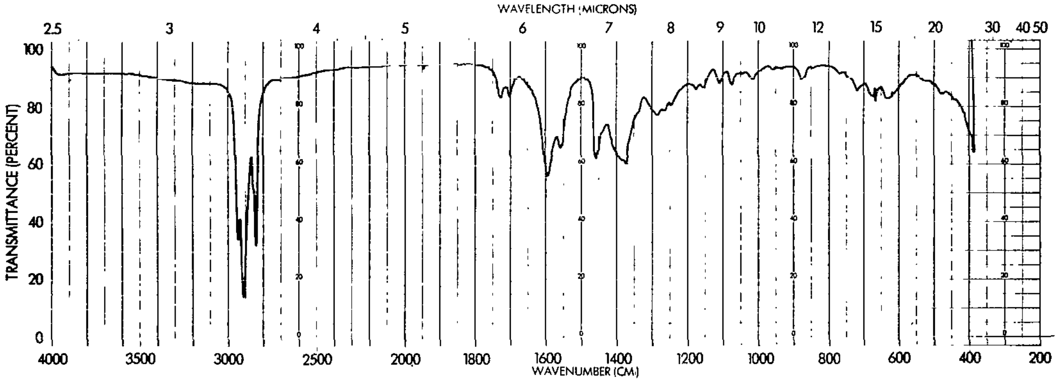

Figure 3.15. Dibutyl tin dilaurate.

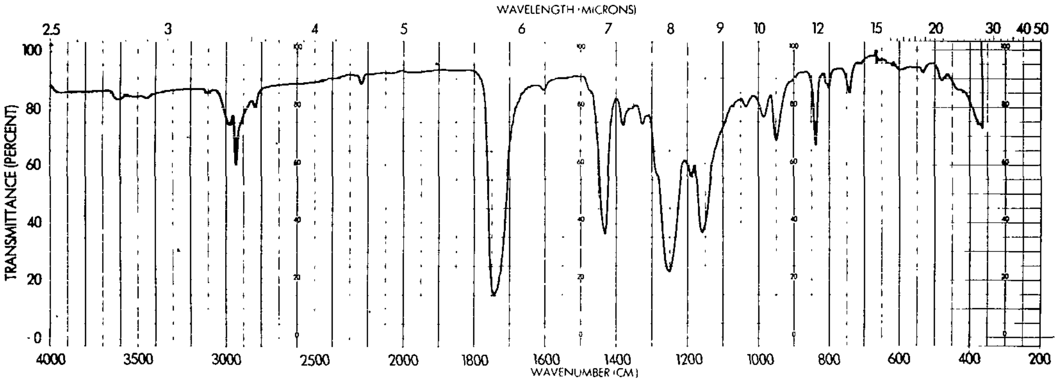

Figure 3.16. Eastman 910.

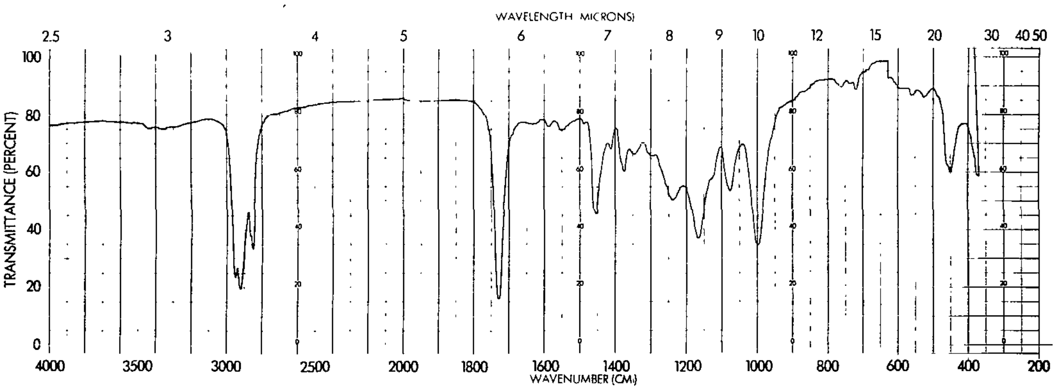

Figure 3.17. Aeroshell 17 grease.

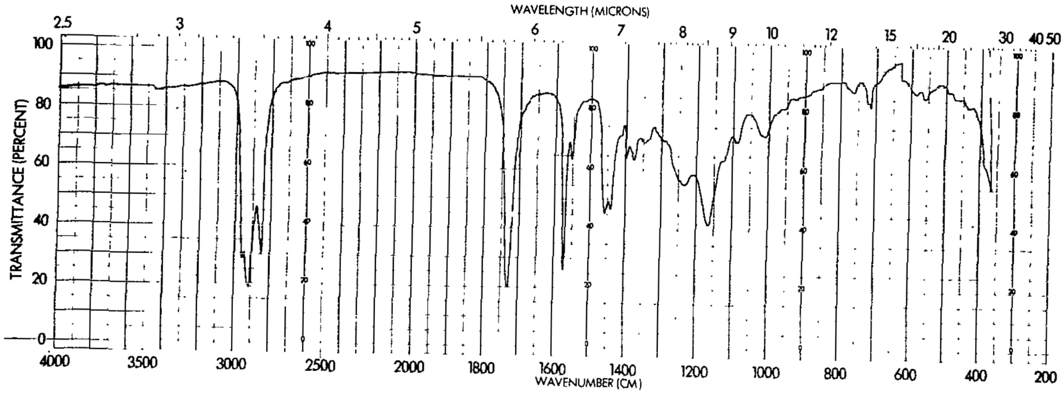

Figure 3.18. Beacon 325 grease.

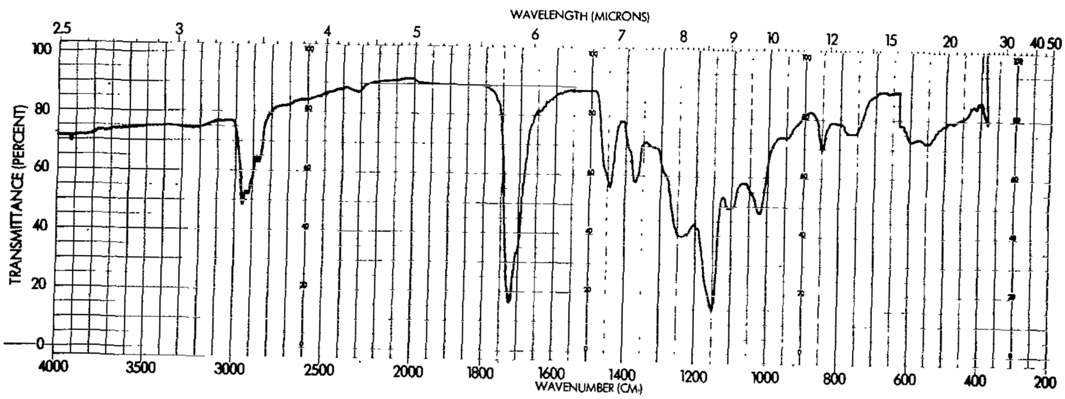

Figure 3.19. 3M #850 tape adhesive.

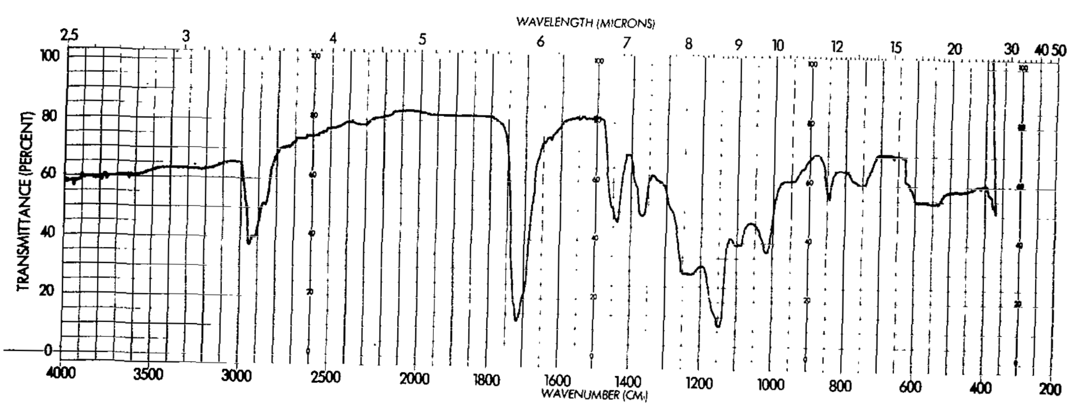

Figure 3.20. 3M #852 tape adhesive.

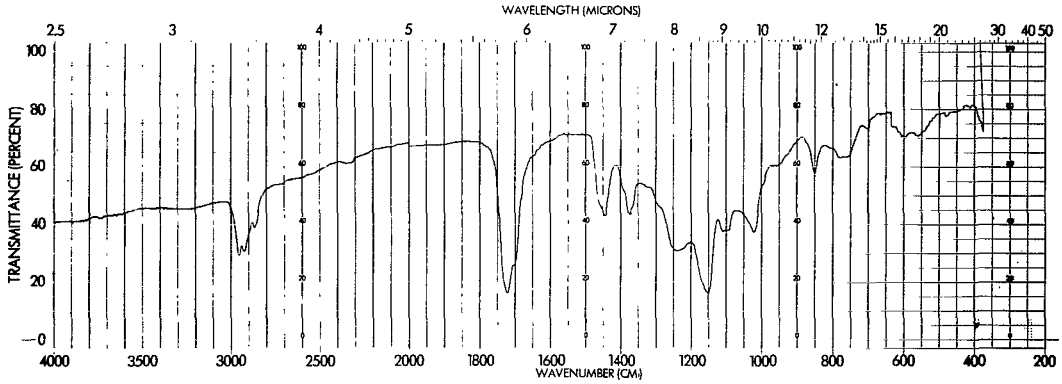

Figure 3.21. 3M #848 tape adhesive.

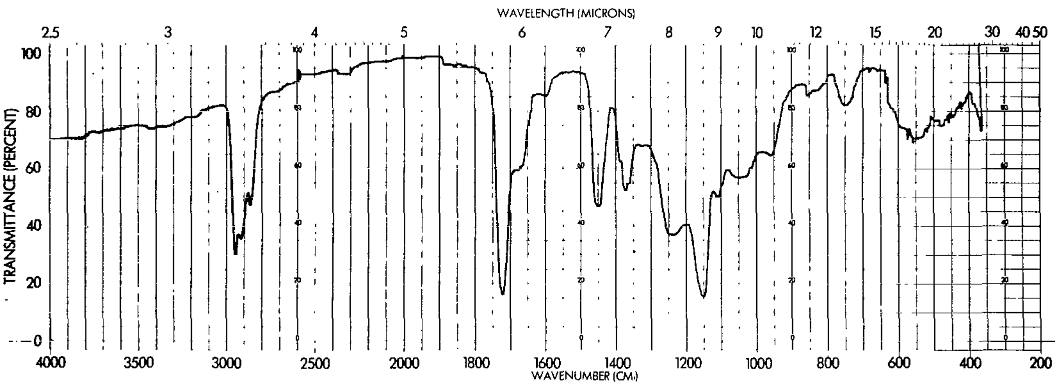

Figure 3.22. 3M X-1205 tape adhesive.

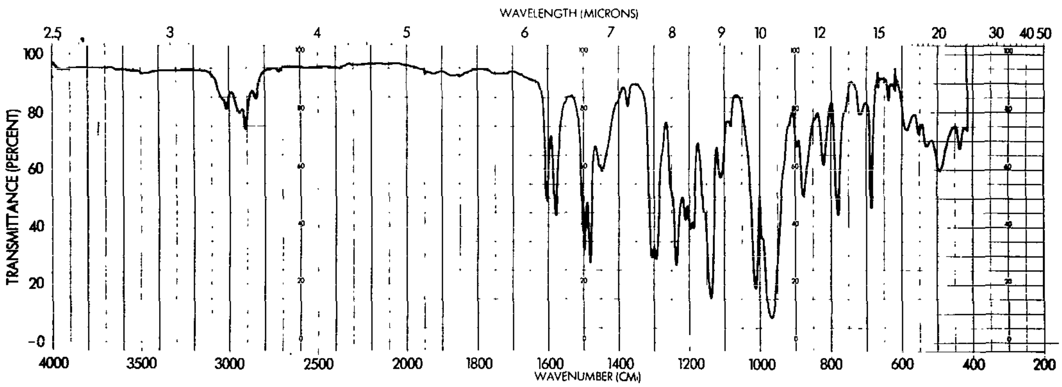

Figure 3.23. Tricresyl phosphate (TCP).

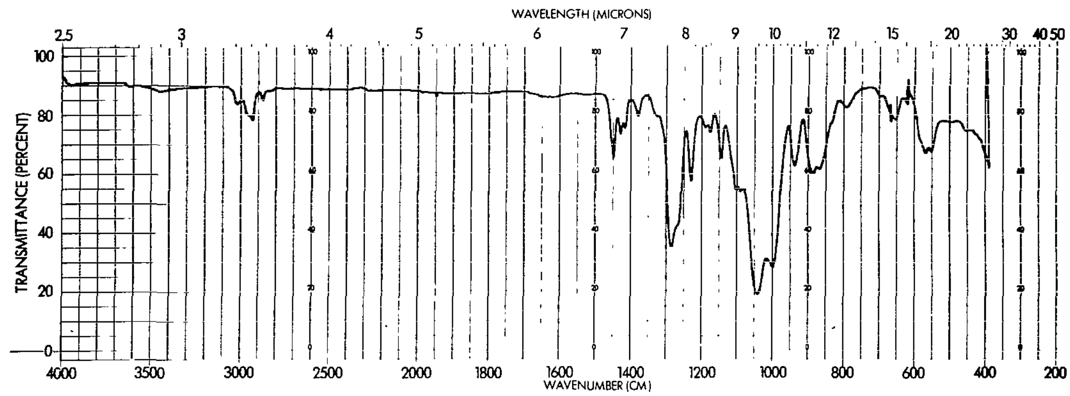

Figure 3.24. Tris-2, 3-dibromopropyl phosphate.

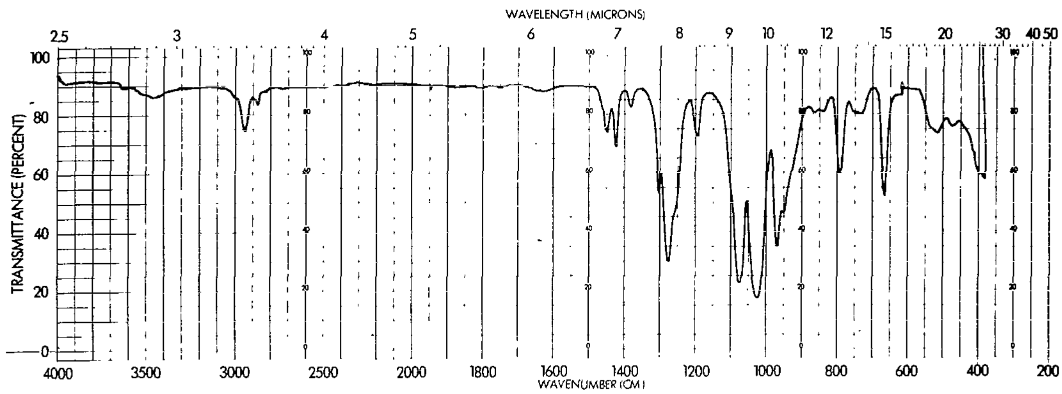

Figure 3.25. Tris-B-chloroethyl phosphate.

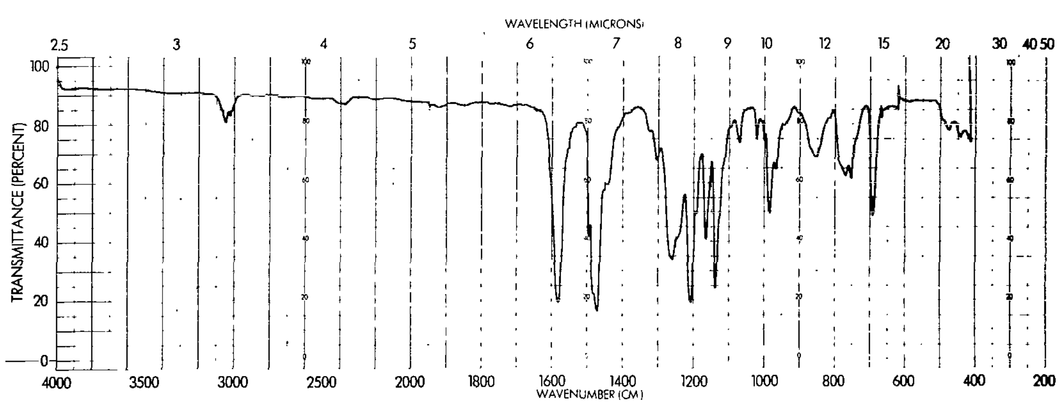

Figure 4.1. Convalex 10.

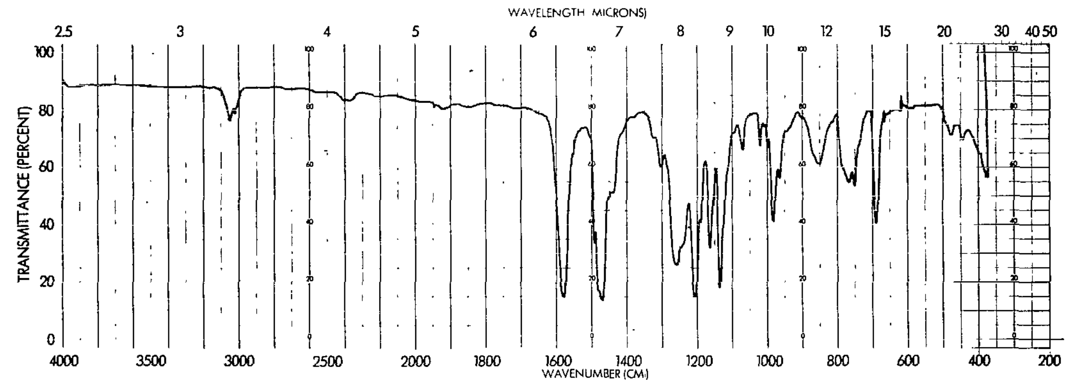

Figure 4.2. Santovac 5.

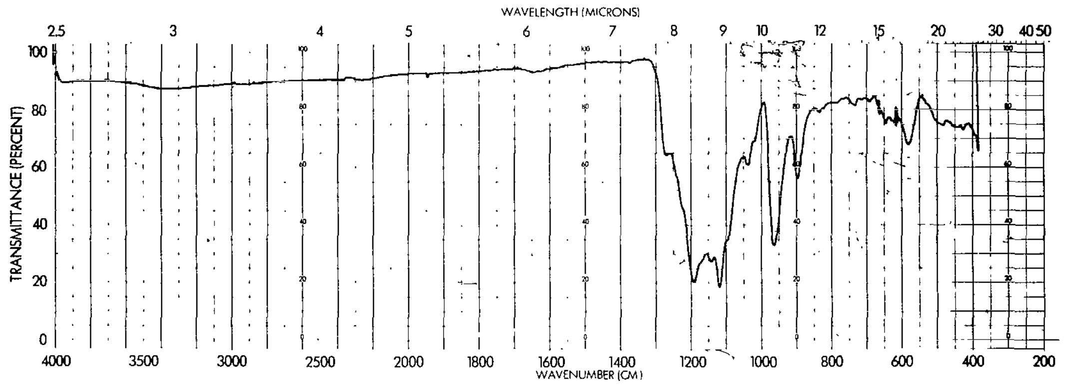

Figure 4.3. Kel-F (#90) grease.

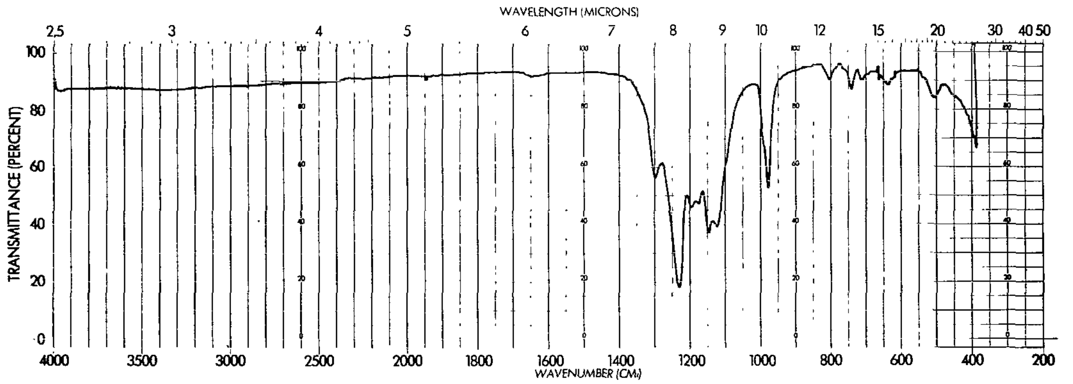

Figure 4.4. Krytox 240 AB grease.

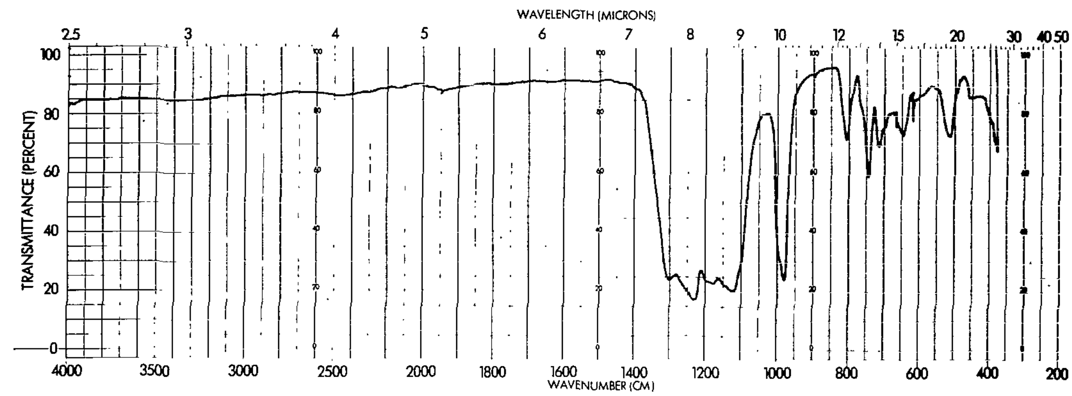

Figure 4.5. Krytox 143 AB oil.

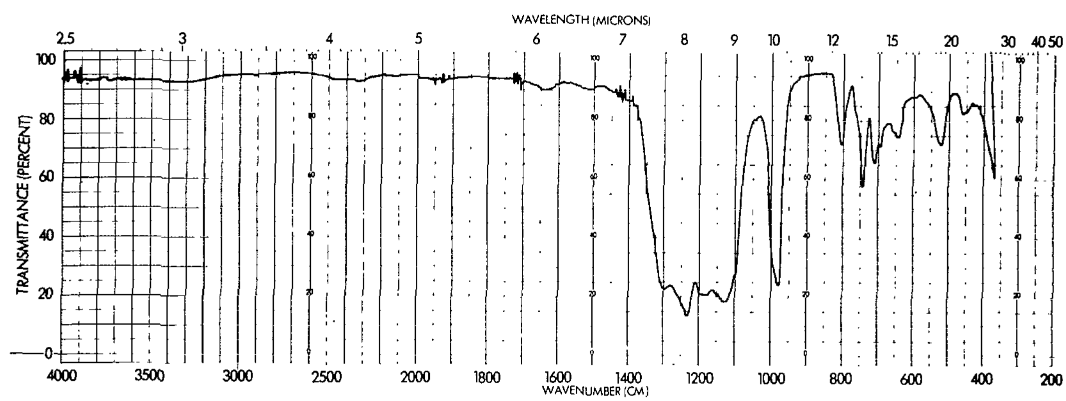

Figure 4.6. Krytox 143 AZ oil.

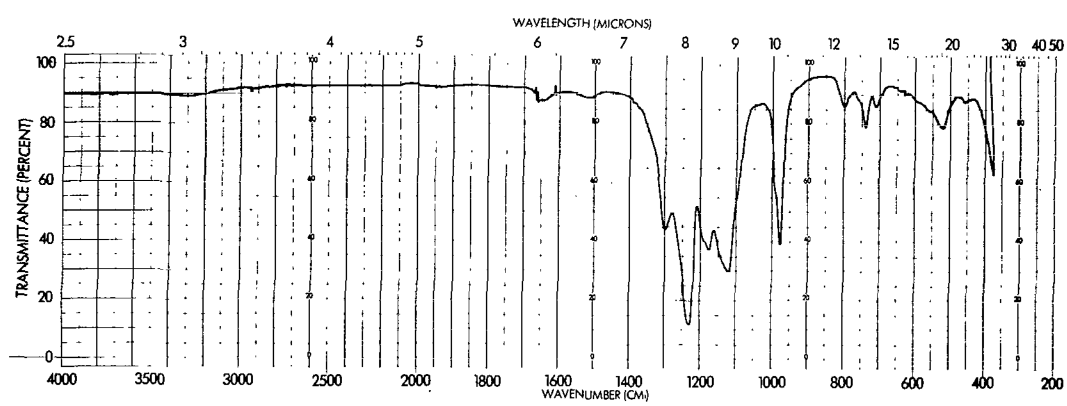

Figure 4.7. Krytox 143 AX oil.

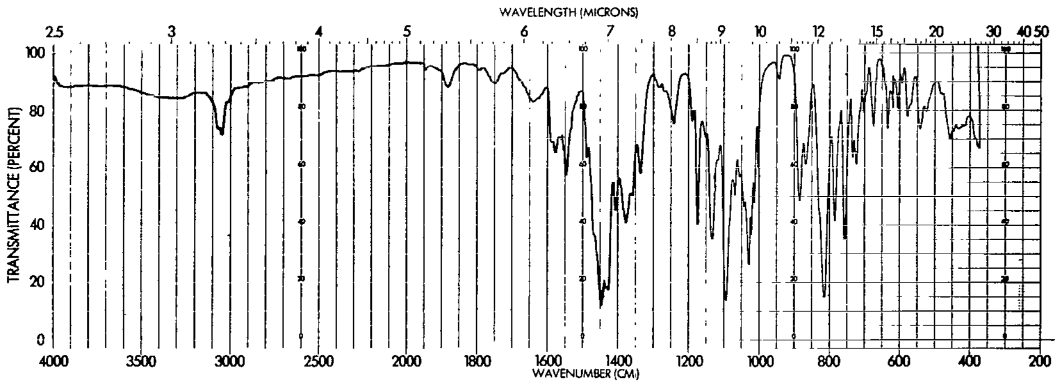

Figure 4.8. Arochlor 1254.

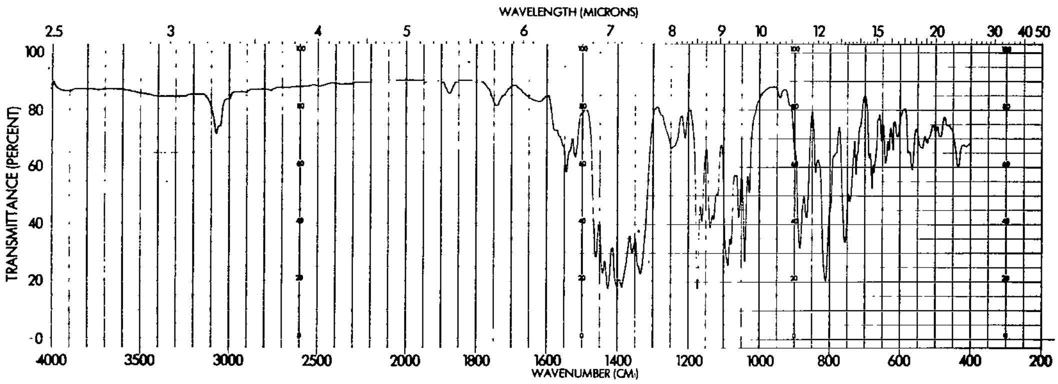

Figure 4.9. Arochlor 1260.

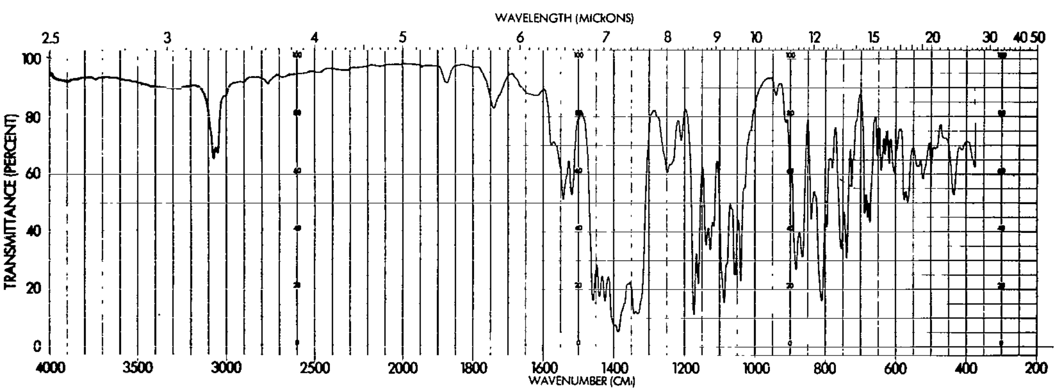

Figure 4.10. Arochlor 1262.

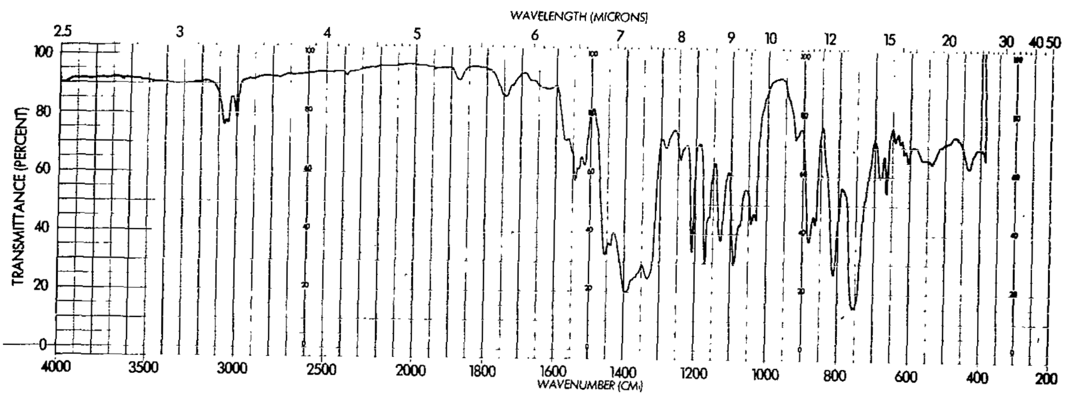

Figure 4.11. Arochlor 5460.

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