NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

A SPECTROPHOTOMETRIC METHOD FOR IDENTIFICATION AND ESTIMATION OF ALKYLNAPHTHALENIC-TYPE HYDROCARBONS IN KEROSENE

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SUMMARY

A spectrophotometric method for identifying and estimating approximate amounts of naphthalenic-type hydrocarbons, which is suitable for finding differences in the naphthalenic content of kerosene fractions of petroleum, is presented. Comparison of the ultraviolet spectra of several naphthalenic compounds, regarded as typical standards, with the spectra of cuts of a kerosene or with the spectrum of the whole kerosene is the basis for the method. Estimates of the naphthalenic content of the cuts and of the kerosene investigated are included to illustrate the method; possible effects of spectroscopic interference are considered. The spectra of the cuts were found to be very similar to the spectra of the respective naphthalenic compounds chosen as typical.

INTRODUCTION

The nature and extent of some effects of variation in the chemical composition and physical properties of fuels upon the performance in the burners of jet-propulsion engines are being investigated at the NACA Cleveland laboratory. Smoking characteristics of several fuels in a laboratory burner have been reported in reference 1. Fuel investigations are being conducted on jet-propulsion burners for both static sea-level conditions and simulated-altitude conditions. In connection with a survey of sources of satisfactory jet-propulsion fuels information concerning the types and amounts of hydrocarbon in cuts of the kerosene fraction of several American crudes has been obtained at the Petroleum Experiment Station, Bureau of Mines, Bartlesville, Oklahoma. As part of the Bartlesville investigation, the total amount of aromatics in the cuts was determined by the method of reference 2. The content of dicyclic aromatics was estimated at Bartlesville by a method based on the refractivity intercept of the aromatic portion extracted by silica

gel. Knowledge of the approximate amounts of several naphthalenic types present is probably desirable but a method for making this estimation has been unavailable.

A study of the ultraviolet spectra of some representative aromatic compounds presented in references 3 and 4 and of the comprehensive survey of such spectra given in reference 5 suggests the feasibility of identifying types and estimating the approximate amount of naphthalenic hydrocarbons by an ultraviolet-spectrophotometric method. Such a method and its applications to cuts of a kerosene and to a whole kerosene is presented. This investigation, conducted during the spring of 1945, is based on the ultraviolet spectra of a kerosene, its cuts, and several alkylnaphthalenes.

DISCUSSION OF METHOD

Survey of analytical problem. - Development of a spectroscopic method for the detection and the estimation of naphthalenic homologs requires a region of the spectrum where these compounds absorb more intensely than any others that may be present in kerosene. Ultraviolet absorption in the region from 3100 to 3250 A is characteristic of naphthalene (b.p., 218° C) (fig. 1), methylnaphthalenes (b.p., about 245° C) (fig. 2), and other naphthalene homologs (figs. 3 and 4) in much the same way that absorption in the region from 2500 to 2750 A is characteristic of benzene (b.p., 80° C), toluene (b.p., 110° C), and other benzene homologs. Paraffins, naphthenes, and noncyclic olefins are transparent in the region from 3000 to 4000 A. For these reasons, the principles of spectrochemical analysis that make possible the analysis of binary and more complex mixtures of aromatics in gasoline are applicable in the higher boiling range. These principles were presented in reference 6. The number of individual dicyclic aromatics possibly present in kerosene, however, is larger than in the lower boiling range. Accuracy in the application of the principles is therefore subject to limitations because of increased difficulties of isolation of naphthalenic homologs by distillation, decreased availability of spectra of pure isomers, and some new possibilities of interference, which will be discussed in the section Problem of interference. In view of these limitations, the method described is at present proposed for only detection and estimation of the naphthalenic homologs either in kerosene or in cuts of kerosene. If naphthalene is isolated in a cut, however, single component analysis for it is accurate to about ±2 percent of the amount present.

Apparatus. - A commercial quartz photoelectric spectrophotometer (reference 7) with slits set at 0.50 millimeter was used for the

measurements. By a survey of some lines in the mercury-arc spectrum, the effective slit width (that is, the half-intensity band width mentioned in reference 7) was found to be about 20 A at 3200 A; and wavelength settings were reproducible to about ±2 A. The ultraviolet method of detection is inherently so sensitive that if interference is absent 0.02 percent by volume of naphthalenic homologs can be recognized in the 0.5-centimeter matched quartz cells that were used for all measurements. Estimation of the amount of naphthalenic homologs in a kerosene sample was accomplished by comparing the spectrum of the sample with the spectrum of a standard solution of typical napththalenic homologs.

Details of method. - Dilution of all samples with isooctane (aromatic content less than 0.001 percent by volume) in order that extinctions at peaks of bands were between 0.3 and 1.0 was a routine part of the procedure. The procedure involved approximate matching of extinctions at a chosen wavelength and comparing dilution factors, as will be explained. (Dilution factor is the ratio of volume of solution to volume of solute.)

If cell thickness and slit width are maintained constant, the product of the extinction E_o measured at the wavelength of a particular band and of the dilution factor D_o for the solution in the cell is proportional to the concentration of naphthalenic aromatics in the original undiluted sample. This product E_oD_o for a naphthalenic compound or mixture of compounds chosen as a typical standard corresponds to 100-percent concentration. The amounts of the same or similar naphthalenic aromatics in other samples are estimated by finding the products E_iD_i ($i = 1,2,3,4...$) at the same wavelength and expressing them as percentages of E_oD_o. The E_oD_o products given are approximately 500 times as large as specific extinctions. The density of the aromatic solute is d. As a precaution to minimize the effect of spectroscopic interference, it is recommended that the extinction of the diluted sample at 3400 A be subtracted from E_i before further calculations are made.

Probably the chief source of error in this estimation lies in the possibility that the compound or the mixture chosen as a standard may not be spectroscopically typical of the compounds actually present. Comparisons between various spectra of compounds such as those presented in figures 2 to 5 and in references 3 and 4 yield some knowledge of typical specific extinctions and of limits of error for particular cases. These data indicate that the uncertainty in unusual cases may be as much as a factor of 2 applied to the amount present. In natural mixtures, the condition for maximum error (namely, that of a possible group only one abnormally high- or low-absorbing compound

be present in a cut) would probably seldom occur. For example, measured values of E_oD_o for the four naphthalenic homologs reported vary only 20 percent from a mean value. The integrating effect of the relatively wide effective slit width used (20 A) probably favors improved accuracy in the estimation of multicomponent mixtures; whereas, a narrower slit would aid more precise qualitative identifications. Because naphthalenic aromatics are usually minor constituents of a kerosene, the uncertainties in terms of percentage of a kerosene are often small in magnitude.

Problem of interference. - Even approximate analysis for naphthalenic-type aromatics in naturally occurring mixtures such as kerosenes, which usually distill within the range 150° to 300° C and may contain scores of hydrocarbon compounds, may be affected by interfering absorption. Benzene and naphthalenic homologs constituted by far the greater portion of the aromatics identified in reference 8 as present in the gasoline and kerosene fractions of a Burma crude. In addition, the compounds indene (b.p., 182° C), tetralin (b.p., approximately 200° C), and fluorene (b.p., 298° C) have been designated in reference 9 as found in kerosene. Thirty aromatic hydrocarbons, which have boiling points in and somewhat above the kerosene range (150° to 300° C) and are believed to be representative of the aromatics that are in kerosene or could be in kerosene so far as the boiling points are involved, are listed in table I together with some of their physical properties. The presence in kerosene of noncondensed dicyclic homologs or of the other aromatics not designated in table I as found in kerosene has not been reported in the literature. In some cases, this fact may be due to the lack of methods sufficiently sensitive to detect these hydrocarbons in low concentrations in kerosene. References 3, 4, 5, and 10 contain the ultraviolet spectra of many of the compounds listed in table I. On the basis of the intensity and the nature of the interfering absorption as determined from these spectra and from the spectra in figure 5, most of the nonnaphthalenic aromatics in table I can be divided into three groups.

The first group consists largely of benzene homologs and includes nearly all the nonnaphthalenic aromatics that have been found in kerosene. The first five compounds listed in table I and also compounds 7, 9, and 14 are typical of this group, which interferes very little and may be present to the extent of 30 percent of a sample without seriously affecting an extimation. Determination of whether tetralins such as compound 6 (1,2,3,4-tetrahydronaphthalene) may be included in this first group is not easy because of the difficulty of removing all traces of naphthalenic impurities. As the result of an extensive study, the authors of reference 4 (p. 920)

concluded that "the principal constituent of commercial tetralin is a substance devoid of the 290-320 mμ [2900 to 3200 A] narrow bands present in naphthalene." The specific extinction of about 0.08 at 3100 A in the tetralin spectrum given in figure 5 is therefore due largely to naphthalenic impurities and tetralin (compound 6, table I) may also be included in the first group.

The second group includes noncondensed dicyclic aromatics that have not been found in kerosenes, such as compounds 13, 15, 20, and 23 in table I. The spectra of bibenzyl and 1,1-diphenylethane shown in figure 5 may be affected by traces of naphthalenic impurities although tests were made to verify the probable absence of such impurities. On the basis of these spectra, which show specific extinctions less than 0.04 in the wavelength range from 3100 to 3300 A, it may be predicted that compounds of the second group, if present in an amount equal to the naphthalenic aromatics in a kerosene, cannot be detected by the method proposed but might cause an estimate of naphthalenes to be high by as much as 4 percent of the amount present. A low tolerable limit would allow the interfering compounds of the second group to be present in an amount about twice the naphthalenic content.

Other compounds such as fluorene, 9, 10-dihydroanthracene, and anthracene (compounds 25, 26, and 28, respectively) constitute a third group characterized by absorption at 3400 A as intense as at 3200 A; hence, their presence can be detected by finding appreciable absorption at 3400 A. An approximate base-line correction for the presence of these compounds can be made by subtracting the extinction measured at 3400 A from the value at the wavelength chosen for estimation before any calculations are made. Although there is evidence that, in general, compounds interfering with estimation, if present, are merely traces in kerosene, a tolerable limit for their presence is an amount equal to the naphthalenic concentration. Absence in kerosenes of another group of interfering compounds, namely, olefinic naphthalenes and acenaphthene, is assumed here because they have not been reported and because of the low bromine numbers that usually characterize kerosenes. If present, the ultraviolet absorption of the olefinic naphthalenes and acenaphthene is probably such that they would either be reported as corresponding amounts of alkylnaphthalenes or be detected as interfering compounds of the anthracenic type previously described.

HYDROCARBONS

The kerosene for the tests was purchased from the Standard Oil Company of Ohio without knowledge of the source of the original crude.

According to laboratory inspection tests, specific gravity 60/60 was 0.809; freezing point, -42° C; flash point, 32° C; and average molecular weight about 167.

The naphthalene for figure 1 was estimated at the Cleveland laboratory to be 98 percent pure on the basis of its freezing point. The wavelength of the peak in its spectrum shown at 3111 A in figure 1 agreed within 1 A with the value 3110 A given in references 3 and 4. Differences noted between specific extinctions for naphthalene in these references and in figure 1 were largely attributed to the wider effective slit width used in this investigation. The methyl-, amyl-, and diamylnaphthalenes were of technical grade and were probably mixtures of isomers. The spectra of the isomers of methylnaphthalene given in reference 3 showed that figure 2 was the spectrum of a mixture. The spectra in references 3 and 4 showed that other alkylnaphthalenes were also characterized by absorption of a similar magnitude. These technical compounds therefore were assumed to be spectroscopically typical of mixtures of the naphthalenic compounds in the kerosene cuts. The 1,1-diphenylethane and the bibenzyl used for the spectra shown in figure 5 were of technical grade. Two recrystallizations of the bibenzyl did not decrease its absorption in the region shown.

NAPHTHALENIC AROMATICS IN CUTS OF A KEROSENE

As an example of the information concerning naphthalenic aromatics furnished by spectroscopic data, the significance of the ultraviolet spectra of some cuts of a kerosene obtained with a still of 100 theoretical plates will be discussed. In this prototype investigation, the known boiling range for each cut is used to confirm deductions from the spectra. Data for the eight cuts are given in the following table:

Cut	1	2	3	4	5	6	7	8
Distillation range, °C	100 - 161	161 - 181	181 - 199	199 - 216	216 - 232	232 - 245	245 - 252	252 - End
Percentage of kerosene by volume	6.7	11.0	13.2	14.4	19.1	11.9	3.4	15.3

The spectrum of undiluted cut 3 in a 0.5-centimeter quartz cell is shown for the region from 3030 to 3370 A in figure 6. This cut is the lowest boiling cut that shows appreciable absorption in this region. The peak of absorption at 3111 A is characteristic of the spectrum of naphthalene, which is also shown in figure 6 for similar experimental conditions. The relatively greater intensity of absorption

by cut 3 than by naphthalene at 3205 A can be caused by a small amount of methylnaphthalenes. (See fig. 2.) Values of E_OD_O for some naphthalenic compounds are given in table II. The value E_OD_O for methylnaphthalenes at 3192 A is 900 and that of E_3D_3 for cut 3 in figure 6 is 6.25. If the naphthalene concentration is assumed to be the same as that used for the comparison spectrum in figure 6, namely, about 0.1 percent by volume, the concentration of the methylnaphthalenes is found to be of the order of 0.02 percent by volume. This amount is negligible but its determination indicates the sensitivity of the estimation technique. Presence of this concentration of monoalkylnaphthalenes would account for about 0.2 in the extinction of cut 3 at 3111 A; hence, the concentration of naphthalene in cut 3 is nearly the same as that of the solution used for the naphthalene spectrum or about 0.1 percent by volume.

The spectrum of a solution containing three parts of cut 4 in twenty five parts of isooctane solution is shown in figure 7. This spectrum is so similar to the naphthalene spectrum also given in figure 7 that cut 4 evidently contains essentially naphthalene in a concentration about nine times as large as that of the solution used for the naphthalene spectrum, that is, about 1 percent by volume in the cut. Differences between the spectra in figure 7, however, can be interpreted, as were those in figure 6, to indicate less than 0.01 percent of monoalkylnaphthalenes in the cell or less than 0.1 percent in cut 4.

The similarity of the spectra of the isomeric mixture of methylnaphthalenes and cuts 5 and 6, evident in figure 8 together with the evidence in reference 11 that the isomers occur together, are reasons for using this particular mixture as a basis for estimations. Characteristic bands of methylnaphthalenes and amylnaphthalenes are at 3192 A and 3181 A, respectively. According to reference 4, dialkylnaphthalenes have these first bands at 3218 ±10 A; whereas for trialkylnaphthalenes the first bands are at 3246 ±14 A. Because the peak for cut 5 is rather sharp at 3191 A, the presence of dialkylnaphthalenes or trialkylnaphthalenes is improbable. The spectrum of cut 5 can be duplicated in the 3100 to 3300 A region by proper dilution of a mixture of 10-percent naphthalene and about 90 percent of methylnaphthalenes used for the spectrum shown in figures 2 and 8. Nevertheless, this composition cannot be given as an indisputable qualitative analysis because a higher content of the α-methylnaphthalene isomer in the cut than in the reference standard would produce a similar modification of the spectrum according to the spectra in reference 3. The present estimation procedure gives 1.6 percent by volume of monoalkylnaphthalenes in cut 5.

The differences evident in figure 8 between the spectrum of cut 6 and that of cut 5, especially the broader peak for cut 6 at about 3184 A and relatively more intense absorption in the vicinity of 3220 A, indicate that cut 6 contains a larger variety of monoalkylnaphthalenic and dialkylnaphthalenic compounds than cut 5. The sharpness of the first peak in the spectrum of cut 7 shown in figure 9 and its position at 3225 A rather than at 3250 A indicate that a few dialkylnaphthalenes predominate in the mixture and other naphthalenes are minor components. This deduction from the spectrum is in agreement with the effect of the narrow distillation range of 7° C for cut 7. The shape of the spectrum of cut 8 (the residue), also shown in figure 9, would correlate better with a more complex mixture including some trisubstituted naphthalenes. The finite absorption by cut 8 persisting to 3400 A and beyond is an example of the presence of the third type of interfering compounds previously mentioned in DISCUSSION OF METHOD. The presence of compounds such as fluorene or dihydroanthracene in the cut seems probable and about 0.1 should be subtracted from the extinction of cut 8 before an estimate of naphthalenic compounds is made.

The spectrum for the whole kerosene presented in figure 10 shows absorption by various alkylnaphthalenes from 3100 to 3300 A and that interference of anthracenic compounds near 3400 A is much smaller than in the case of the residue as would be expected. On the basis of an average E_oD_o of approximately 800 at 3200 A, the presence of about 2.7 percent by volume of naphthalene homologs is indicated. This value is slightly higher than the sum of values estimated for the cuts, as will be seen in the summary of data and estimates of naphthalenic content given in table II. The total aromatic content of the kerosene was estimated at this laboratory by A.S.T.M. method ES-45 to be approximately 25 percent by volume. The sum of estimated naphthalenic content of cuts in table II (2.3 percent by volume) is therefore approximately 10 percent of all aromatics present. Admittedly, these estimations are subject to considerable error; however, in a survey of cuts of various crudes they could be used to indicate large differences.

DISCUSSION OF RESULTS

As a consequence of the presence of a greater variety of naphthalenic homologs in successively higher boiling cuts of kerosene, the uncertainty of estimates increases. Shifts of absorption toward longer wavelength can be correlated with the presence of mono-, di-, and trisubstituted naphthalenes in the successively higher boiling cuts. The spectroscopic evidence indicates that naphthalenic aromatics constitute only a very small part of the kerosene investigated because

they amount to about only one-tenth of the aromatics present. The presence of any compounds that interfere with the estimations because they absorb in the 3100 to 3300 A region would tend to make the estimates high rather than low. The probability of the presence of interfering compounds is greater for cut 8, which is the residue of the kerosene. The low extinction of cut 8 at 3400 A sets a limit to the amount of anthracenic-type compounds in the cut. If bibenzyl (b.p., 284° C) were present to the improbable extent of 20 percent of the residue, the estimate of naphthalenic aromatics would be high by about 0.4 percent of the residue or 0.07 percent of the kerosene.

The presence of interfering compounds in large quantities would be expected to cause the spectra of the cuts to differ in some detectable way from the spectra of typical naphthalenic compounds possibly present. The small magnitude of these differences in the spectra of the cuts investigated gives assurance, independent of the distillation temperatures, that such interference was not serious.

SUMMARY OF RESULTS

Naphthalene and certain types of naphthalenic homolog were identified spectrophotometrically in cuts of kerosene and the total concentration of naphthalenic homologs in mixtures of hydrocarbons as complex as kerosenes were estimated by use of the absorption in the ultraviolet region from 3100 to 3300 A. The degree of certainty of the estimates was chiefly limited by divergence of the specific extinction of the mixture of naphthalenic homologs present from the specific extinction of a particular naphthalenic homolog or mixture of homologs chosen as a typical standard. Although the literature indicated that at high resolution the specific extinctions of pure naphthalenic isomers may vary from as much as twice a mean value to one-half that value, this wide variation was not probable in

naphthalenic mixtures that occur in kerosene. Measurements of the specific extinctions of four naphthalenic aromatics using relatively wide spectrophotometer-slit settings differed from a mean value by only 20 percent.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, January 28, 1947.

REFERENCES

1. Ebersole, Earl R., and Barnett, Henry C.: Smoking Characteristics of Various Fuels as Determined by Open-Cup and Laboratory-Burner Smoke Tests. NACA MR Nos. E5F20 and E5I12, 1945.

2. Mair, Beveridge J.: Separation and Determination of Aromatic and Monoolefin Hydrocarbons in Mixtures with Paraffins and Naphthenes by Adsorption. Res. Paper 1652, Nat. Bur. Standards Jour. Res., vol. 34, no. 5, May 1945, pp. 435-451.

3. de Laszlo, Henry G.: Die Absorptionsspektren und Aktiverungsstufen von Naphthaline und einigen Methylderivaten. Zeitschr. f. Phys. Chem., Bd. 118, Heft 5-6, Dez. 30, 1925, pp. 369-414.

4. Morton, R. A., and de Gouveia, A. J. A.: Chromophoric Groups. Part I. Ultra-violet Absorption Spectra of Indene and Certain of its Derivatives. Part II. Absorption Spectra of Naphthalene, Hydronaphthalenes, and Related Compounds. Jour. Chem. Soc. (British), 1934, pp. 911-930.

5. Jones, R. Norman: The Ultraviolet Absorption Spectra of Aromatic Hydrocarbons. Chem. Rev., vol. 32, no. 1, Feb. 1943, pp. 1-46.

6. Cleaves, Alden P.: Ultraviolet Spectrochemical Analysis for Aromatics in Aircraft Fuels. NACA ARR No. E5B14, 1945.

7. Cary, H. H., and Beckman, Arnold O.: A Quartz Photoelectric Spectrophotometer. Jour. Optical Soc. Am., vol. 31, no. 11, Nov. 1941, pp. 682-689.

8. Carpenter, J. A.: Composition of Petroleum. Jour. Inst. Petroleum Tech., vol. 13, 1926, p. 526.

9. Doss, M. P.: Physical Constants of the Principal Hydrocarbons. The Texas Co. (New York), 4th ed., 1943.

10. Henri, V.: Spectres D'Absorption. Vol. VII of Tables Annuelles de Constantes et Données Numériques de Chimie, de Physique, de Biologie et de Technologie, pt. I, 1925-1926, pp. 801, 806.

11. Mair, Beveridge J., and Streiff, Anton J.: Separation of the Aromatic Hydrocarbons, and the Isolation of n-Dodecane, Naphthalene, 1-Methylnaphthalene, and 2-Methylnaphthalene, from the Kerosene Fraction of Petroleum. Res. Paper 1289, Nat. Bur. Standards Jour. Res., vol. 24, no. 4, April 1940, pp. 395-414.

12. Anon.: Handbook of Chemistry and Physics. Chem. Rubber Pub. Co. (Cleveland), 28th ed., 1944.

TABLE I - PHYSICAL PROPERTIES OF SOME AROMATICS HAVING BOILING POINTS IN AND SOMEWHAT ABOVE KEROSENE RANGE (150°-300° C)

[Values for compound 2 were determined on a pure sample prepared at this laboratory. Other values are taken from reference 9, except those for compounds 20 and 26, which are taken from reference 12. Boiling-point range, 180° to 360° C; index of refraction at 20° C for sodium light, n^{20}; specific gravity at 20° C relative to water at 4° C taken as unity, d_4^{20}.]

Compound	Hydrocarbon	Boiling point at 760 mm (°C)	Freezing point (°C)	cd_4^{20}	n^{20}
1	Indene[a]	182	-1.5	0.9968	1.5764
2	n-Butylbenzene[a]	183.2	-88.0	.8601	1.4899
3	1,2,4,5-Tetramethylbenzene[a]	195.9	79.2	.8380	1.463
4	1-Methyl-4-butylbenzene	198.0	-85.0	.8586	1.4916
5	Amylbenzene	205.0	-78.2	.8577	1.4883
6	1,2,3,4-Tetrahydronaphthalene[a]	206.8	-35.8	.9707	1.5438
7	1,2-Dimethyl-4-propylbenzene	209.0	<-20.0	.8641	1.4954
8	Naphthalene[a]	218.0	80.3	.9752	1.5898
9	Pentamethylbenzene	231.9	54.0	.921	1.5287
10	1-Methyl-5,6,7,8-tetralin[a]	234.3	-22.9	.9720	1.5440
11	1-Methylnaphthalene[a]	244.8	-30.8	1.0163	1.6149
12	1-Ethylnaphthalene[a]	252.0	-15.0	1.019	1.6089
13	Biphenyl	255.2	69.2	1.041	1.588
14	Diamylbenzene	261-267	<-75.0	.851	1.4819
15	Diphenylmethane	261-262	25.3	1.044	1.5739
16	1-Isopropylnaphthalene[a]	263-264	------	--------	1.5756
17	1,4-Dimethylnaphthalene[a]	262-264	<-18.0	1.0180	1.6157
18	2,3-Dimethylnaphthalene	265-266	104.0	1.008	------
19	Acenaphthylene	265-275	92-93	.8988	------
20	1,1-Diphenylethane	272	------	1.006	1.5761
21	1,3,7-Trimethylnaphthalene	280.0	13.5	1.007	1.5759
22	Acenaphthene	280.7	96.2	1.024	1.6048
23	Bibenzyl	286.3	53.0	.9581	1.5339
24	2-Amylnaphthalene[a]	279-320	-60.0	.96-.97	1.5718
25	Fluorene[a]	298.0	113.5	.9165	------
26	9,10-Dihydroanthracene	305	108.5	.8976	------
27	Phenanthrene	340.0	96.3	1.025	1.5943
28	Anthracene	342.3	215.0	1.25	------
29	Diamylnaphthalene	329-366	-30.0	.93-.94	1.5516
30	1-Methylanthracene	>360	85.5	1.047	1.6803

[a]Designated in reference 9 as found in kerosene.

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TABLE II - ESTIMATED NAPHTHALENIC CONTENT OF KEROSENE CUTS

Cut	Typical compounds used as standards	Wavelength (A)	$E_oD_o \times 10^{-2}$	E_iD_i	Estimates of naphthalenic aromatics (percent by volume)		Probable type
					In cut	In kerosene	
3	Naphthalene	3111	7	0.7	0.1	0.02	Naphthalene
4	Naphthalene	3111	7	7	1	.14	Naphthalene
5	Methylnaphthalenes	3192	9	15	1.6	.32	Monoalkyl-naphthalenes
6	Methylnaphthalenes Amylnaphthalenes	3192 3190	9 6	13	1.7	.2	Monoalkyl- and dialkyl-naphthalenes
7	Diamylnaphthalenes	3219	7	48	7	.2	Various alkyl-naphthalenes
8	Diamylnaphthalenes	3219	7	65	9	1.4	Various alkyl-naphthalenes
	Total					2.3	

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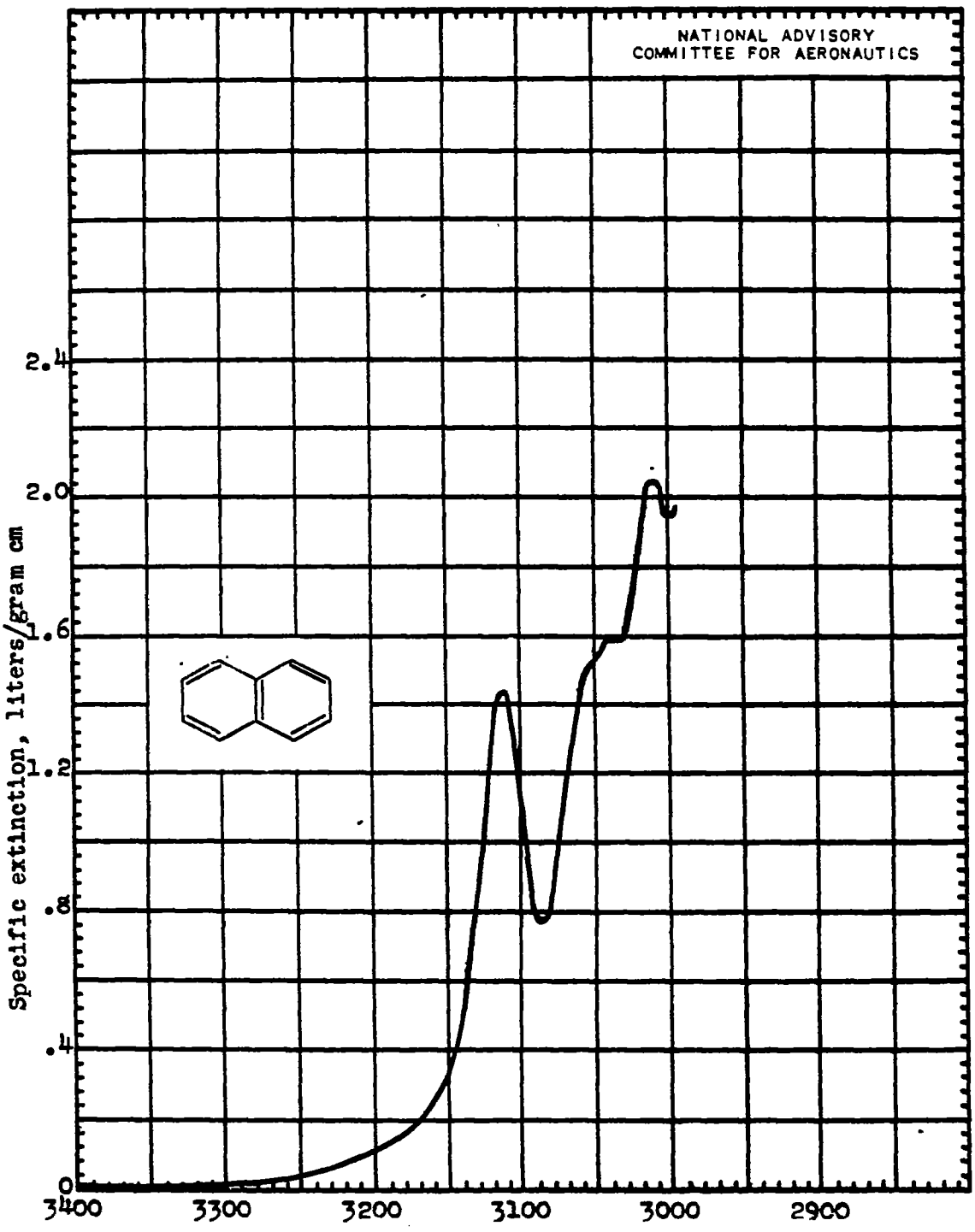

Figure 1. - Ultraviolet absorption spectrum of naphthalene determined by photoelectric spectrophotometer. Solvent, isooctane; slit widths, 0.50 millimeter.

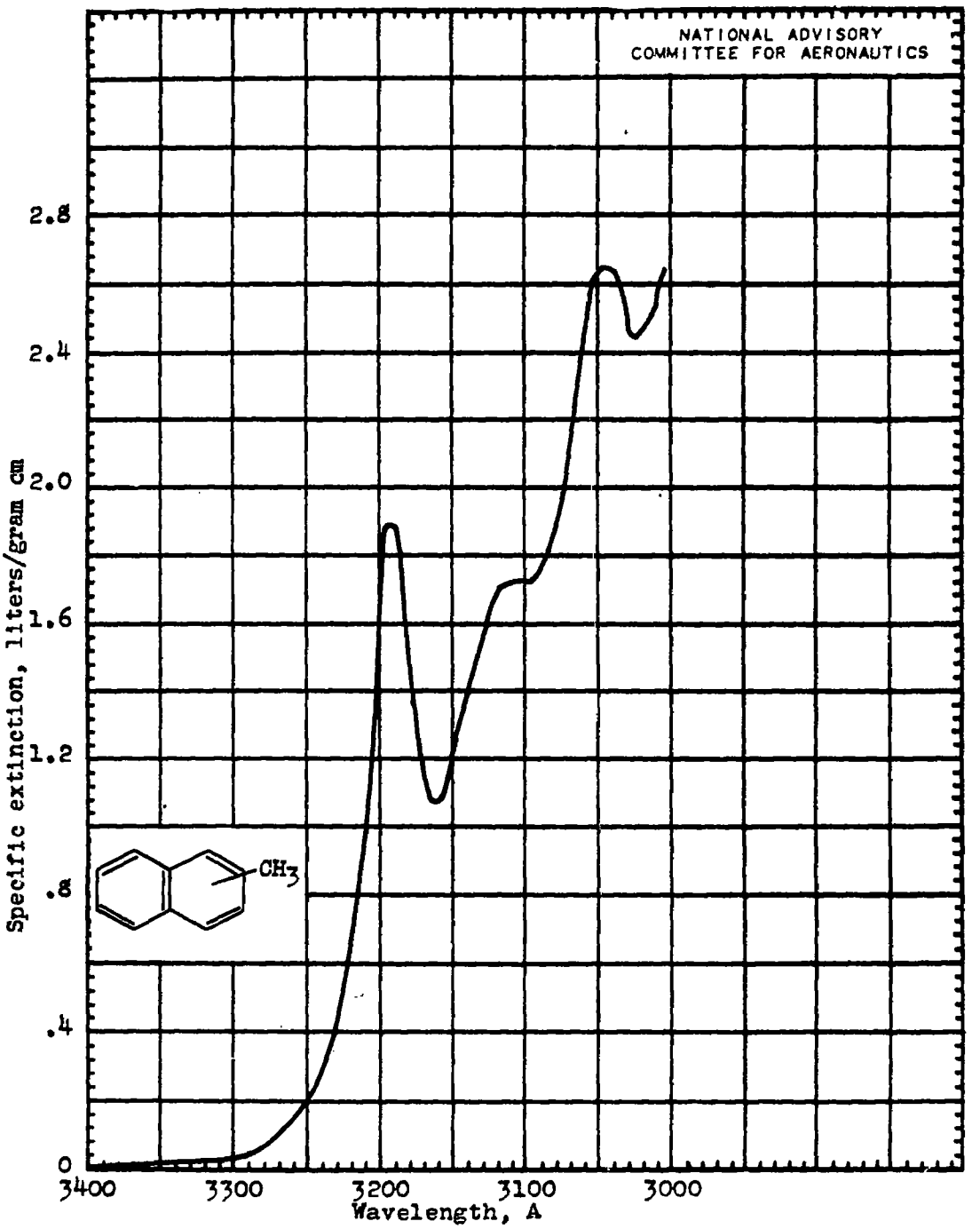

Figure 2. - Ultraviolet absorption spectrum of methylnaphthalene (isomeric mixture) determined by photoelectric spectrophotometer. Solvent, isooctane; slit widths, 0.50 millimeter.

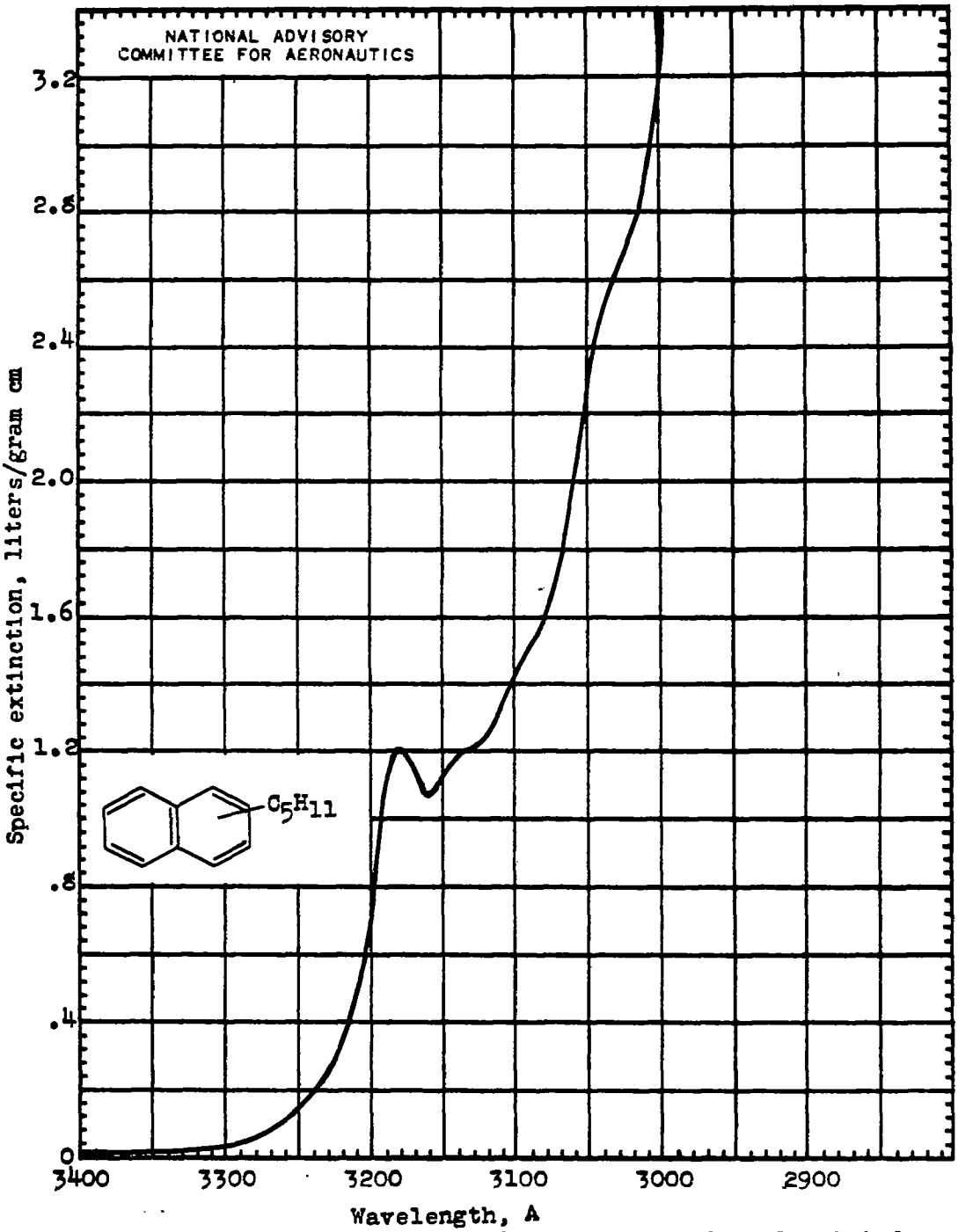

Figure 3. - Ultraviolet absorption spectrum of amylnaphthalene (isomeric mixture) determined by photoelectric spectrophotometer. Solvent, isooctane; slit widths, 0.50 millimeter.

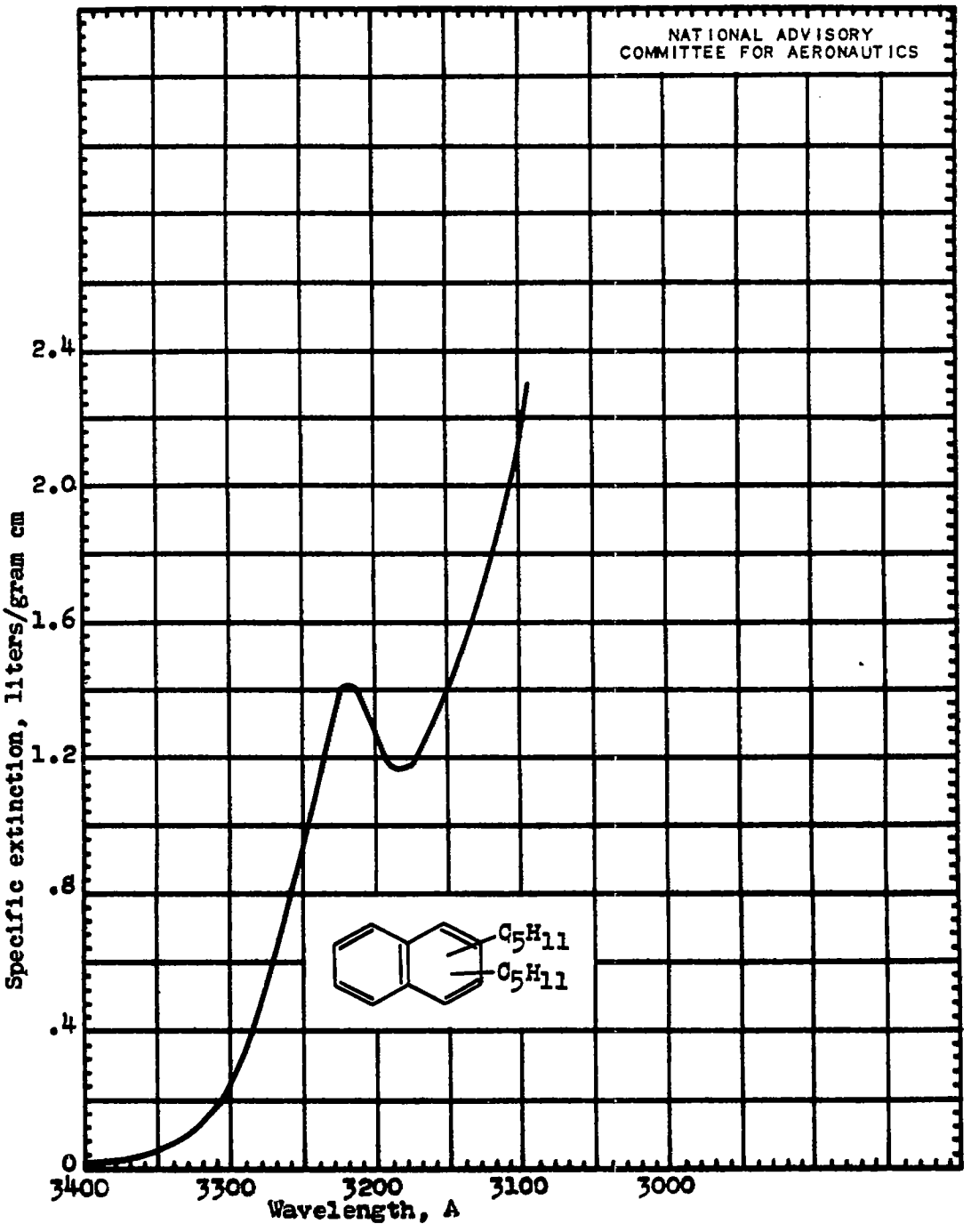

Figure 4. - Ultraviolet absorption spectrum of diamylnaphthalene (isomeric mixture) determined by photoelectric spectrophotometer. Solvent, isooctane; slit widths, 0.50 millimeter.

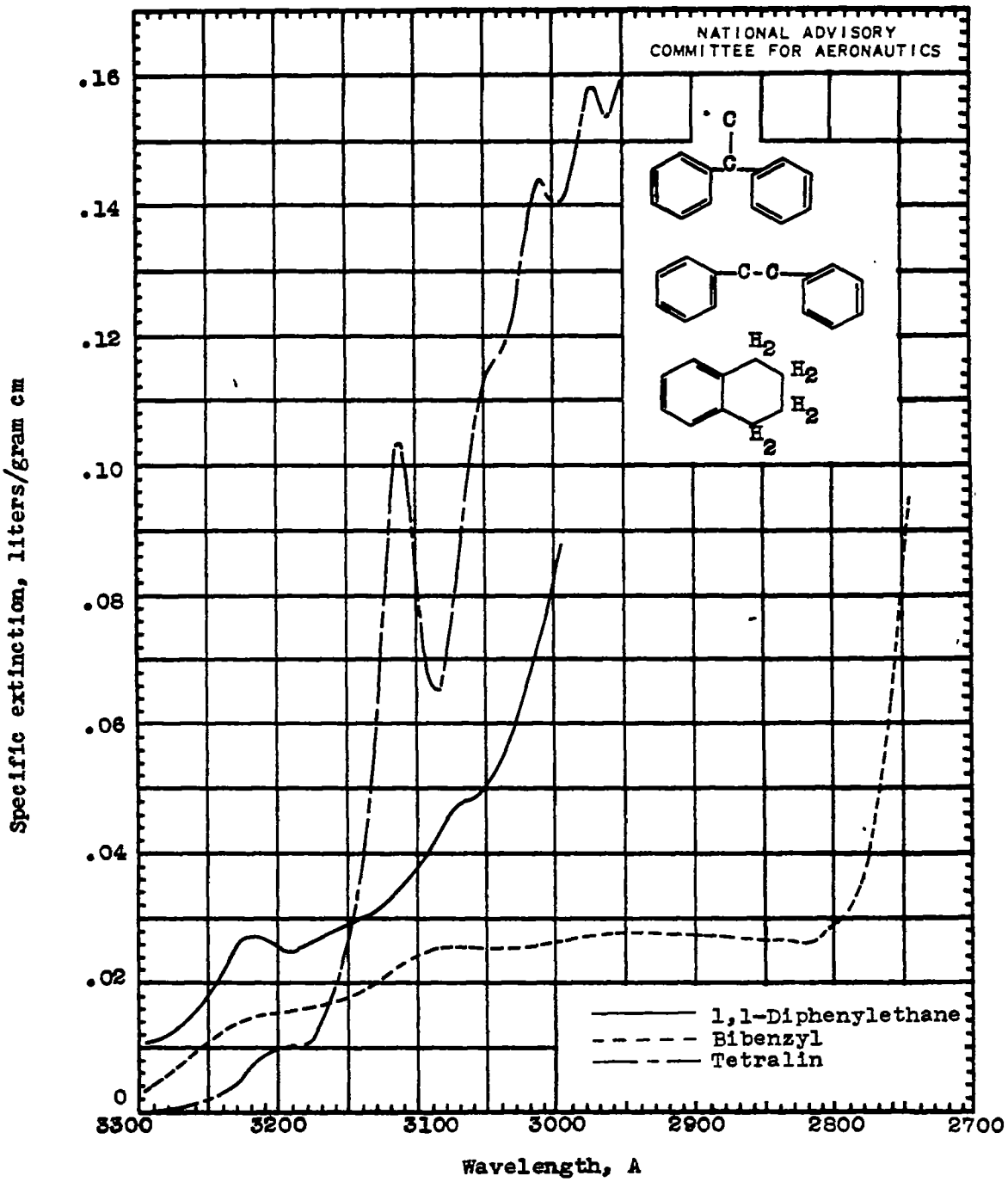

Figure 5. - Ultraviolet absorption spectra of bibenzyl, 1,1-diphenylethane, and tetralin determined by photoelectric spectrophotometer. Solvent, isooctane; slit widths, 0.50 millimeter.

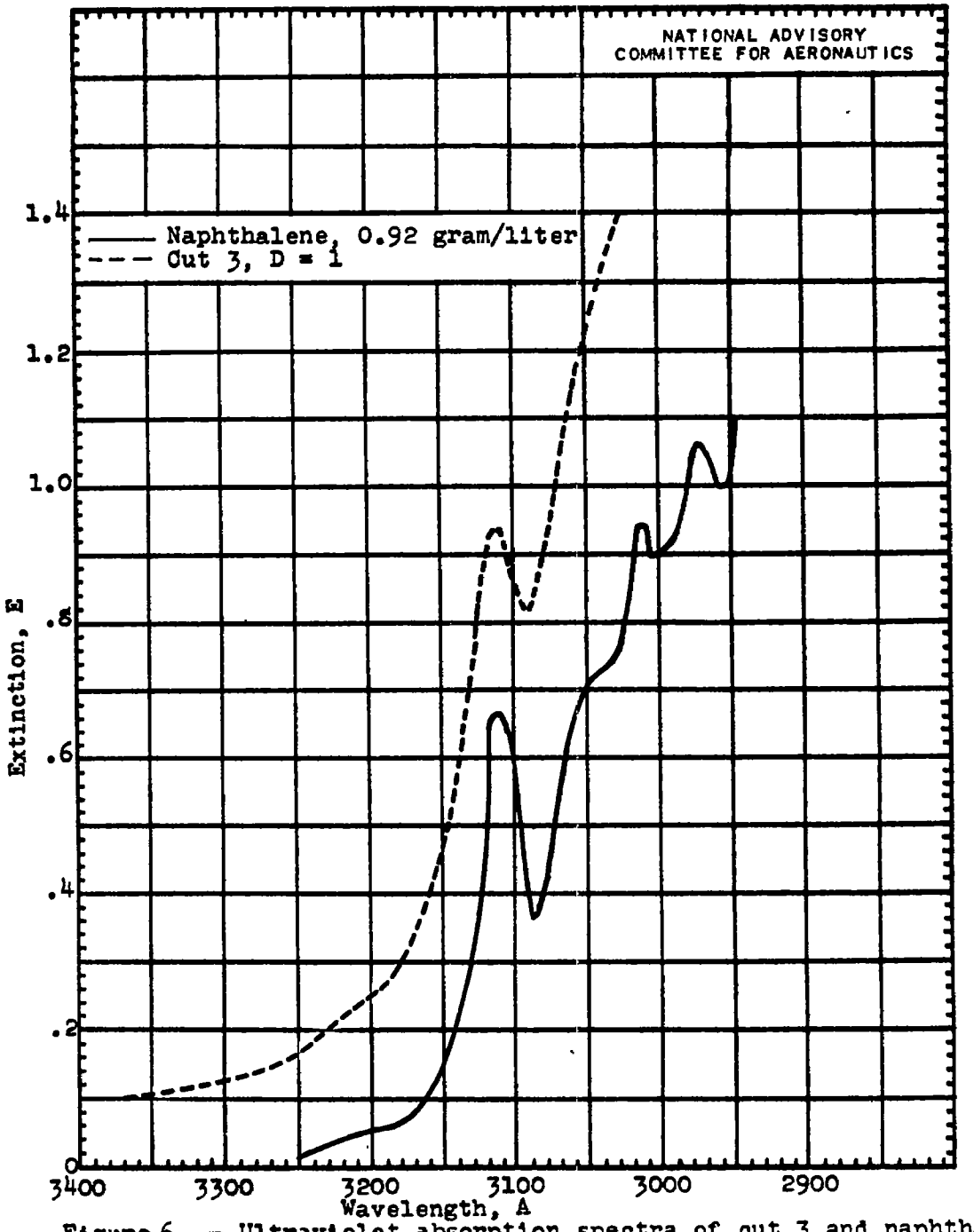

Figure 6. - Ultraviolet absorption spectra of cut 3 and naphthalene determined by photoelectric spectrophotometer. Solvent, isooctane; slit widths, 0.50 millimeter; cell thickness, 0.50 centimeter.

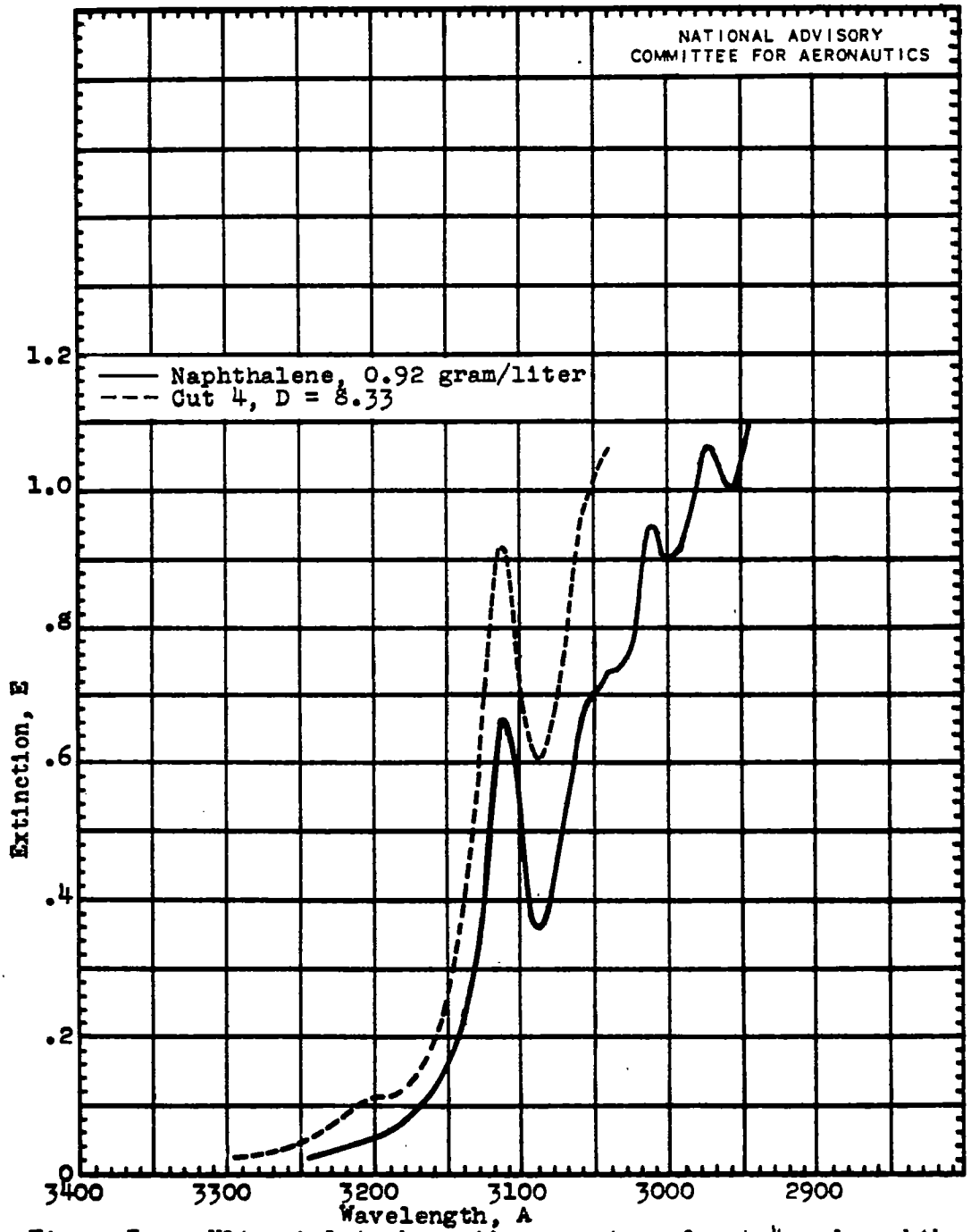

Figure 7. - Ultraviolet absorption spectra of cut 4 and naphthalene determined by photoelectric spectrophotometer. Solvent, isooctane; slit widths, 0.50 millimeter; cell thickness, 0.50 centimeter.

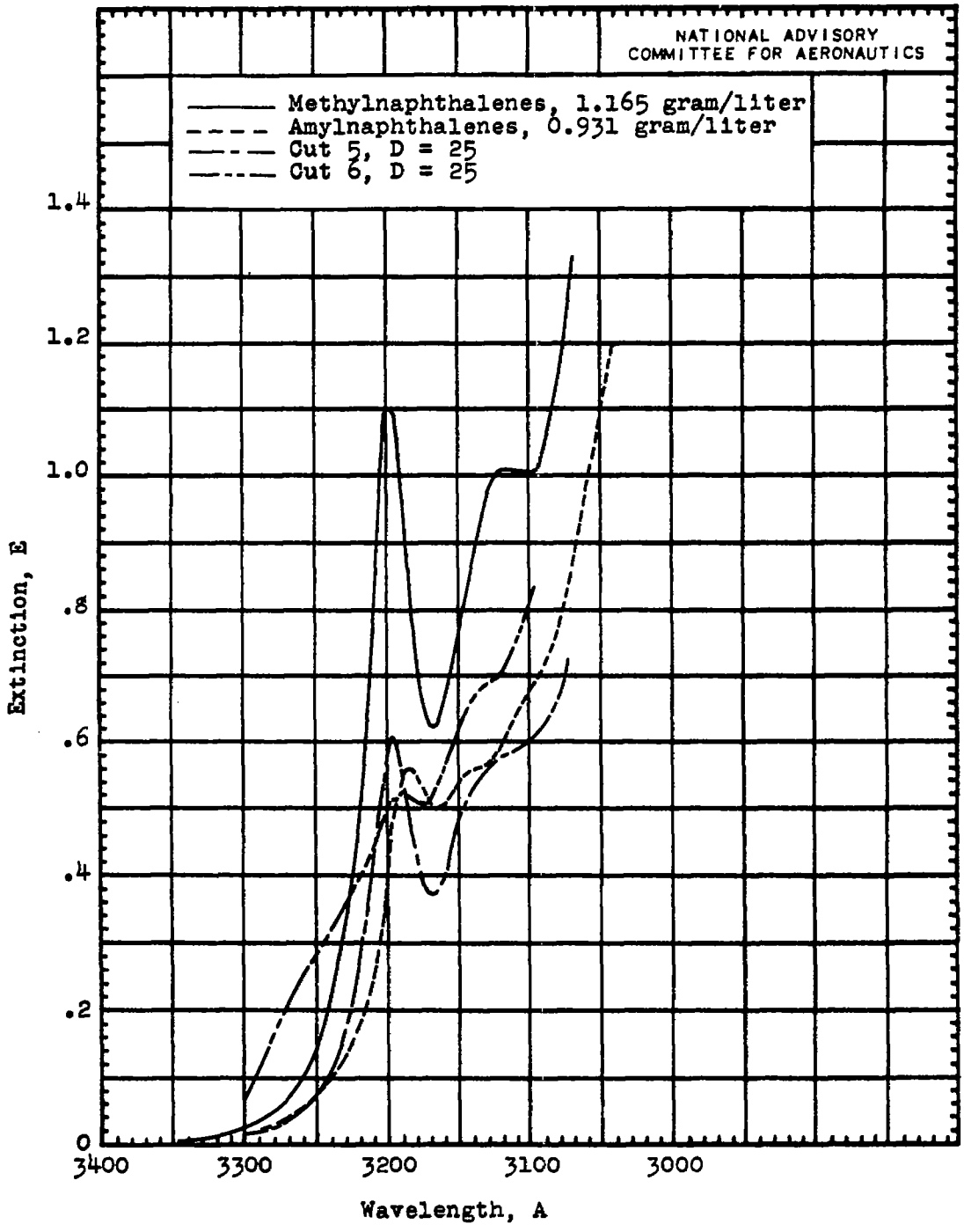

Figure 8. - Ultraviolet absorption spectra of cut 5, cut 6, methylnaphthalenes, and amylnaphthalenes determined by photoelectric spectrophotometer. Solvent, isooctane; slit widths, 0.50 millimeter; cell thickness, 0.50 centimeter.

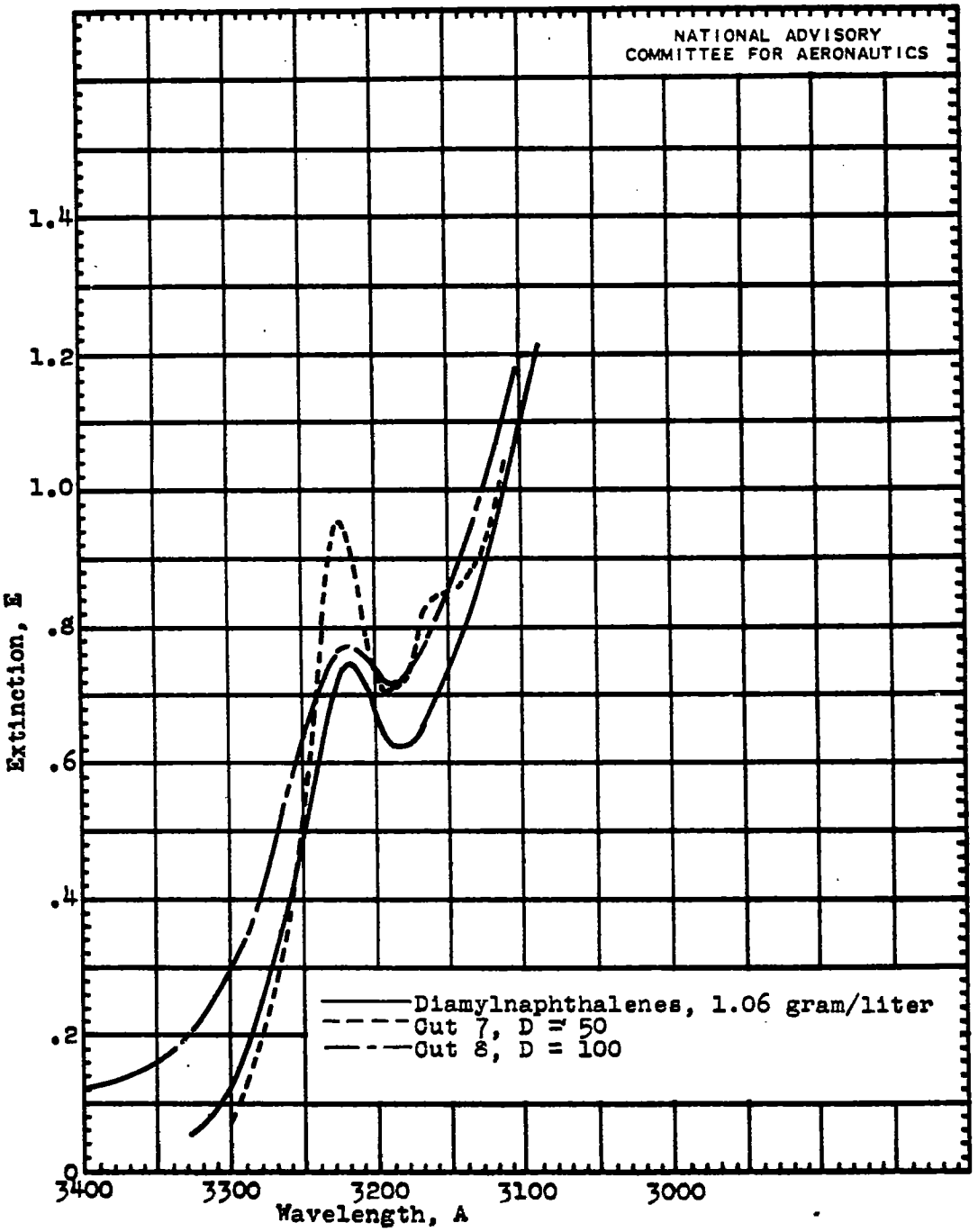

Figure 9. - Ultraviolet absorption spectra of cut 7, cut 8, and diamylnaphthalenes determined by photoelectric spectrophotometer. Solvent, isooctane; slit widths, 0.50 millimeter; cell thickness, 0.50 centimeter.

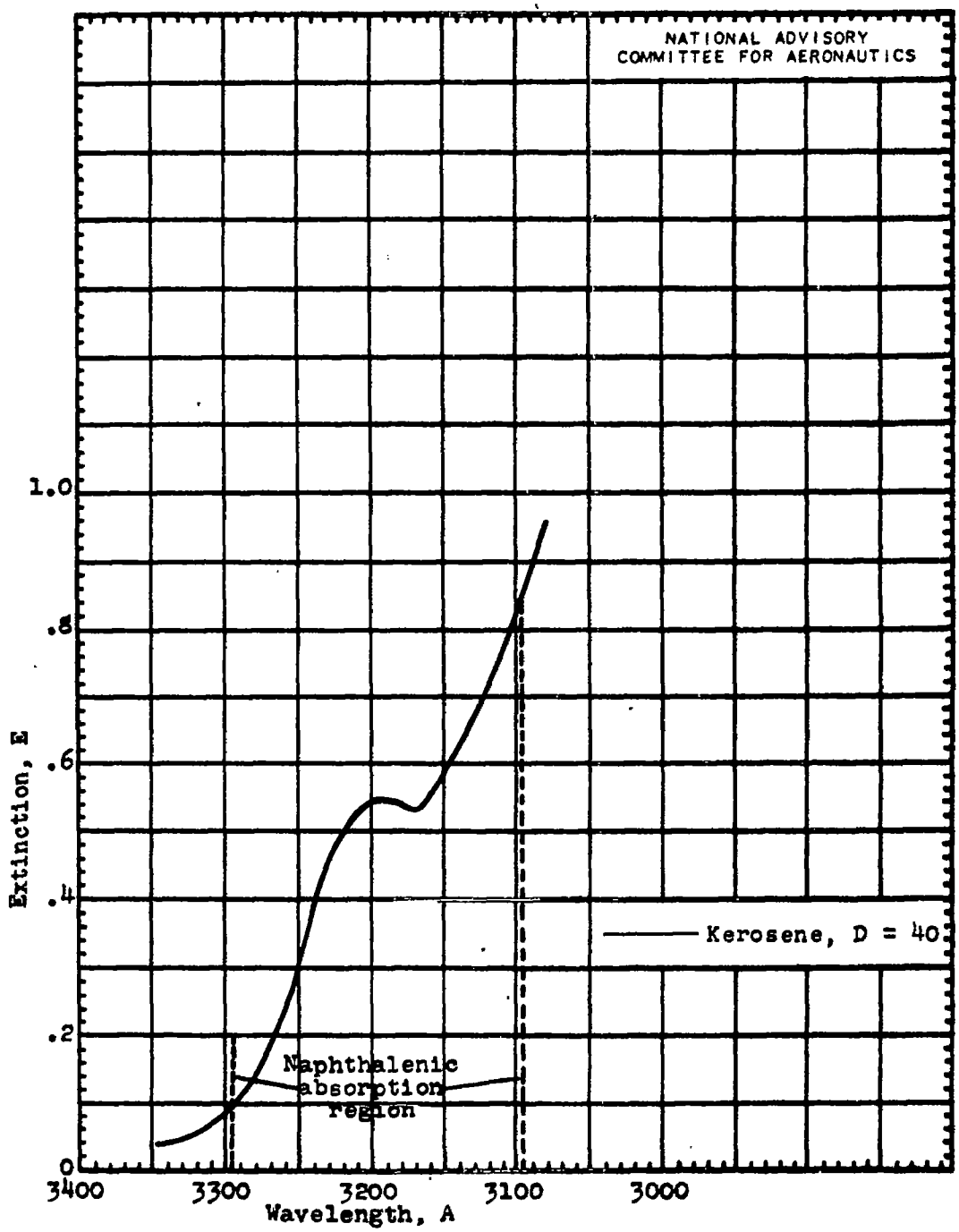

Figure 10. - Ultraviolet absorption spectrum of kerosene determined by photoelectric spectrophotometer. Solvent, isooctane; slit widths, 0.50 millimeter; cell thickness, 0.50 centimeter.