RESTRICTED

ENCLOSURE (B)

ENCLOSURE (B) 1

ON THE SYNTHESIS OF LUBRICATING OILS

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by

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ENCLOSURE (B)1

LIST OF TABLES
~~AND ILLUSTRATIONS~~

ENCLOSURE (B)1

I. INTRODUCTION

Extensive studies have been carried out in regard to the chemical composition of lubri cating oils derived from petroleum oils.[1] The results of these studies show that lubricating oils are, in general composed largely of cylic hydrocarbons expressed as C_nH_{2n-2}, C_nH_{2n-4} etc. The relation between the structure and the viscosity of hydrocarbons has also been studied, but mainly for aliphatic compounds.[2]

Practically nothing is known concerning the relation of ring structure to the viscosity and other properties of cyclic compounds.

Thus, the author intended to conduct a systematic survey of the relationship between the structures and the lubricating properties of cylic compounds in order to synthesize better lubricating oils. Various hydro-aromatic hydrogenated bezene, diphenyl, 1,3 - or 1,4 - diphenyl bezene, naphthalene, anthracene, phenanthrene, acenaphthene and pyrene, by the reduction of corresponding aromatic compounds at high temperatures and pressures in the presence of reduced nickel.

The chemical stability of hydroaromatic compounds was discussed from the point of view of their reduction mechanism. The physical properties such as boiling point, specific gravity, specific and molecular refraction and viscosity of these compounds were determined, and the relation between the molecular volume and visocity, and molecular structure were surveyed.[3]

With these results, a new method for the synthesis of superios lubricants has been proposed.

II. THE CHEMICAL STABILITY OF HYDROAROMATIC COMPOUNDS VIEWED FROM THE STANDPOINT OF REDUCTION MECHANISM

The aromatic hydrocarbons which were uaws in the experiment were benzene, diphenyl, 1,3 - or 1,4 - diphenyl benzene, naphthlene, anthracene, phenanthrene acenaphthene and pyrene, and they were all found to be chemically pure; their physical constants are shown in Table I(B)1. These compounds were completely or partially reduced by hydrogen at high pressure in the presence of reduced nickel, the reaction products being purified by distillation or recrystallization, and identified by elementary and chemical analysis.

The conditions and results of reduction are shown in Table II(B)1. In the case of the reduction of benzene, diphenyl and diphenyl benzene, the reaction took place easily at about 200°C. and completely hydrogenated compounds were formed

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(1) C. Engler, Das Erdol, Bd. I, S. 382-387; C. F. Mabery, J. Amer. Chem. Soc., 30 (1908), 992; J. Ind. Eng. Chem., 5 (1923), 1233; A. E. Dunstan, J. Inst. Petr. Tech., 4 (1918), 191; 7 (1921), 417; Chem. Met. Eng., 28 (1923), 289; M. Bestuschew, Erdol u. Teer, 7 (1931), 159, 191, 205; A Sachv n U. R. Wirabiaz, Erdol u. Teer, 9 (1933), 170, 187, 202, 220; B. J. M ir & C. E. Willingham, J. Ind. Eng. Chem., 28 (1936), 1452.

(2) W. R. Wiggins, J. Inst. Petr. Tech., 22 (1936), 305; E. B. L. Evans J. Inst. Petr. Tech., 241 (1938), 38, 321, 537.

(3) Dr. I. KAGEHIRA, The Report of Imperial Naval Fuel Depot, No. 128, June, 1938.

quantitatively. Hydrogenation of diphenyl at 250°C. and the restriction of the absorption of hydrogen to three mols, however, resulted in the formation of phenylcychohexane, owing, perhaps to the catalytic oxidation of the dicychohexyl formed directly from diphenyl:

$$C_6H_{11} - C_6H_{11} \xrightarrow{\hspace{3cm}} C_6H_5 - C_6H_{11}$$

Analogous phenomena were observed in the case of hydrogenation of diphenylbenzene which was reduced to the hexa-hydro or the dodecahydro compound by restricting the absorption of hydrogen at 140 - 180°C. However, in the reduction of diphenylbenzene, it was observed that the meta isomer was partially reduced easily, while the para isomer was not.

Naphthalene, on reduction at 200°c., yielded tetra-hydro-naphthalene which was converted into a decahydro compound at 160°c. In the reduction of phenanthrene, the tetrahydro compound was formed at 170°c. and was reduced to the octahydro compound at 180°c., which was converted into a perhydro compound at 160°c.

Anthracene, on the other hand, behaved differently from phenanthrene in the reduction. It was reduced to the perhydro compound in one reaction step, while by restricting the absorption of hydrogen, it could be partically reduced.

In the reduction of acenaphthene at 200 c a decahydro compound was formed. The hydrogenation at higher temperatures (270°C), however, produced tetrahydroacenaphthene due to the reverse reaction which occurs in the decahydro compound and which is favoured by high temperature. The hydrogenation of pyrene was the most difficult of these hydrocarbons. A hexahydro compound was first formed at 300°c and the hexahydro compound was reduced to the decahydro compound at 170°c, which was by further catalytic reduction at 240°c. converted into perhydro-pyrene.

As will be seen from the previous observations, aromatic hydrocarbons may be divided into two groups from the point of view of catalytic reduction. Some can be reduced completely by one experimental condition as was noticed in the case of benzene, diphenyl or diphenylbenzene, but in the case of the other group to which naphthalene, phenanthrene, anthracene, acenaphthene and pyrene belong, complete reduction can be achieved only through two or more reaction steps, with changes in the experimental conditions especially in the reaction temperature.

In the case of the reduction of anthracene or acenaphthene, however, the completely reduced compounds were obtained in one step with changes in the experimental condition, but the reduction velocity differed markedly from that of diphenyl. Analogous phenomena were also seen in the comparison of the reduction of benzene to that of linolic acid.(4) Thus, these facts indicate that anthracene or acenaphthene are compounds of a series to which diphenyl does not belong.

reduction of benzene to that of linolic acid.(4) Thus, these facts indicate that anthracene or acenaphthene are compounds of a series to which diphenyl does not belong.

Reaction differences in the reduction of isomers is noteworthy. For example, in the case of diphenyl benzene, it is more difficult to reduce the para

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(4) S. KOMATSU, Bull. Chem. Soc., Japan, 56 (1935).

ENCLOSURE (B)

isomar to the partially hydrogenated compound than the meta isomer. These differences in reaction were also observed in the reduction of anthracene and phenanthrene; in the former, benzene rings are combined in the para position and in the latter in the meta position.

If the partial reduction of the above-mentioned compounds can be attributed to the ununiform distribution of energy in the molecule, it may be considered that the molecule, in which the energy distribution is uniform, will be completely hydrogenated in one easy reaction step.

In view of these considerations, it may be predicted that the hydro-aromatic compounds, obtained by hydrogenation, will behave differently towards oxidation, the inverse reaction of reduction. Thus, a hydro-aromatic compound, derived from an aromatic molecule in which the distribution of energy is ununiform, would sustain easily partial oxidation, while a compound derived from an aromatic molecule in which the distribution of energy is uniform would be difficult to oxide.

The latter compouns, therefore, would be well suited for a lubricating oil. In other words, it may be claimed that a compound which is to be suitable as a lubricating oil consists of such molecules as those in which the distribution of energy is uniform, such as perhydro-diphenyl or diphenylbenzene.

These principles show that some partially hydrogenated compounds would also be useful as lubricating oils, sunce the partially hydrogenated compound may be considered to be in the same energy state as the completely hydrogenated product of diphenyl benzene.

III. MOLECULAR VOLUME OF HYDROAROMATIC COMPOUND

In view of the hydrogenation reaction, hydroaromatic compounds have been classfied into two groups:

A. Hydro compounds of benzene, diphenyl and 1,3 - or 1,4 - diphenyl benzene.

B. Hydro compounds of naphthalene, anthracene, phenanthrene, acenaphthene and pyrene.

Also, differences between para and meta isomers have been observed.

These differences may be considered in light of their molecular volumes. As shown in Table III(B)1, in the case of the first group, the difference of molecular volume between the neighbouring saturated compounds decreases with the increase of molecular weight, while this difference increases in the case of the second group.

The effect on the molecular volume of a benzene ring which is observed by comparing the molecular volumes of saturated compounds with those of partially hydrogenated compounds, is also shown to decrease with an increase in molecular weight in the case of the first group but is nearly constant in the case of the second group, as shown in Table IV(B)1

The effect on the molecular volume of the naphthalene ring is almost constant in every case of the second group. This analogous to the effect of the benzene ring (see TableV(B)1.

As shown in Table VI(B)1 the difference of molecular volume between para and meta isomers could not be practically observed.

ENCLOSURE (B)1

IV. VISCOSITY OF HYDROARMOMATIC HYDROCARBONS

Dunstan and Wilson(5) proposed in viscosity formular for a liquid as follows: log - (1/B) X (M-A) in which . is the viscosity of the liquid, M is the molecular weight, A is a specific constant depending on the particular series to which the liquid belongs, and B is a general constant.

By applying the viscosities of benzene solutions of the hydroaromatic compounds used in this experiment to ISHIKAWA's viscosity formular for binary mixtures,(6)

$$\frac{\frac{k_2a_2}{k_1a_1}}{(1-Z_m) \quad (k_2a_2) \; Z_m \over k_1a_1}$$

in which 1, 2 and are viscosities of benzene, hydroaromario compound and their mixtures respectively, Z_m is the molar fraction of the liquid, k_1 and k_2 are the characteristic "field constants" of benzene and the hydroaromatic compound, and a_1 and a_2 are the degrees of association of benzene and the hydromatic compound, respectively, the author determined the degrees of association and concluded that the viscosity of a liquid depends not only on the molecular weight and molecular association but may also depend on another factor namely on the structure of the molecule.(7)

A. Effect of Ring Form.

Comparing the viscosities of saturated compounds of the two groups classified according to reduction mechanism and change of molecular volume, the effect of ring form on viscosity is considered, the viscosity being compared with the ratio of the viscosity difference to the molecular weight difference.

The difference of viscosity ratio between cyclohexane and dicyclohexyl is 0.03, and between dicyclohexyl and perhydro-1,3-diphenyl benzene is 0.83. In the case of the second group, the difference between cyclohexane and decahydronaphthalene is 0.04, between decahydronaphthalene and perhydro-anthracene 0.11, between decahydronaphthanlene and decahydroacenaphthene0.13 and between decahydroacenaphthene and perhydro-pyrene 0.32. The compounds of the first group show a much greater increase of viscosity with increase of molecular weight than do these or the second group. The results are shown in Table VII(B)1

Analogous results were obtained in comparing the viscosity of 0.1M benzene solutions of these compounds in the same manner, as shown in Table VIII(B)1.

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(5) A. E. Dunstan & R. W. Wilson, J. Chem. Soc., 91 (1907) 90.

(6) T. ISHIKAWA, Bull. Chem. Soc., Japan, 4 (1929), 288.

(7) I. KAGEHIRA, the Report of Imperial Naval Fuel Depot, No. 97, August, 1935.

ENCLOSURE (B)1

In view of these results, from the standpoint of viscosity, it may be concluded that compounds of the homologous series to which perhydro-diphenyl or diphenylbenzene belong, are the most suitable and that such a compound as perhydro-pyrene will be also useful as lubricating oils.

B. Effect of Benzene Ring

In the first group, to which hydro-diphenyl or -diphenylbenzene belongs, the viscosities of the saturated compounds are greater than the unsaturated in which the molecules have a benzene ring, while in the second group, with one exception, the unsaturated compound is more viscous than the corresponding saturated compound (see Table IX(B)1) However, in benzene solutions, the unsaturated compounds are more viscous than the saturated compounds in every case (See Table X).

C. Effect of Naphthalene Ring

The compounds which have naphthalene ring are crystalline at ordinary temperatures, so their viscosities in benzene solution were compared.

As may be seen in Table XI, the ratio of the viscosity of an unsaturated compound in which the molecule has a naphthalene ring to that of the corresponding saturated compound is almost the same in each case.

The difference between the effect on viscosity of the naphthalene ring and the benzene ring may be determined from the results shown in Tables X(B)1 and XI(B)1; the naphthelene ring increases the viscosity more than the benzene ring.

This fact suggests that compounds in which the molecule has a naphthalene ring, such as hexahydro-pyrene, will be useful as lubricating oils.

D. Effect of Isomerization

The effect on viscosity of isomerization may be observed by comparing hydro-1,4 - to the corresponding hydro -1,3- diphenylbenzene or hydro-anthracene to the corresponding hydrophenanthrene (See Table XII(B)1. The para compound is more viscous than the meta compound. Therefore, the compounds in which the cyclohexane rings combine in the para position, whould be more useful as lubricating oils.

V. SYNTHESIS OF LUBRICATING OILS

A systematic investigation of the relation of molecular structure to the chemical stability and the viscosity of hydroaromatic compounds has suggested that saturated compounds in which the molecules consist of cyclohexane rings combined by single bonds in the para position, such as perhydro-1,4 -diphenylbenzene, will have the best characteristics for use in the synthesis of lubricating oils.

If the relation between the viscosities of cyclohexane, dicyclohexyl and perhydro-1,3-diphenylbenzene is extended to higher compounds of the same series, the viscosity of dicyclohexyl-dicyclohexyl (C_6H_{11}-C_6H_{10}-C_6H_{10}-C_6H_{11}) would be in the order of 20-30 poise at 25°C. (See table VII(B)1, which is of the proper range for aero lubricating oils.

It is generally recognized that the change of viscosity with temperature of paraffine hydrocarbons is the least of all types of hydrocarbons. Hence, a cyclic compound which has a long paraffinic chain might be expected to be

ENCLOSURE (B)1

of the proper viscosity and be less susceptible to change in viscosity with changing temperature.

The author's surveys, therefore, suggest a new method of synthesizing lubricating oils to be used for automobiles or aero-engines, where constancy of viscosity with varying temperatures and high oxidation stability are required.

TABLE I(B)1
AROMATIC HIDROCARBON

Aromatic Hydrocarbon	Structural formula	Emprical formula	Appearance	Boil Pt. (°C)	Melt. Pt. (°C)	Picrate Appearance	Picrate Melt. Pt. (°C)
Benzene		C_6H_6	Colorless liquid	80- 80.5			
Diphenyl		$C_{12}H_{10}$	White Thin Plates	248- 249	68.5-69.5		
1,3,-diphenyl benzene		$C_{18}H_{14}$	White needles		85.5-86.5		
1,4-diphenyl benzene		$C_{18}H_{14}$	White thin plates		211.5- 212		
Naphthalene		$C_{10}H_8$	White granular	212.5-213.5	80 - 81	Pale Yellow needles	150-150.5
Anthracene		$C_{14}H_{10}$	White thin plates		212.5-213.5	Red needles	139-140
Phenanthrene		$C_{14}H_{10}$	White thin Plates		97-98	Orange yellow thin plates	141-142
Acenaphthene		$C_{12}H_{10}$	White needles	266.5-267.5	93-94	Orange red	160.8-161.8
Pyrene		$C_{16}H_{10}$	Yellow tetrahedral crystals		148-149	Red needles	222-223

RESTRICTED

TABLE II(B)1

THE CONDITIONS AND RESULTS OF HYDROGENATION OF AROMATIC AND PARTIALLY HYDR

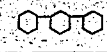
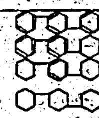
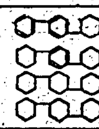
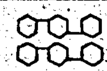
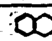
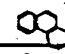
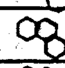
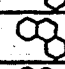
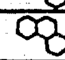
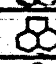
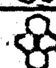
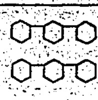
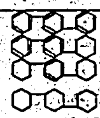
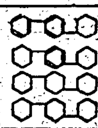
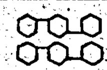
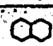
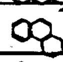
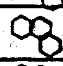
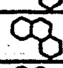
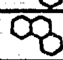
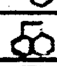
Aromatic compound	Amount used in experiment (gr.)	Reaction temperature (°C)	Initial pressure of hydrogen at 0°C (atm.)	Hydrogen absorbed		Reaction time (hr-min.)	Hydroaromatic compound	Structural formula	Yield (wt.%)
				Obs.	Calc.				
Benzene	100	200	76	182	168	5-15	Cyclohexane		96
Diphenyl	40	250	75	91	92	11-0	Phenylcyclohexane		93
Diphenyl	65	200	95	115	98	3-45	Dicyclohexyl		94
1,3-diphenylbenzene	62	140	113	36	34	1-0	Hexahydro-1,3-diphenyl-benzene		95
1,3-diphenylbenzene	75	150	119	85	83	1-45	Dodecahydro-1,3 diphenyl-		100
Dodecahydro- 1,3-diphenylbenzene	36	150	102	18	18	2-30	Perhydro-1,3-diphenyl-benzene Perhydro-1,3-diphenyl-benzene	 	46 52
1,4-diphenylbenzene	100	180	103	76	61	7-0	1,4-diphenylbenzene Hexahydro-1,4-diphenyl-benzene Dodecahydro-1,4-diphenyl-benzene Perhydro-1,4-diphenyl-benzene		25 49 18 small quantity
1,4-diphenylbenzene	50	170	108	53	53	2-0	Hexahydro-1,4-diphenyl-benzene Dodecahydro-1,4-diphenylbenzene Perhydro-1,4-diphenyl-benzene Perhydro-1,4-diphenyl-benzene		small quantity 87 3 3
1,4-diphenylbenzene	50	220	108	85	80	6-30	Perhydro-1,4-diphenyl-benzene Perhydro-1,4-diphenyl-benzene		36 46
Naphthalene	100	200	91	71	67	13-0	Tetrahydro-naphthalene		91
Tetrahydro-naphthalene	100	160	91	119	67	7-0	Dodecahydro-naphthalene		97
Anthracene	50	200	100	32	21	3-15	Tetrahydro-anthracene		
Anthracene	50	200	99	48	48	2-15	Octahydro-anthracene		
Anthracene	100	270	98	198	147	19-15	Perhydro-anthracene Perhydro-anthracene		84 14
Phenanthrene	50	170	95	26	25	7-0	Tetrahydro-phenanthrene		
Tetrahydro-phenanthrene	72	180	90	40	36	2-15	Octahydro-phenanthrene		
Tetrahydro-phenanthrene	65	220	102	82	82	8-0	Perhydro-phenanthrene		
Octahydro-phenanthrene	15	160	77	3	9	16-30	Perhydro-phenanthrene		
Acenaphthene	100	270	102	[illegible]	[illegible]	3-[illegible]	Tetrahydro-acenaphthene		[illegible]
Acenaphthene	100	200	[illegible]	[illegible]	112	9-0	Dodecahydro-acenaphthene		100
Pyrene	[illegible]	[illegible]	[illegible]	29	29	3-30	Hexahydro-pyrene		100
Hexahydro-pyrene	30	170	[illegible]	62	62	11-15	Dodecahydro-pyrene		100
Hexahydro-pyrene	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Perhydro-pyrene		[illegible]
							Perhydro-pyrene		[illegible]

TABLE II(B)1

D RESULTS OF HYDROGENATION OF AROMATIC AND PARTIALLY HYDROGENATED COMPOUNDS

Reaction time (hr-min.)	Reaction Products: Hydroaromatic compound	Structural formula	Yield (wt.%)	Boil. pt. (°C)	Melt. pt. (°C)	Density (25/4)	Refractive index (25 D)	Molecular refraction Obs.	Molecular refraction Calc.
5-15	Cyclohexane		96	80-80.5		0.7741	1.4235	26.67	27.70
11-0	Phenylcyclohexane		93	234-236		0.943	1.5313	52.56	51.82
3-45	Dicyclohexyl		94	231-233		0.8836	1.4777	53.20	53.22
1-0	Hexahydro-1,3-diphenylbenzene		95	176-178/2.6mm		1.0102	1.5798	77.78	75.82
1-45	Dodecahydro-1,3 diphenyl-		100	176-178/2mm		0.9742	1.5425	78.31	77.32
2-30	Perhydro-1,3-diphenylbenzene Perhydro-1,3-diphenylbenzene		46 52	182-184/5mm 182-184/5mm	625-630	0.9443	1.5176	79.61	78.72
7-0	1,4-diphenylbenzene Hexahydro-1,4-diphenylbenzene Dodecahydro-1,4-diphenylbenzene Perhydro-1,4-diphenylbenzene		25 49 18 small quantity	178-180/1.5mm	74.5-75.5 96-97				
2-0	Hexahydro-1,4-diphenylbenzene Dodecahydro-1,4-diphenylbenzene Perhydro-1,4-diphenylbenzene Perhydro-1,4-diphenylbenzene		small quantity 87 3 3	178-180/1.8mm	96-97 48-49 162-163				
6-30	Perhydro-1,4-diphenylbenzene Perhydro-1,4-diphenylbenzene		36 46	130-134/2.5mm	48.5-49.5 162-163				
13-0	Tetrahydro-naphthalene		92	201.5-203.5		0.9683	1.5392	42.79	42.58
7-0	Dodecahydro-naphthalene		97	189-191		0.8906	1.4784	43.82	43.87
3-15	Tetrahydro-anthracene				101.5-102.5				
2-15	Octahydro-anthracene				72-73				
19-15	Perhydro-anthracene Perhydro-anthracene		84 14	139-141/11mm	89-90	0.9380	1.4990	60.34	60.25
7-0	Tetrahydro-phenanthrene			140-142/10.9mm		1.0706	1.6260	60.[illegible]	57.92
2-15	Octahydro-phenanthrene			159-160/12mm		1.0247	1.5630	57.38	58.05
8-0	Perhydro-phenanthrene			132-134/10.7mm		0.9708	1.5080	59.69	60.25
16-30	Perhydro-phenanthrene								
3-40	Tetrahydro-acenaphthene		96	245-247		1.0046	1.5550	50.42	49.42
9-0	Dodecahydro-acenaphthene		100	235-237		0.9442	1.5000	51.30	51.46
3-30	Hexahydro-pyrene		100		131-132				
11-15	Dodecahydro-pyrene		100	138-140/2mm		1.0477	1.5742	64.71	63.[illegible]
40-45	Perhydro-pyrene		80	144-146/4mm		0.9835	1.5030	67.43	67.77
[illegible]	Perhydro-pyrene		18		85.8-87.2				

ENCLOSURE (B)1

TABLE III(B)1
EFFECT OF RING FORM ON MOLECULAR VOLUME

	Cyclohexane	Dicyclohexyl	Perhydro-1,3-diphenyl benzene	
Empirical formula	C_6H_{12}	$C_{12}H_{22}$	$C_{18}H_{32}$	
Diff.		C_6H_{10}	C_6H_{10}	
Mol. Wt.	84	166	248	
Spec. grav (25/4)	0.7741	0.8836	0.9443	
Mol. vol (at 25°C)	109	188	263	
Diff.		79	75	
	Cyclohexane	Decahydro-naphthalene	Perhydro-anthracene	
Empirical formula	C_6H_{12}	$C_{10}H_{18}$	$C_{14}H_{24}$	
Diff.		C_4H_6	C_4H_6	
Mol. Wt.	84	138	192	
Spec. grav. (25/4)	0.7741	0.8906	0.9383	
Mol. vol. (25°C)	109	155	205	
Diff.		46	50	
		Decahydro-naphthalene	Decahydro-acenaphthene	Perhydro-pyrene
Empirical formula		$C_{10}H_{18}$	$C_{12}H_{20}$	$C_{16}H_{26}$
Diff.			C_2H_2	C_4H_6
Mol. Wt.		138	164	218
Spec. grav (25/4)		0.8906	0.9462	0.9835
Mol. vol. (25°C)		155	174	222
Diff.			19	48

ENCLOSURE (B)1

TABLE IV(B)1
EFFECT OF BENZENE RING ON MOLECULAR VOLUME

	Cyclohexane	Benzene	Dicylohexyl	Phenylcyclo-hexane	Perhydro-1,3-diphenyl-benzene	Decahydro-1,3-diphenyl-benzene		
Empirical formula	$C_6\ H_{12}$	$C_6\ H_6$	$C_{12}\ H_{22}$	$C_{12}\ C_{16}$	$C_{18}\ H_{16}$	$C_{18}\ H_{26}$		
Diff	H_6		H_6		H_6			
Mol. Wt.	84	78	166	160	248	242		
Spec. Grav ($^{25}/_4$)	0.7741	0.8740	0.8836	0.9431	0.9443	0.9741		
Mol. Vol. (25°C)	109	89	188	170	263	249		
Diff.	20		18		14			
			Debahydro-naphthalene	Tetrahydro-naphthalene	Perhydro-phenanthrene	Octahyaro-phenanthrene		
Empirical formula			$C_{10}\ C_{18}$	$C_{10}\ C_{12}$	$C_{14}\ H_{24}$	$C_{14}\ H_{18}$		
Diff.			H_6		H_6			
Mol. Wt.			138	132	192	186		
Spec. Grav ($^{25}/_4$)			0.8906	0.9683	0.9502	1.0167		
Mol Vol (25°C)			155	136	202	183		
Diff.			21		19			
					Perhydro-acenaphthene	Tetrahydro-acenaphthene	Perhydro-pyrene	Decahydro-pyrene
Empirical formula					$C_{12}\ H_{20}$	$C_{12}\ H_{14}$	$C_{16}\ H_{26}$	$C_{16}\ H_{20}$
Diff.					H_6		H_6	
Mol. Wt.					164	158	218	212
Spec. Grav. ($^{25}/_4$)					0.9462	1.0065	0.9835	1.0497
Mol. Vol. (25°C)					174	157	222	202
Diff.					17		20	

ENCLOSURE (B)1

TABLE V(B)1
EFFECT OF NAPHTHALENE RING ON MOLECULAR VOLUME

		Decahydro-naphthalene	Naphthalene	Perhydro-anthracene	Tetrahydro-anthracene	Perhydro Phenanthrene	Tetrahydro-phenanthrene
Benzene solution of 0.1 molar fraction	Mol wt.	84	83	90	89	90	89
	Spec. Grav.(25/4)	0.8744	0.8975	0.8856	0.9041	0.8888	0.9031
	Mol Vol.(25°C)	96	92	101	98	101	98
	Diff.	4		3		3	

		Decahydro-acenaphthene	Acenaphthene	Perhydro-pyrene	Hexahydro-pyren
Benzene solution of 0.1 molar fraction	Mo. Wt.	87	86	92	insoluble
	Spec. Grav.(25/4)	0.8850	0.9129	0.8932	
	Mol. Vol.(25°C)	98	94	103	
	Diff.	4			

ENCLOSURE (B)1

TABLE VI(B)1
EFFECT OF ISOMERISATION ON MOLECULAR VOLUME

		Hexahydro- 1,3-diphenyl-benzene	Hexahydro- 1,4-diphenyl benzene	Dodecahydro- 1,3-diphenyl-benzene	Dodecahydro- 1,4-diphenyl-benzene	Perhydro 1,3-diphenyl-benzene (liquid)	Perhydro 1,4-diphenyl benzene (M.P.485-495°C)
	Mol. Wt.	236	236				
	Spec. Grav(25/4)	0.9849	0.9846				
	Mol. Vol.(80°C)	240	240				
Benzene solution of 0.1 molar fraction	Mol. Wt.	94	94	95	95	95	95
	Spec. Grav.(25/4)	0.9083	0.9088	0.8992	0.8959	0.8926	0.8865
	Mol. Vol.(25°C)	103	103	105	106	107	107
		Tetrahydro- phenanthrene	**Tetrahydro- anthracene**	**Octahydro- phenanthrene**	**Octahydro- anthracene**	**Perhydro- Phenanthrene**	**Perhydro- anthracene**
	Mol. Wt.					192	192
	Spec. Grav (25/4)					0.9502	0.9388
	Mol. Vol.(25°C)					202	205
Benzene solution of 0.1 molar fraction	Mol. Wt.	89	89	90	90	90	90
	Spec. Grav (25/4)	0.9031	0.9041	0.9053	0.9050	0.8888	0.8856
	Mol. Vol.(25°C)	98	98	98	98	101	101

ENCLOSURE (B)1

TABLE VII(B)1
EFFECT OF RING FORM ON VISCOSITY

	Cyclohexane	Dicyclohexy	Perhydro-1,3-diphenyl benzene		
Empirical formula	C_6H_{12}	$C_{12}H_{22}$	$C_{18}H_{22}$		
Mol. Wt.	84	166	248		
Diff.		82	82		
Viscosity in poise at 25°C	0.008991	0.031467	0.614263		
Vis. ratio	1	3.5	68.3		
Vis. diff.		2.5	64.8		
Vis. ratio diff/M.W.diff.		0.03	0.83		
	Cyclohexane	Decahydro-naphthalene	Perhydro-anthracene		
Empirical formula	C_6H_{12}	$C_{10}H_{18}$	$C_{14}H_{24}$		
Mol. Wt.	84	138	192		
Diff.		54	54		
Viscosity in poise at 25°C	0.008991	0.026526	0.080397		
Vis. ratio	1	2.9	8.9		
Vis. ratio diff.		1.9	6.0		
Vis. ratio diff/M.W-diff.		0.04	0.11		
			Decahydro-naphthalene	Decahydro-acenaphthene	Perhydro-pyrene
Empirical formula			$C_{10}H_{18}$	$C_{12}H_{20}$	$C_{16}H_{26}$
Mol. Wt.			138	164	218
Diff.				26	54
Viscosity in poise at 25°C			0.026526	0.058821	0.21215
Vis. ratio			2.9	6.2	23.6
Vis. ratio diff				3.3	17.4
Vis. ratio diff/M.W.diff.				0.13	0.32

TABLE VIII(B)1
EFFECT OF RING FORM ON VISCOSITY

		Cyclohexane	Dicyclohexy	Perhydro-1,3-diphenyl benzene	
Benzene solution o.1 molar	Mol. Wt.	79	87	95	
	Diff.		8	8	
	Viscosity in poise at 25°C	0.005909	0.007085	0.009388	
	Vis. ratio	1	1.2	1.59	
	Diff.		0.2	0.39	
	Vis. ratio diff/M.W.diff.		0.025	0.049	
		Cyclohexane	Decahydro-naphthalene	Perhydro-anthracene	
Benzene solution o.1 molar	Mol. Wt.	7.9	84	90	
	Diff.		5	6	
	Viscosity in poise at 25°C	0.005909	0.006738	0.07722	
	Vis. ratio	1	1.14	1.32	
	Diff.		0.14	0.18	
	Vis. ratio diff./M.W.diff.		0.032	0.03	
			Decahydro-naphthalene	Decahydro-acenaphthene	Perhydro-pyrene
Benzene solution o.1 molar	Mol. Wt.		84	87	92
	Diff.			3	5
	Viscosity in poise at 25°C		0.006738	0.007268	0.008073
	Vis. ratio		1.14	1.23	1.37
	Diff.			0.09	0.14
	Vis. ratio diff./M.W.diff			0.03	0.028

ENCLOSURE (B)1

TABLE IX(B)1
EFFECT OF BENZENE RING ON VISCOSITY

	Cyclohexane	Benzene	Dicyclohexyl	Phenyl-cyclohexane	Perhydro-1,3-diphenyl benzene	Dodecahydro-1,3-diphenyl benzene		
Empirical formula	C_6H_{12}	C_6H_6	$O_{12}H_{22}$	$O_{12}H_{16}$	$C_{18}H_{32}$	$C_{18}H_{26}$		
Mol. Wt.	84	78	166	160	248	242		
Diff.	6		6		6			
Viscosity in poise at 25°C	0.008971	0.006096	0.031167	0.025713	0.614263	0.319378		
Vis. ratio	1	0.7	1	0.8	1	0.5		
Diff.	-0.3		-0.2		-0.5			
			Decahydro-naphthalene	Tetrahydro-naphthalene	Perhydro-phenanthrene	Octahydro-phenanthrene		
Empirical formula			$C_{10}H_{18}$	$C_{10}O_{12}$	$C_{14}H_{24}$	$C_{14}H_{18}$		
Mol. Wt.			138	132	192	186		
Diff.			6		6			
Viscosity in poise at 25°C			0.026526	0.020215	0.076323	0.12511		
Vis. ratio			1	0.8	1	1.6		
Diff.			-2		+0.6			
					Decahydro-acenaphthene	Tetrahydro-acenaphthene	Perhydro pyrene	Decahydro-pyrene
Empirical formula					$C_{12}H_{20}$	$C_{12}H_{14}$	$C_{16}H_{26}$	$C_{16}H_{20}$
Mol. Wt.					162	158	218	212
Diff.					6		6	
Viscosity in poise					0.058821	0.059731	0.21215	0.54961
Vis ratio					1	1.0	1	2.6
Diff.					+0.0		+1.6	

ENCLOSURE (B)1

TABLE X(B)1
EFFECT OF BENZENE RING ON VISCOSITY

	Cyclohexane	Benzene	Dicyclohexyl	Phenyl-cyclohexane	Perhydro-1,3-diphenyl-benzene	Dodecahydro-1,3-diphenyl-benzene	Perhydro-1,4-diphenyl-benzene	Dodecahydro-1,4-diphenyl-benzene
Viscosity of 0.1 mol. benzene solution in poise at 25°C	0.009909	0.006096	0.007085	0.007204	0.009388	0.009414	0.009485	0.009656
Vis. ratio	1	1.03	1	1.02	1	1.00	1	1.02
			Dodecahydro-naphthalene	Tetrahydro-naphthalene	Perhydro-phenanthrene	Octahydro-phenanthrene	Perhydro-anthracene	Octahydro-anthracene
Viscosity of 0.1 mol. benzene solution in poise at 25°C			0.006738	0.006894	0.007665	0.008047	0.007792	0.008070
Vis. ratio			1	1.02	1	1.05	1	1.05
					Decahydro-acenaphthene	Tetrahydro-acenaphthene	Perhydro pyrene	Decahydro-pyrene
Viscosity of 0.1 mol. benzene solution in poise at 25°C					0.007268	0.007517	0.008073	0.008696
Vis. ratio					1	1.03	1	1.08

ENCLOSURE (B)1

TABLE XI(B)1
EFFECT OF NAPHTHALENE RING ON VISCOSITY

	Decahydro-naphthalene	Naphthalene	Perhydro-anthracene	Tetrahydro-anthracene	Perhydro-phenanthrene	Tetrahydro-phenanthrene		
Viscosity of 0.1 mol. benzene solution in poise at 25 C	0.006738	0.007105	0.007722	0.008191	0.007665	0.008159		
Vis. ratio	1	1.05	1	1.06	1	1.06		
					Decahydro acenaphthene	Acenaphthene	Perhydro-pyrene	Hexahydro-pyrene
Viscosity of 0.1 mol. benzene solution in poise at 25 C					0.007268	0.007756	0.008073	insoluble
Vis. ratio						1.07		

ENCLOSURE (B)1

TABLE XII(B)1
EFFECT ON ISOMERISATION ON VISCOSITY

	Hexahydro-		Dodecahydro-		Perhydro-	
	1,3-diphenyl benzene	1,4-diphenyl benzene	1,3-diphenyl benzene	1,4-diphenyl benzene	1,3-diphenyl benzene (liquid)	1,4-diphenyl benzene (M.P.485-49.5°C)
Viscosity in poise at 82°C	0,043384	0,048997			0,057706	0,067687
Vis. ratio	1	1.13			1	1.17
Viscosity of 0.1 mol-benzene solution in poise at 25°C	0,009603	0,009975	0,009414	0,009656	0,009388	0,009485
Vis. ratio	1	1.04	1	1.03	1	1.01
	Tetrahydro-		Octahydro-		Perhydro-	
	phenanthrene	anthracene	phenanthrene	anthracene	phenanthrene	anthracene
Viscosity in poise at 25°C					0.076323	0.086397
Vis. ratio					1	1.05
Viscosity of 0.1 mol-benzene solution in poise at 25°C	0,008159	0,008192	0.008047	0,008070	0,007665	0,007722
Vis. ratio	1	1,00	1	1,01	1	1.01