$\log i/(i_d - i)$ affords a convenient and reliable means of determining the *n*-values of reversible electrode reactions, other methods are generally used when dealing with irreversible reactions. The Ilkovic equation can be used to calculate the *n*-values of irreversible as well as reversible electrode reactions, but the paucity of diffusion coefficient data severely limits the usefulness of this procedure. Coulometric measurements afford the most reliable means of determining *n*- values in irreversible reactions.[12] Such measurements for the aliphatic polyene aldehydes will be reported in a later paper.

Acknowledgment.—We wish to express our appreciation to Mr. Marshall Kane, who assisted in the preparation and measurement of many of these compounds.

Summary

The polarographic behavior of aliphatic polyene aldehydes has been examined in buffered 50% dioxane solution over the *p*H range 1 to 11. The variations in half-wave potentials and the $i_d/Cm^{2/3}t^{1/6}$ ratios have been examined as functions of *p*H and the number of double bonds in the molecule.

CAMBRIDGE 39, MASSACHUSETTS

RECEIVED APRIL 26, 1947

---

[12] Lingane, THIS JOURNAL, **67**, 1916 (1945).

[CONTRIBUTION FROM THE ATLANTIC REFINING CO.]

The Isolation and Physical Properties of the Diisopropylbenzenes

BY F. W. MELPOLDER, J. E. WOODBRIDGE AND C. E. HEADINGTON

Introduction

The physical properties of the isomeric diisopropylbenzenes reported in the literature are fragmentary and the wide variations in these values indicate that only incomplete separations of the isomers have previously been accomplished.[1–7] Newton,[8] however, isolated meta and para diisopropylbenzene by distillation from a propylated benzene which apparently contained none of the ortho isomer. The physical properties reported by him for the two isomers are in substantial agreement with those found by the authors in the work to be described (Table I).

TABLE I

PHYSICAL PROPERTIES OF THE ISOMERIC DIISOPROPYLBENZENES

Property		Found by this study Ortho	Meta	Para	Found by Newton[8] Meta	Para
Purity, mole %		99.6	99.6	99.8		
Melting point, °C.		−56.68	−63.13	−17.07		
Cryoscopic constant, mole frac./°C.		0.0221	0.0285	0.0292		
Boiling point, °C.	760 mm.	203.75	203.18	210.37	203.0	210.3
	300 mm.	168.33	167.83	174.4	168.9[b]	174.4[b]
	100 mm.	133.9	133.4	139.3		
	50 mm.	115.4	114.9	120 2		
Antoine constants[a]	A	6.9800	6.9805	7.0667	7.1710[b]	7.0726[b]
	B	1619.5	1616.6	1711.9	1766.4[b]	1709.2[b]
	C	191.33	191.15	198.59	207.40[b]	197.51[b]
Refractive index	20°	1.49603	1.48883	1.48983	1.4884	1.4895
	25°	1.49373	1.48748	1.48758		
Specific dispersion 25°		157	155	157		
Density, g./ml. 20°		0.87007	0.85593	0.85676	0.8566	0.8571
Molecular weight		161.93	161.38	162.67		
Carbon–hydrogen ratio		7.96	7.92	7.91		

[a] Antoine equation, $\log_{10} P = A - B/(C + t)$, P = pressure, mm. t = boiling point, °C. [b] Calculated from data of Newton.

In this work the isolation of substantially pure ortho, meta, and para diisopropylbenzenes from benzene–propylene alkylate was accomplished by a combination of distillation, fractional crystallization, adsorption, sulfonation, and hydrolysis. Precise physical properties as well as ultraviolet, infrared and mass spectra are reported on each of the isomers.

Initial Separation.—The source of these compounds was a high boiling by-product fraction, b. p. 200–215°, produced by a commercial process for making cumene wherein benzene is alkylated with propylene over U. O. P. phosphoric acid catalyst. To roughly determine the distribution of the isomeric diisopropylbenzenes in the mixture a 700-cc. volume was fractionally distilled through a 100-plate Heligrid column into 5% cuts. Although the distillation curve (Fig. 1) exhibits only two boiling point flats, the refractive index curve indicates that at least two distinct compounds are present in fraction I, b. p. 203–204°, and one in fraction II, b. p. 210–211°. Inspection of the refractive indices and ultraviolet spectra indicated that the material present in fraction I contained a major amount of meta diisopropylbenzene and a minor concentration of the ortho isomer, while fraction II, comprising nearly half of the crude mixture, was largely para isomer. The next step was therefore to distil 15 liters of the charge stock into two fractions, one boiling at 203–204° and the other at 210–211°.

Separation of *o*- from *m*-Diisopropylbenzene.—It was found that repeated high efficiency distillations of the 203–204°, material resulted in only a partial separation of ortho and meta isomers. The best distillate fraction of ortho isomer froze to a viscous partially crystalline mass at −80° whereas the meta isomer fraction crystallized with some difficulty at −72°.

Since *m*-xylene was successfully purified by Mair, Termini, Willingham and Rossini[9] by the selective sul-

---

(1) V. N. Ipatieff, B. B. Corson and H. Pines, THIS JOURNAL, **58**, 919 (1936).

(2) V. N. Ipatieff and H. Pines, *ibid.*, **59**, 56 (1937).

(3) T. U. Ju, C. E. Wood and F. H. Gorner, *J. Inst. Petr.*, **28**, 159 (1942).

(4) J. F. McKenna and F. J. Sowa, THIS JOURNAL, **59**, 470 (1937).

(5) S. J. Slanina, F. J. Sowa and J. A. Nieuwland, *ibid.*, **57**, 1547 (1935).

(6) D. R. Stull, *Ind. Eng. Chem.*, **39**, 517 (1947).

(7) Uhlhorn, *Ber.*, **23**, 3142 (1890).

(8) A. Newton, THIS JOURNAL, **65**, 320 (1943).

(9) B. J. Mair, D. J. Termini, C. B. Willingham and F. D. Rossini, *J. Res. Nat. Bur. Stds.*, **37**, 229 (1946).

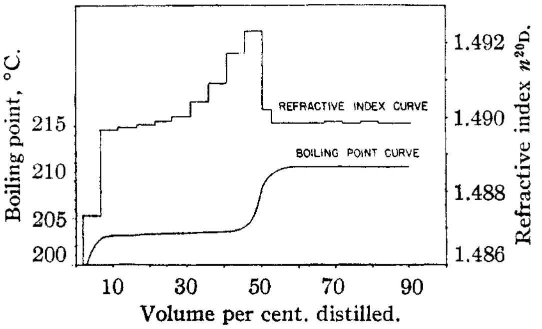

Fig. 1.—Distillation of the crude diisopropylbenzene mixture.

fonation and hydrolysis of a meta and para xylene mixture, the same technique was applied to this separation. A small quantity of ortho-meta-diisopropylbenzene mixture was sulfonated at room temperature with 105% H_2SO_4, the reaction reaching completion in about half an hour. The mixture was diluted with ice and then steam distilled at elevated temperatures. A small amount of unreacted hydrocarbon distilled over at 120°, but no appreciable hydrolysis occurred until a temperature of 135° was reached. At this point there was collected a large fraction of nearly pure meta as evidenced by the low refractive index, n^{20}D 1.4890, and high freezing point, −64°. As the temperature of the hydrolysis was raised the concentration of ortho in the distillate gradually increased to a maximum at 160°. A graph showing the progress of the hydrolysis (Fig. 2) is indicative of the sharpness of the separation of the ortho and meta isomers. In view of the separation obtained, 4 liters of 203–204° material were similarly treated. To further purify the meta isomer, the fraction which hydrolyzed at 135° was resulfonated and hydrolyzed. Similar treatment of the fractions which hydrolyzed at 160°, however, failed to enrich the ortho isomer.

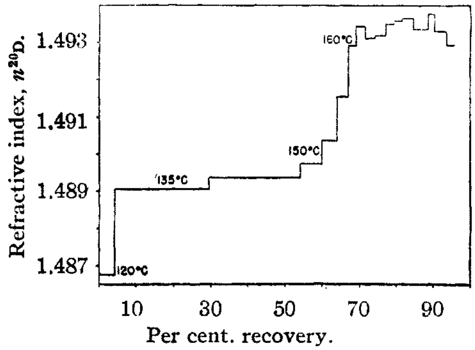

Fig. 2.—Hydrolysis of *o*–*m*-diisopropylbenzene sulfonic acids.

Isolation of *o*-Diisopropylbenzene.—The hydrolyzed ortho isomer fraction was washed with caustic solution and water and then distilled in a 100-plate column. A 150 cc. middle fraction, n^{20}D 1.4955, f. p. −60°, was collected. A time–temperature melting test[10] showed this fraction to be only about 90% pure.

A new technique for purification of compounds by silica gel adsorption was recently reported by Hirschler and Amon[11] wherein it is possible to adsorb preferentially small concentrations of impurities having adsorbabilities similar to that of the major component at higher concentrations. In accordance with this the 150-cc. distillate fraction was percolated several times through an 11-mm. i. d. column packed with fine silica gel as recommended by Mair.[12] The total length of column utilized was equivalent to about 30 feet. The first 17 cc. of percolate, n^{20}D 1.4960, f. p. −57°, was found to be 99.6% pure by the time–temperature melting test.

Isolation of *m*-Diisopropylbenzene.—After washing and drying, the meta isomer fraction was distilled in a 100-plate column at high reflux ratio. About 500 cc. of distillate was collected, n^{20}D 1.4888, f. p. −63°. A time–temperature melting test indicated that this material was also 99.6% pure.

Isolation of *p*-Diisopropylbenzene.—The fraction boiling at 210–211° was subjected to an 80-plate distillation. A volume of 3 liters of para isomer concentrate was collected which was estimated from a freezing test to be about 90% pure. A second distillation failed to increase the purity of this material. It formed large crystals from a non-viscous solution at approximately −20°, the symmetry of the para molecule accounting for the high freezing point.

Three liters of para isomer concentrate were therefore fractionally crystallized in four stages. Batches up to 500 cc. each were slowly crystallized with constant stirring in a partially evacuated Dewar type vessel immersed in a Dry Ice-bath. The slush was then transferred to a precooled basket centrifuge inside a large Dewar and the contents spun until the crystals were dry. By properly blending the crystalline and mother liquor fractions from the various stages more than half of the para isomer fraction was isolated as best crystals, f. p. −17°. The purity of the final product was found to be 99.8% by the melting point test.

Physical Properties.—Precise physical properties (Table I) were determined for each isomer by the following methods:

1. Purities were determined by the time–temperature freezing and melting point procedure described by Glasgow, Streiff and Rossini.[10] Since time–temperature freezing tests were found to be unsuitable due to the existence of non-equilibrium conditions between solid and liquid phases, purities were calculated from time–temperature melting curves.

A special melting point apparatus was constructed to accommodate the small quantity of pure ortho isomer fraction. A glass liner was placed in the conventional apparatus in order to reduce the required sample volume to 5 cc. A stirrer was then constructed from piano wire in spiral form, slightly larger in diameter than the platinum resistance thermometer. The accuracy of this apparatus was checked by comparing the melting point of a 50-cc. sample of meta isomer measured in the larger apparatus and a 5-cc. sample of the same material in the modified tube. The difference in melting point was 0.02° and no significant change was noted in the shape of the time–temperature curves.

2. Cryoscopic constants were determined by adding a known quantity of impurity to each pure isomer and measuring the corresponding melting point depression. *m*-Diisopropylbenzene was added to the ortho isomer, *m*-methylethylbenzene to the meta isomer, and *p*-methylethylbenzene to the para isomer.

3. To check the relative concentrations of the isomers in the original starting mixture the cryoscopic method of Streiff and Rossini[13] was employed. This was done by adding a measured amount of the crude diisopropylbenzene mixture to each isomer and finding the resultant melting point depression. These tests revealed that the 200 to 215° alkylate fraction contained 6% ortho, 36% meta and 42% para diisopropylbenzene.

4. Boiling points were determined in a Cottrell type ebulliometer and temperatures were measured to 0.002° with the same platinum resistance thermometer used in

---

(10) A. R. Glasgow, A. J. Streiff and F. D. Rossini, *J. Research Nat. B. Stds.*, **35**, 355 (1945).

(11) A. E. Hirschler and S. Amon, *Ind. Eng. Chem.*, **39**, 1585 (1947).

(12) B. J. Mair, *J. Res. Nat. Bur. Stds.*, **34**, 435 (1945).

(13) A. J. Streiff and F. D. Rossini, *J. Research Nat. Bur. Stds.*, **39**, 303 (1947).

TABLE II

WAVE LENGTHS, FREQUENCIES AND INTENSITIES OF INFRARED ABSORPTION MAXIMA OF THE DIISOPROPYLBENZENES

λ(μ)	ν(cm.⁻¹)	Intensities	λ(μ)	ν(cm.⁻¹)	Intensities
		o-Diisopropylbenzene			
3.38	2959	10	8.58	1166	3
3.66	2732	2s	8.77	1140	2
5.18	1931	1s	9.04	1106	6
5.24	1908	1	9.32	1073	9
5.33	1876	0s	9.55	1047	5
5.47	1828	1	9.70	1031	9
5.56	1799	1	10.04	996	0
5.77	1733	0s	10.25	976	1
5.91	1692	1	10.39	962	1s
6.27	1595	3	10.61	943	4
6.72	1488	10	10.83	923	2
6.84	1462	10	11.17	895	3
7.23	1383	8	11.33	883	1s
7.32	1366	8	11.54	867	1
7.66	1305	3	12.38	808	0s
7.81	1280	4	13.23	756	10s
7.90	1266	5	13.26	754	10
8.17	1224	4	13.29	752	10s
8.44	1185	4	14.26	701	3
		m-Diisopropylbenzene			
3.40	2941	10	8.42	1188	6
3.65	2740	2s	8.54	1171	3
3.86	2591	1	8.73	1145	1
5.20	1923	1	9.06	1104	5
5.39	1855	1	9.23	1083	6
5.63	1776	2	9.52	1050	8
5.93	1686	2	10.04	996	1
6.26	1597	9	10.35	966	1
6.53	1531	1	10.48	954	1
6.73	1486	10	10.82	924	7
6.88	1453	10	11.23	890	8
6.93	1443	10s	12.34	810	4s
7.25	1379	8	12.61	793	10
7.34	1362	8	14.23	703	10
7.61	1314	7	14.82	675	1s
7.88	1269	4	15.02	666	1
		p-Diisopropylbenzene			
3.40	2941	10	8.11	1233	1s
5.28	1894	2	8.25	1212	2
5.62	1779	1	8.41	1189	1
5.74	1742	0s	8.72	1147	5
6.04	1656	3	9.08	1101	6
6.11	1637	0s	9.35	1070	8
6.42	1558	1s	9.52	1050	8
6.62	1511	9	9.84	1016	7
6.85	1460	10	10.41	961	2
7.05	1418	9	10.64	940	1
7.12	1404	8	10.84	923	3
7.25	1379	8	11.22	891	3
7.35	1361	8	11.50	870	1s
7.52	1330	6	12.05	830	10
7.70	1299	6	12.50	800	1s
7.83	1277	5	12.86	778	1
			13.11	763	1s

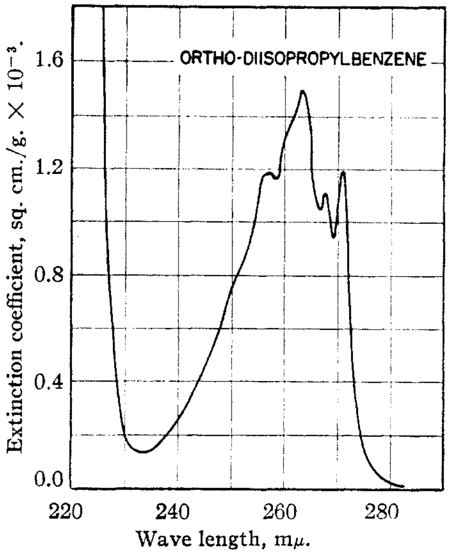

Fig. 3.—Ultraviolet spectrum of *o*-diisopropylbenzene.

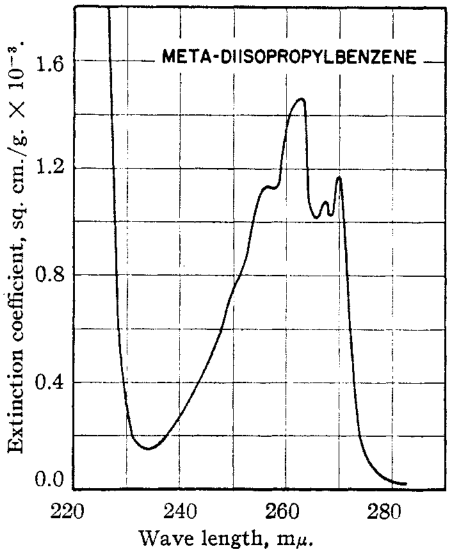

Fig. 4.—Ultraviolet spectrum of *m*-diisopropylbenzene.

the melting point tests. The pressure was regulated by a manostat system to ± 0.5 mm. Pressures were read on an open arm mercury manometer and corrected for barometric fluctuations. Boiling point measurements were made at the pressures 760, 300, 100 and 50 mm. and the data were fitted to the Antoine equation to permit calculation of boiling points at intermediate pressures.

5. Refractive indices were measured with a Bausch and Lomb precision refractometer at 20 and 25 ± 0.05°. A sodium lamp and filter provided the source of 5890 A. light. The accuracy of the refractive index values is believed to be ±0.0001.

6. Specific dispersions were determined with the Bausch and Lomb refractometer at 25° using the hydrogen 4860 and 6570 Å. lines.

7. Densities were measured at 20° in a 10-cc. pycnometer described by Lipkin, Davison, Harvey and Kurtz.[14] The temperature of the thermostat was automatically controlled by an electronic regulator at 20.00 ± 0.01°.

---

[14] M. R. Lipkin, J. A. Davison, W. T. Harvey and S. S. Kurtz, *Ind. Eng. Chem., Anal. Ed.*, **16**, 55 (1944).

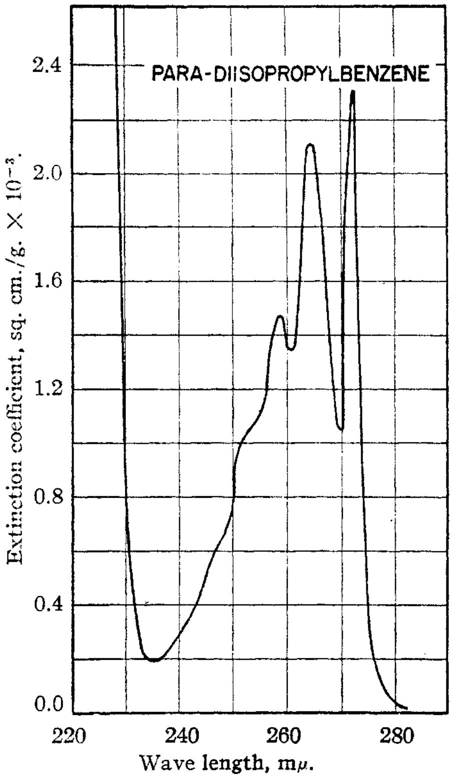

Fig. 5.—Ultraviolet spectrum of *p*-diisopropylbenzene.

The accuracy of these measurements by comparison with other pure compounds was better than ±0.0001 g./ml.

8. Molecular weights were determined for each isomer by observing the freezing point depression in benzene at several concentrations. Good agreement was found between the calculated molecular weights at different concentrations, indicating that the ideal solution laws apply.

9. Carbon-hydrogen ratios were found by the usual combustion method. Based on results of other known samples the accuracy is within ±0.5%.

10. A structure analysis of each isomer was made by oxidation of the side chains to the corresponding phthalic acids, and preparation of derivatives. Of particular interest was the resistance of the ortho isomer to oxidation. Both chromic acid and permanganate solution at 100° gave little conversion, but vapor phase oxidation over vanadium oxide catalyst at 350° gave a good yield of orthophthalic acid. The meta and para isomers were readily oxidized with chromic acid at 100°. The following derivatives were prepared; phthalanil from orthophthalic acid, dimethyl isophthalate from isophthalic acid, and dimethyl terephthalate from terephthalic acid. Melting points of these derivatives checked those appearing in the literature thereby verifying the structure of the isomers.

Absorption and Mass Spectra.—Ultraviolet absorption spectra of the isomers were obtained with a Beckman spectrophotometer. The curves showing the extinction coefficients, sq. cm./g., at various wave lengths are shown in Figs. 3, 4 and 5. The extinction coefficient k is defined as $k = E/cd$ where E = optical density, c = concentration g./cc. and d = cell length. It will be observed that distinctive and characteristic peaks appear at 264 and 272 mμ for the para isomer, but that the ortho and meta spectra are not readily distinguishable.

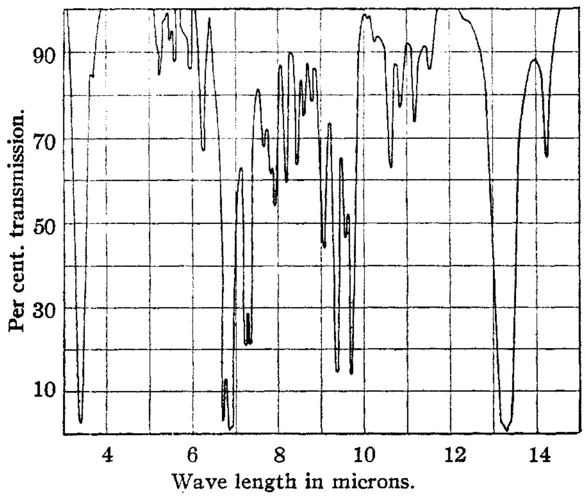

Fig. 6.—Infrared spectrum of *o*-diisopropylbenzene measured at 25°, 0.051 mm. cell length.

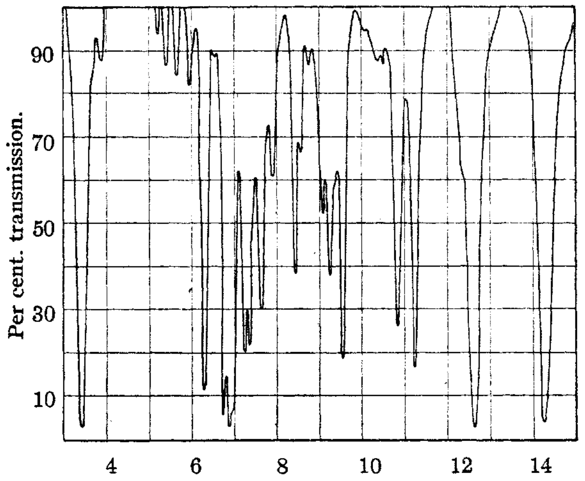

Fig. 7.—Infrared spectrum of *m*-diisopropylbenzene measured at 25°, 0.051 mm. cell length.

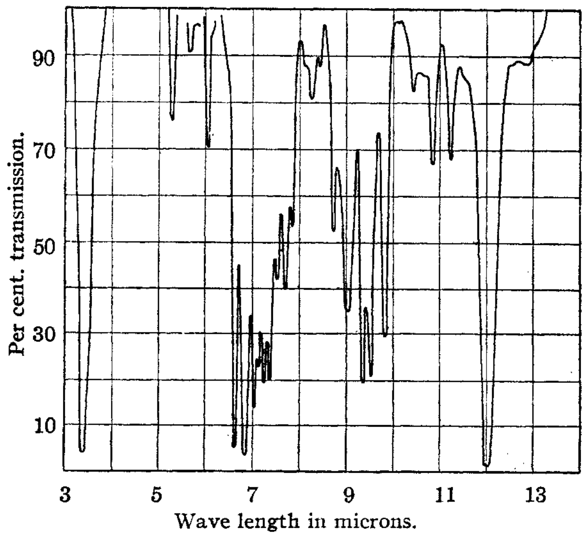

Fig. 8.—Infrared spectrum of *p*-diisopropylbenzene measured at 25°, 0.051 mm. cell length.

Infrared spectrograms of the isomers were determined on a Perkin-Elmer Infrared Spectrometer, Model 12A. These spectra (Figs. 6, 7, 8, and Table II) are seen to confirm the proof of structure by chemical means, the strong absorption bands characteristic of ortho occurring at 13.3 microns, of meta at 12.6 and 14.2 microns, and para at 12.0 microns. The isopropyl group is evident from the doublet in the region of 7.3 microns.

The mass spectra of the isomers, obtained on a Consolidated Engineering instrument, are shown in Table III. As would be expected no significant differences are seen in the mass spectra of the individual isomers.

TABLE III

MASS SPECTRA OF THE ISOMERIC DIISOPROPYLBENZENES

Mass	*o*-Diisopropylbenzene	*m*-Diisopropylbenzene	*p*-Diisopropyl benzene	*n*-Butane
27	31.4	44.9	38.0	
28	5.34	3.29	5.57	275
29	14.5	9.15	7.60	346
39	23.5	22.3	21.5	124
40	2.48	3.81	2.32	
41	51.8	48.8	41.8	239
42	2.82	2.45	2.58	102
43	23.1	85.6	59.5	826
44	0.80	3.01	1.97	
51	13.7	12.8	12.2	
52	3.88	3.79	3.49	
53	8.25	7.48	7.58	
58	4.08	0.75	1.61	100.0
63	7.03	7.36	6.01	
64	7.67	5.65	5.12	
65	15.3	12.3	10.9	
66	6.87	11.3	5.87	
77	23.0	24.3	22.7	
78	8.13	8.92	8.32	
79	20.2	15.1	13.0	
91	82.1	64.6	59.7	
92	6.67	5.34	4.92	
95–98[a]	4.75	0.64	0.56	
103	10.8	13.8	12.8	
104	4.48	5.79	6.06	
105	32.2	64.7	51.0	
106	2.72	5.01	4.18	
115	25.1	14.9	14.8	
116	11.1	7.79	9.03	
117	18.4	8.85	25.6	
118	4.28	3.72	5.31	
119	115	111	96.6	
120	8.96	10.4	8.20	
131	14.6	10.4	18.3	
132	2.1	2.4	13.5	
147	281	283	342	
162	100.0	100.0	100.0	
Sensitivity	23.0	22.0	23.3	4.73

[a] Metastable peak.

Acknowledgment.—Acknowledgment is hereby made to Barton Zieber for the infrared spectra and to C. W. Warfield for much of the laboratory manipulation.

Summary

The isolation of the three isomeric diisopropylbenzenes from a high boiling propylene-benzene alkylate is described. The most important physical properties and the relative concentrations of the isomers in the alkylate are listed. Infrared, ultraviolet, and mass spectra also are given, the former confirming the chemical evidence of the structure of the compounds isolated.

PHILADELPHIA, PA. RECEIVED JUNE 7, 1947

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF NORTHWESTERN UNIVERSITY]

The Thermodynamics of Metallo-protein Combinations. Copper with Bovine Serum Albumin

BY IRVING M. KLOTZ AND HENRY G. CURME

The importance of metal ion–protein complexes in biological systems has long been recognized, and numerous studies have been made of the extent of combination of such cations with proteins.[1,2,3] Unfortunately most of these investigations have utilized protein preparations of questionable homogeneity and have correlated their quantitative data in terms of equations which are essentially empirical in nature. With the recent availability of crystallized plasma proteins[4] it has seemed opportune to make a careful quantitative study of metal complexes with pure proteins and to treat the data obtained in terms of relations similar to those used in describing the multiple equilibria between proteins and organic anions.[5]

Experimental

Apparatus.—The extent of binding of cupric ions by bovine serum albumin was measured by the equilibrium dialysis technique described previously.[5] However, the apparatus was modified slightly so that a bead could be suspended by a glass thread within the bag containing the protein solution. With the bead to facilitate stirring within the bag and with a mechanical shaker to agitate the outside solution, the time for the attainment of equilibrium was reduced materially.

Time Required to Attain Equilibrium.—With the modified apparatus the dialysis tubes reached equilibrium in

---

[1] J. H. Northrup and M. Kunitz, *J. Gen. Physiol.*, **7**, 25 (1924); **9**, 351 (1925); **11**, 481 (1928).

[2] D. M. Greenberg, in M. L. Anson and J. T. Edsall, "Advances in Protein Chemistry," Volume I, Academic Press, New York, N. Y., 1944, pp. 121–151.

[3] C. L. A. Schmidt, "The Chemistry of the Amino Acids and Proteins," Charles C. Thomas, Springfield, Ill., 1945, pp. 293–296, 746–762, 1091–1092, 1213–1214.

[4] E. J. Cohn, J. L. Oncley, L. E. Strong, W. L. Hughes, Jr., and S. H. Armstrong, Jr., *J. Clin. Invest.*, **23**, 417 (1944).

[5] I. M. Klotz, F. M. Walker and R. B. Pivan, THIS JOURNAL, **68**, 1486 (1946); **69**, 1609 (1947).