butyrolactone[18] and γ,γ-dimethyl-γ-butyrolactone[19] were prepared by published methods. The lactones were all freshly distilled at reduced pressure immediately before use, and their physical constants were in excellent agreement with published values. Their infrared spectra were determined in carbon tetrachloride solution using a Baird-Atomic double beam instrument.

Kinetics. Preliminary experiments showed that the saponification of γ-butyrolactone in 80% ethanol was too rapid (0.16 mole^{-1} sec.$^{-1}$) to be conveniently followed by titration and to be rather too slow (0.0087 mole^{-1} sec.$^{-1}$) in absolute ethanol. The measurements were accordingly carried out in 92.3% ethanol (d_{25}^{25} 0.8096), which had been purified by treatment with zinc dust and sodium hydroxide.

The lactone (0.2–0.3 g.) was dissolved in purified 92% ethanol (100-x ml.), allowed to equilibrate in a constant temperature bath at 25.08 ± 0.02° or in an ice water bath at 0.00 ± 0.02° and 0.04*M* sodium hydroxide (x ml.) in the same solvent and at the same temperature added. Aliquots (10 ml.) were withdrawn at intervals, added to excess 0.06*N* hydrochloric acid (5 ml.) and ice-cold distilled water (20 ml.) and the excess acid immediately titrated with standard 0.045*N* sodium hydroxide solution, using phenolphthalein as indicator. The purity of the lactone was determined by dissolving samples (0.04–0.06 g.) in 0.045*N* aqueous sodium hydroxide (15 ml.) and titrating the excess base with standard acid after 2–3 days. The purity was always at least 95% and was taken into account in calculating the kinetics. The rate constants were determined from the slope of the second order rate plots in the usual manner. Each run was carried out at least three times and the means and their mean errors are given in Table I. The E act and log PZ values are probably accurate to ± 0.2 units.

Acknowledgment. This work was supported in part by a grant from the National Research Council of Canada.

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(18) B. E. Hudson, Jr., and C. R. Hauser, *J. Am. Chem. Soc.*, **63**, 3156 (1941).

(19) R. T. Arnold, J. S. Buckley, Jr., and J. Richter, *J. Am. Chem. Soc.*, **69**, 2322 (1947); J. Cason, P. B. Brewer, and E. L. Pippen, *J. Org. Chem.*, **13**, 239 (1948); R. L. Frank, R. Armstrong, J. Kiviatek, and H. A. Price, *J. Am. Chem. Soc.*, **70**, 1379 (1948).

[CONTRIBUTION FROM THE STERLING CHEMISTRY LABORATORY, YALE UNIVERSITY]

Electron Exchange Polymers. XV. NMR Spectra of Some Methylated Hydroquinones and Their Derivatives[1]

KENNETH A. KUN[2] AND HAROLD G. CASSIDY

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NMR spectra are reported on the *tau* scale for 1,4-dimethoxybenzene; 2-methyl-, 2,5-dimethyl-, 2,3,5-trimethyl-, and 2,3,5,6-tetramethyl-1,4-dimethoxybenzenes; 2-vinyl-3,6-dimethyl- and 2-vinyl-3,5,6-trimethyl-1,4-dimethoxybenzenes; 2-(2-hydroxyethyl)-, 2-(2-hydroxyethyl)-3,6-dimethyl-, 2-(2-hydroxyethyl)-3,5-6-trimethyl-, and 2-(1-hydroxyethyl)-3,5,6-trimethyl-1,4-dimethoxybenzene; and α,α'-bis(2,5-dimethoxy-3,4,6-trimethylphenyl)diethyl ether. The chemical shifts of the aromatic, methoxyl, and methyl protons are interpreted.

The use of NMR spectra has increased rapidly since the initial work of Purcell and co-workers,[3] and its application to structural organic chemistry by Gutowsky and co-workers.[4] Detailed discussions of theory and applications may be found in the works of Pople and co-authors,[5] Roberts,[6] Conroy,[7] and Jackman.[8] With this rapidly increasing use of NMR it seemed of interest to report the chemical shifts of the aromatic methoxyl and methyl protons of several methylated hydroquinones and their derivatives.

Measurements described in this paper were made with a 60 mc./sec. Varian NMR spectrometer using analytical grade carbon tetrachloride as the solvent. All chemical shifts were measured with reference to an internal standard, tetramethylsilane, and are given on the "tau" (τ) scale as described by Tiers.[9] The numbers of parentheses indicate relative intensities. Concentrations of 40% by volume were used. As a result, no bulk-susceptibility corrections are required, but some dilution effects characteristic of aromatic compounds are no doubt present.[5]

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(1) (a) Taken from the Dissertation submitted by Kenneth A. Kun to the Graduate School of Yale University in partial fulfillment of the requirements for the Ph.D. degree. (b) For other papers in this series see K. A. Kun and H. G. Cassidy, *J. Polymer Sci.*, **44**, 383 (1960).

(2) Present address: Rohm and Haas Company, Research Laboratories, Bristol, Pa.

(3) E. M. Purcell, H. C. Torrey, and R. V. Pound, *Phys. Rev.*, **73**, 679 (1948).

(4) L. H. Meyer, A. Saika, and H. S. Gutowsky, *J. Am. Chem. Soc.*, **75**, 4567 (1953).

(5) J. A. Pople, W. G. Schneider, and H. J. Bernstein, *High-resolution Nuclear Magnetic Resonance*, McGraw-Hill, New York (1959).

(6) J. D. Roberts, *Nuclear Magnetic Resonance*, McGraw-Hill, New York (1959).

(7) H. Conroy, "Nuclear Magnetic Resonance in Organic Structural Elucidation," in *Advances in Organic Chemistry, Methods and Results*, R. Raphael, ed., Interscience, New York (1960).

(8) L. M. Jackman, *Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry*, Pergamon Press, New York (1959).

(9) (a) G. V. D. Tiers, *J. Phys. Chem.*, **62**, 1151 (1958); (b) G. V. D. Tiers, *Characteristic Nuclear Magnetic Resonance "Shielding Values" for Hydrogen in Organic Structures. Part I. Tables of τ-Values for a Variety of Organic Compounds. Exploratory NMR Studies.* Project 737602, Central Research Department, Minnesota Mining & Manufacturing Co., St. Paul, Minn.

Table I gives the chemical shifts of methylated hydroquinone dimethyl ethers; Table II gives the chemical shifts of vinyl methylhydroquinone dimethyl ethers, and Table III gives the chemical shifts of α- and β-hydroxyethylmethylhydroquinone dimethyl ethers.

TABLE I

Chemical Shifts of Methylated Hydroquinone Dimethyl Ethers

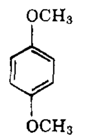
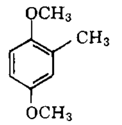
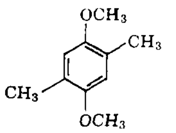
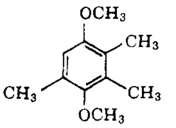
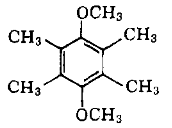
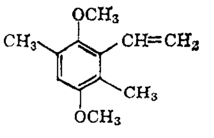
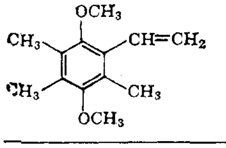
	Types of Protons		
	Aromatic	Methoxyl	Methyl
	3.33 (2)	6.34 (3)	—
	3.44, 3.51 (1) (2)	6.34, 6.38 (3) (3)	7.8 (3)5
	3.53 (1)	6.30 (3)	7.88 (3)
	3.65 (1)	6.33, 6.48 (3) (3)	7.81, 7.88, (3) (3) 7.95 (3)
	—	6.46 (3)	7.89 (6)

TABLE II

Chemical Shifts of Vinyl Methylhydroquinone Dimethyl Ethers

	Types of Protons		
	Aromatic	Methoxyl	Methyl
	3.43 (1)	6.34, 6.47 (3) (3)	7.81, 7.88 (3) (3)
	—	6.45, 6.50 (3) (3)	7.84, 7.90 (3) (6)

The compounds studied were prepared as follows. 2,5-Dimethoxytoluene was prepared from p-toluhydroquinone by treatment in absolute methanol with dimethyl sulfate and methanolic potassium hydroxide. The preparation of 1,4-dimethoxy-2,5-dimethylbenzene and 1,4-dimethoxy-2,3,5-trimethylbenzene will be described elsewhere.[10] 1,4-Dimethoxydurene (1,4-dimethoxy-2,3,5,6-tetramethylbenzene)[11] was prepared from 1,4-dimethoxy 2,6 - di(chloromethyl) - 3,6 - dimethylbenzene[12] by treatment with lithium aluminum hydride in ether. The preparations of the two methoxymethyl-substituted styrenes (Table II) and the methoxymethyl-substituted α- and β-hydroxyethylbenzenes (Table III) will be reported.[10] β-Hydroxyethylhydroquinonedimethyl ether was prepared by the method of Barnes,[13] according to which hydroquinone dimethyl ether was treated first with n-butyllithium and then with ethylene oxide.

From Table I several generalizations concerning the aromatic methyl and methoxyl protons may be suggested. Pople, Schneider, and Bernstein[5] discussed aromatic protons on a variety of aromatic hydrocarbons and on substituted benzenes. They state, "The spectra of the ring protons of the methyl-substituted benzenes consist essentially of one unresolved signal, the only compound in which pronounced separation of signals is apparent being m-xylene. The position of the ring-hydrogen signal and methyl group signal in the field does vary, however, with substitution." Analogously with methyl-substituted 1,4-dimethoxybenzenes the aromatic protons consist of one unresolved peak with the exception of 2,5-dimethoxytoluene where there are two peaks, one of which is twice as large as the other. (A coupling constant of 1.5 cycles was observed for the *meta* proton). As with m-xylene the separation of signals is due to differences in environment of the ring-protons. Here also the position of ring-hydrogens varies with substitution. Increasing the number of methyl substituents in the ring increases the up-field shift of the aromatic protons. Similarly, for methyl substitution in hydroquinone dimethyl ethers, the methyl proton of the spectrum has a single peak with the exception of the unsymmetrical trimethylated compound (1,4-dimethoxy-2,3,5-trimethylbenzene). Here, as with the unsymmetrical ring protons, the methyl peak is resolved into more than one signal. In this case three peaks are found indicating the resolution of each methyl group, that is, the three methyl groups are different. This is easily shown by comparing the groups *ortho*, *meta* and *para* to each methyl group. Signals due to methoxyl protons suggest a variation due to the number of methyl groups ortho to the methoxyl group. 1,4-Dimethoxy-2,3,5-trimethylbenzene is shown to have two different methoxyl groups, one at 6.33 τ and the other at 6.48 τ. One of these methoxyl groups is *ortho* to a methyl group and an

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(10) K. A. Kun and H. G. Cassidy, "Electron Exchange Polymers XVII," *J. Polymer Sci.*, in press.

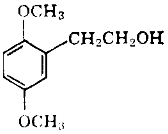
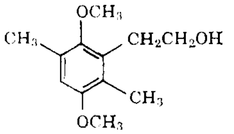
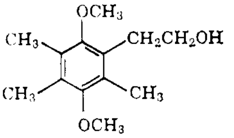
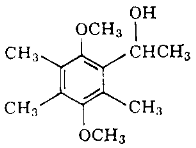
(11) L. I. Smith and H. C. Miller, [*J. Am. Chem. Soc.*, **64**, 440 (1942)] give the melting point of the compound.

(12) The preparation of this compound will be reported shortly.

(13) R. A. Barnes, *J. Am. Chem. Soc.*, **75**, 3004 (1953).

TABLE III

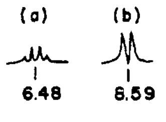
CHEMICAL SHIFTS OF SOME α- AND β-HYDROXYETHYLHYDROQUINONE DIMETHYL ETHERS

	Types of Protons			
			Methyl	
	Aromatic	Methoxyl	Aromatic	Aliphatic
	3.20, 3.33 (1) (2)	6.33, 6.36 (3) (3)	—	—
	3.58 (1)	6.34, 6.37 (3) (3)	7.81, 7.86 (3) (3)	—
	—	6.54, 6.58 (3) (3)	7.84, 7.91 (3) (6)	—
	—	5.97, 6.08 (3) (3)	7.77, 7.90 (3) (3)	8.59 (3)

aromatic hydrogen while the other is *ortho* to two methyl groups. One may differentiate between the two by comparing the chemical shifts of the methoxyl group with 1,4-dimethoxy-2,5-dimethylbenzene and 1,4-dimethoxy-2,3,5,6-tetramethylbenzene. The former has methoxyl groups *ortho* to a methyl group and an aromatic proton, while the latter has methoxyl groups *ortho* to two methyl groups. As shown in Table I, the methoxyl group in 1,4-dimethoxy-2,5-dimethylbenzene is located at 6.30 τ and in 1,4-dimethoxy-2,3,5,6-tetramethylbenzene the absorption is observed at 6.46 τ. The difference in chemical shifts between the values 6.30 and 6.33 τ and 6.46 and 6.48 τ is probably due to an inductive and/or steric effect of the 3-methyl group in 1,4-dimethoxy-2,3,5-trimethylbenzene. This effect, naturally, would be absent from 1,4-dimethoxy-2,5-dimethylbenzene and may or may not be present in 1,4-dimethoxy-2,3,5,6-tetramethylbenzene. Coupling effects of a methyl group which does not have another methyl group para to it may be shown in the case of 2,5-dimethoxytoluene. The chemical shifts of these methoxyl protons were found at 6.34 and 6.38 τ while the chemical shift of the methoxyl protons of 1,4-dimethoxybenzene is 6.34 τ. Therefore, it is strongly suggested that for 1,4-dimethoxy-2,3,5-trimethylbenzene the methoxyl group having a methyl group and an aromatic hydrogen in the *ortho* positions has a chemical shift at 6.33 τ and the methoxyl group with two methyl groups in *ortho* positions has a chemical shift at 6.48 τ. Analogous trends may be suggested for the substituted styrenes described in Table II and the substituted α- and β-hydroxyethylbenzenes.

The spectra of the vinyl group in the substituted styrenes showed the twelve strong lines of the ABC (approximately ABX) system,[14] —$CH_X = CH_A H_B$, which comprise three symmetrically split quartets.[9a] For example, the vinyl group of 2,5-dimethoxy-3,4,6-trimethylstyrene has a set of peaks whose quartets are centered at the following τ values: (X) 3.28, (A) 4.43, and (B) 4.67 with splittings: (X) 10.2 and 17.8 c.p.s.; (A) 1.2 and 17.4 c.p.s.; and (B) 1.2 and 10.2 c.p.s. Coupling between geminal protons A and B within the trigonally hybridized methylene group is expected to be small as in styrene,[5] *p*-methylstyrene,[15] and vinylanthraquinone.[16]

The α-hydroxyethyl group shows a characteristic pattern whereby the methine is split by the three methyl hydrogens to give a quadruplet and the methine proton splits the methyl group to give a doublet. For 2,5-dimethoxy-3,4,6-trimethyl-α-hydroxyethylbenzene, the aliphatic methyl signal is a doublet centered at 8.59 τ and the methine signal is a quadruplet centered at 6.48 τ.



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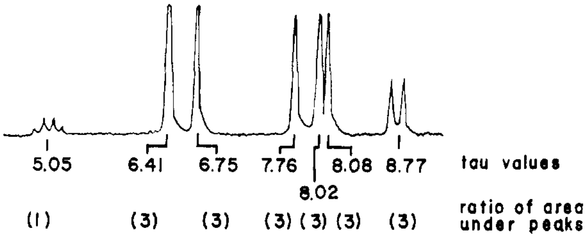
(14) H. J. Bernstein, J. A. Pople, and W. G. Schneider, *Canadian J. Chem.*, **35**, 65 (1957).

Using this information in conjunction with infrared and microanalytical data, α,α'-bis(2,5-dimethoxy-3,4,6-trimethylphenyl)diethyl ether[10] was identified by its NMR spectrum. The methine proton is located at 5.05 τ and is split into a quadruplet by an alpha methyl group. This methyl group is split by the methine proton to give a doublet which is found at 8.77 τ. The methoxyl and aromatic methyl groups are located at 6.41 and 6.75 τ and 7.76, 8.02, and 8.08 τ, respectively.



EXPERIMENTAL

The melting points and boiling points given in this study are uncorrected. All reagents used were of the highest purity available, either purified, reagent or analytical reagent grades.

Preparation of 2,5-dimethoxytoluene. Fifty grams of *p*-toluhydroquinone was dissolved in a solution of 250 ml. of absolute methanol and 504 g. of freshly distilled dimethyl sulfate. The solution was heated to reflux temperature and refluxing was continued for 15 min. Removing the heat source, refluxing was continued by adding methanolic potassium hydroxide (600 g. dissolved in 1.5 l. of methanol) so as to maintain a steady reflux rate. When the resulting reaction mixture was alkaline to litmus paper, the product was isolated by steam distilling it from the reaction mixture. Extraction of the distillate with ether, drying the organic fraction over anhydrous potassium carbonate, filtering and removing the solvent *in vacuo* from the filtrate yielded 53 g. of crude product. This material was distilled to give 50 g. (82%) of a colorless liquid boiling at 46 to 51° at 0.2 mm. (lit. b.p.[17] 214–218°).

Preparation of 1,4-dimethoxydurene. One gram of 1,4-dimethoxy - 2,5 - dichloromethyl - 3,6 - dimethylbenzene[12] was refluxed for 4 hr. with an excess of lithium aluminum hydride in 25 ml. of absolute ether. The unchanged lithium aluminum hydride was decomposed with ethyl acetate and then the metal complex was destroyed with water. After removing the metal hydroxides by filtration, the filtrate was stripped of solvent *in vacuo* and the resulting residue was steam distilled. The desired product, 1,4-dimethoxydurene, was isolated by extracting the distillate with ether, drying the ether solution over anhydrous potassium carbonate, filtering, removing the solvent from the filtrate *in vacuo*, and crystallizing the residue from methanol. The product, a white crystalline solid, melted at 114–115°. (lit. m.p.[11] 112–115°).

Preparation of β-hydroxyethylhydroquinone dimethyl ether. Eight grams of 1,4-dimethoxybenzene was dissolved in 50 ml. of absolute ether and an excess of 0.994N *n*-butyllithium was added with stirring. The reaction mixture was stirred overnight. Four grams of ethylene oxide was added drop-wise to the reaction mixture, keeping the reaction temperature below 5°. The reaction mixture was slowly brought to room temperature and stirred for an additional 4 hr. The organometallic complex was decomposed with very dilute hydrochloric acid, the ether fraction separated and the aqueous fraction was extracted, with ether. Drying the combined ether fractions over anhydrous potassium carbonate, filtering, and distilling the solvent *in vacuo* from the filtrate yielded 7.8 g. of crude residue. This residue was distilled to yield 6.0 g. of product boiling at 115–6° at 0.2 mm. (b.p.[18] 130–142° at 0.7 mm.).

Acknowledgment. The authors wish to thank Dr. Harold Conroy for his helpful discussions during this investigation. The authors also wish to thank Dr. Herman Richie for his advice and aid in teaching one of us (K.A.K.) how to operate the NMR spectrometer. This work was supported by a grant from the Research Corporation and a PHS research grant, A3304, National Institute of Arthritis and Metabolic Diseases, Public Health Service, which we gladly acknowledge.

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(15) R. W. Fessenden and J. S. Waugh, Abs. 132nd Meeting, American Chemical Society, Sept. 1957, p. 72 P.

(16) M. F. Refojo, Y. L. Pan, K. A. Kun, and H. G. Cassidy, *J. Org. Chem.*, **25**, 416 (1960).

(17) I. Heilbron and A. M. Bunbury, *Dictionary of Organic Compounds*, Oxford University Press, New York, 1953.

(18) M. F. Refojo, unpublished work.

[CONTRIBUTION FROM THE EXPLOSIVES DEPARTMENT, EXPERIMENTAL STATION, E. I. DU PONT DE NEMOURS & CO.]

Reactions of Ferrocyanic and Cobalticyanic Acids

WALTER Z. HELDT

Received December 19, 1960

Hexacyanoferric(II) and hexacyanocobaltic(III) acids yield when heated with an aliphatic alcohol an isonitrile complex which in the presence of excess of hydrogen cyanide gives the corresponding isonitrile. The esterification of hexacyanoferric (II) acid and the displacement of the alkyl isonitrile from the isonitrile complex may be combined into one reaction.

The acids of complex cyanides such as hexacyanoferric(II)[1] hexacyanoferric(III),[2] hexacyanocobaltic(III),[2] and hexacyanochromic(III)[2] acids are known to be strong acids approximating hydrochloric acid in strength. When heated with alcohols, hexacyanocobaltic(III)[1,3] and hexacyanoferric-

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(1) F. Hölzl, *Z. Elektrochem.*, **43**, 319 (1937).

(2) J. Brigando, *Bull. soc. chim. France*, 503 (1957).

TABLE I

Reaction of Ferro- and Cobalticyanic Acids

Exp.	Complex Acid (Mole)	Reagent (Mole)	HCN Mole	Reaction Conditions Pressure (atm.)	Time, hr.	Temp.	Product Isolated (G).
1	$H_4Fe(CN)_6$ (0.14)	Ethyl alcohol (8.5)	0.46	Closed vessel	1 hr. at 2 hr. at	70 120	Ethyl isonitrile 10.5
2	$H_4Fe(CN)_6$ (0.05)	Ethyl alcohol (3)	1.0	Closed vessel	15	100	Ethyl isonitrile 14.7
3	$H_4Fe(CN)_6$ (0.05)	*t*-Butyl alcohol (1.25)	1.0	95 N_2	9	150	*t*-Butylformamide 10.0
4	$H_4Fe(CN)_6$ (0.05)	*t*-Amyl alcohol (1.10)	1.0	95 N_2	6	150	*t*-Amylformamide 12.7
5	$H_3Co(CN)_6$ (0.25)	1-Butene (1.0)	1.0	Closed vessel	8 hr. (200 ml. of acetonitrile as the solvent)	150	2-Butaneformamide 4.0

(II)[1,4] acids yielded the "esters" of hexacyanoferric(II) and hexacyanocobaltic(III) acids or isonitrile cyanide complexes identified as pyridinium salts: 2 pyr.$H_2[RNCCo(CN)_5]$,[3] etc. Alkyl isonitrile may be displaced from these transition metal complexes by potassium cyanide,[5] alkali,[6] alcohol,[7] water,[7] and dilute acids.[7] Furthermore, the incompletely "esterified" complex acids are reported to be much less stable than the nonacidic, completely "esterified" acids.[3,4,8] These incompletely "esterified" acids decompose to polymeric, poorly identified products with the evolution of either hydrogen cyanide or alkyl isonitrile. If the displacement of the isonitrile from the partially "esterified" acid could be accomplished with an excess of hydrogen cyanide, a continuous process for the preparation of alkyl isonitriles would be available:

$$\begin{array}{l} H_4Fe(CN)_6 \\ \text{excess } CH_3CH_2OH \xrightarrow{-H_2O} \end{array}$$

$$\left\{\begin{array}{l} H_3[CH_3CH_2NCFe(CN)_5] \\ H_3[(CH_3CH_2NC)_2Fe(CN)_4] \\ H[CH_3CH_2NC)_3Fe(CN)_3] \end{array}\right\} \xrightarrow{HCN} \begin{array}{r} H_4Fe(CN)_6 \\ + CH_3CH_2NC \end{array}$$

Up to quite recently[9] methods which were available gave only low conversions to isonitriles.

To test this working hypothesis, dicyanotetrakis(ethyl isocyano)iron II was synthesized from hexacyanoferric(II) acid and diazoethane according to the procedure of Mayer.[10] In the reaction of dicyanotetrakis(ethyl isocyano)iron(II) with hydrogen cyanide in ethyl alcohol in an autoclave, the ethyl isonitrile was displaced from the complex in about 10% conversion.

When hexacyanoferric(II) acid was heated with a large excess of ethyl alcohol in a stainless steel autoclave (see Table I, Experiment 1), then hydrogen cyanide was added, and the heating continued at 120° ethyl isonitrile was isolated in about 40% conversion in reference to the hydrogen cyanide added, or 1.36 moles of ethyl isonitrile were formed per mole of hexacyanoferric(II) acid employed. When the ratio of hydrogen cyanide to hexacyanoferric(II) acid was increased from 3 to 20 (Experiment 1,2, Table I) the conversion to ethyl isonitrile was still only about 26%, in reference to hydrogen cyanide added, but in this experiment 5.3 moles of ethyl isonitrile were generated per mole of hexacyanoferric(II) acid added to the reaction mixture. Finally, when the partially "esterified" acid, obtained as a blue residue from Experiment 1, was used as a catalyst under the experimental conditions described in Experiment 2, an additional 2.7 g. (or 10% in reference to the hydrogen cyanide added) of ethyl isonitrile were obtained. These experiments seemed to indicate that a continuous synthesis of alkyl isonitriles from alkyl alcohols and complex cyanic acids is possible. The isonitrile appears to be displaced from the intermediate complex either by hydrogen cyanide, by ethyl alcohol, or the complex dissociates perhaps thermally; ethyl isonitrile was formed from hexacyanocobaltic(III) acid and ethyl alcohol upon heating of the reaction mixture without the addition of hydrogen cyanide.

The reaction of hexacyanoferric(II) and hexacyanocobaltic(III) acids with ethyl alcohol is considerably more complex than it would at first appear. An unknown but critical step in the reaction, perhaps the polymerization of the incompletely "esterified" acid, is catalyzed by the surface of the autoclave. An "aged" stainless steel autoclave[11] (*i.e.*, in which the reaction was

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(3) F. Hölzl, T. Meier-Mahar, and F. Viditz, *Monatsh.*, **53-54,** 237 (1929).

(4) F. Hölzl and J. Krakora, *Monatsh.*, **64,** 97 (1933-34).

(5) (a) Freud, *Ber.*, **1,** 934 (1888). (b) E. G. J. Hartley, *J. Chem. Soc.* (*London*), 780 (1928). (c) L. Malatesta, "Isocyanide Complexes of Metals" in *Progress in Inorganic Chemistry*, Vol. I, 1959, p. 283, F. A. Cotton, Editor.

(6) F. Hölzl, W. Hauser, and M. Eckmann, *Monatsh.*, **48,** 71 (1927).

(7) F. Hölzl and G. I. Xenakis, *Monatsh.*, **48,** 689 (1927).

(8) F. Hölzl and A. Sallmann, *Monatsh.*, **58,** 29 (1931).

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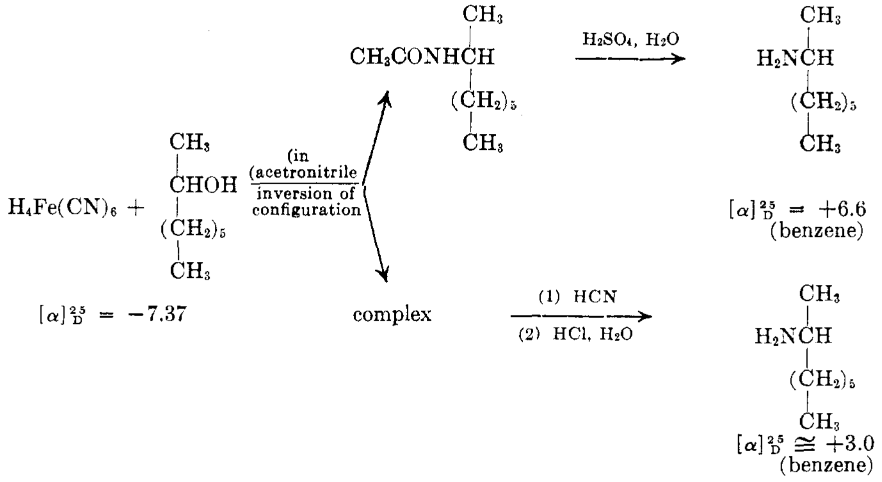
(11) Stainless Steel, No. 31655, Allegheny Ludlum Steel Corp., Pittsburgh, Pa.

performed five to ten times) yielded conversions to ethyl isonitrile or amides as indicated in Table I but a completely new stainless steel autoclave yielded only trace conversions to isonitriles or to N-alkylformamides.

tert-Butyl and *tert*-amyl alcohol and 1-butene (see Table I) yielded the corresponding *N*-alkylformamides instead of the expected isonitriles. Since *sec*-octyl alcohol also yields only the *N*-*sec*-octylformamide but none of the expected isonitrile, it was decided to investigate this reaction in some detail using optically active *sec*-octyl alcohol. The alkylation of higher alcohols or sterically hindered alcohols could proceed by the Ritter[12] reaction or, as in the case of ethyl alcohol, with "esterification" of the cyanic acid, and subsequent displacement or dissociation of the isonitrile complex into the alkyl isonitrile. Since water is generated in the "esterification" of the complex cyanic acid, it is conceivable that the isonitriles formed may hydrolyze in the presence of water and an acid[5c] to the corresponding formamides.



When *sec*-octyl alcohol $[\alpha]_D^{25} = -7.37$ (or 71% pure)[13] was heated with hexacyanoferric(II) acid in acetonitrile as the solvent under conditions given for ethyl alcohol in Table I, a green-bluish solid was formed which was insoluble in acetonitrile and was filtered from the reaction mixture. The filtrate consisted of 12 g. (about 60%) of *sec*-octyl alcohol which was partially racemized under the reaction conditions and of 2.4 g. (about 20%) of *N*-*sec*-octylacetamide. The amide was hydrolyzed with dilute sulfuric acid to the corresponding amine, $[\alpha]_D^{25} = (+)6.6$. Since $[\alpha]_D = (+)8.5$ for *sec*-octylamine in benzene,[14] the optical purity of the amide is ∼76%, and the displacement with acetonitrile proceeded with inversion of configuration with a high degree of stereospecificity.

No optical rotations could be taken of the blue acetonitrile insoluble residue. The *N*-*sec*-octyl isonitrile was displaced from the complex with hydrogen cyanide, and the *N*-*sec*-octyl formamide was hydrolyzed with 1*N* hydrochloric acid to the corresponding *sec*-octylamine. Only 20 mg. of *sec*-octylamine were isolated, $[\alpha]_{D\ \text{benzene}}^{25} \cong (+)3.0$. Due to the large error inherent in this figure all that can be said is that reaction of the *sec*-octyl oxonium ion occurred with both acetonitrile and the complexed cyanide by a concerted mechanism. The complexed cyanide ion is alkylated to the corresponding isonitrile complex, which then decomposes, by an unknown mechanism, to yield *N*-alkylated formamides. This process appears to be different from the Ritter reaction[12] in which hydrogen cyanide is alkylated with alcohols in the presence of sulfuric acid to yield *N*-alkyl formamides.

EXPERIMENTAL

Hexacyanoferric(II) acid. Synthesis of hexacyanoferric(II) acid reported in the literature[4,15] did not yield the complex acid in high conversions and in high purity. Hexacyanoferric(II) acid was prepared in almost quantitative conversions by addition of finely powdered potassium hexacyanoferrate II to 18*N* sulfuric acid: Finely powdered potassium hexacyanoferrate(II) trihydrate (462 g., 1.1 moles) was added to a solution of 318 g. (3.3 moles) of concd. sulfuric acid and 320 g. of ice in such a manner that the temperature did not exceed 30°. The reaction mixture was then stirred with 2.3 l. of absolute ethyl alcohol and was allowed to stand at room temperature over the week end. At the end of this time, the potassium sulfate and bisulfate were removed by filtration. To the filtrate was added 2.5 l. of diethyl ether and the solution was kept at 0–5° for 2 hr. The slightly bluish colored crystals were filtered off and were dried for 1 week in a vacuum desiccator over phosphorus pentoxide. Conversion to hexacyanoferric(II) acid was 25.7 g. or quantitative. After drying in a vacuum pistol at 80° and 1.0 mm. the material was analyzed.

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Anal. Calcd. for $H_4Fe(CN)_6$: C, 33.05; H, 2.77; N, 38.91; Fe, 25.85. Found: C, 33.10; H, 2.46; N, 37.67; Fe, 25.50.

Hexacyanocobaltic(III) acid was prepared in a satisfactory manner according to the procedure of Hölzl[3] from potassium hexacyanocobaltate(III) and aqueous hydrochloric acid. Potentiometric titration with 0.1*N* sodium hydroxide indicated that the purity of hexacyanocobaltic(III) acid was 98% or better.[3]

Dicyanotetrakis(ethyl isocyano)iron(II) was prepared from hexacyanoferric(II) and diazoethane according to the procedure of Mayer.[10] The isonitrile complex crystallized from chloroform. After several recrystallizations from chloroform and drying at 79° and 0.4 mm., 3.5 g. (≈21% conversion), melting at 203.5–206° (uncorrected) reported m.p. 212–214°[5a] was obtained.

Anal. Calcd. for: $(CH_3CH_2NC)_4Fe(CN)_2$: C, 50.55; H, 6.32; N, 24.89; Fe, 16.67. Found: C, 51.11; H, 6.13; N, 25.55; Fe, 16.97.

Infrared (chloroform, cm.$^{-1}$) 3000(s), 2180(vs), 2100(w), 1450(s), 1348(s), 1210(vs), 1098(w), 10.45(w), 9.25(s), 750 broad.

Reaction of dicyanotetrakis(ethyl isocyano)iron(II) with hydrogen cyanide. To 1.3 g. (0.004 mole) of dicyanotetrakis-(ethyl isocyano)iron(II) in 100 ml. of absolute ethanol was added 5 ml. (0.127 mole) of hydrogen cyanide and the reaction mixture was heated in a closed stainless steel autoclave at 100° for 5 hr. The reaction mixture was then decanted from the reaction vessel, the autoclave was washed with 30 ml. of absolute ethyl alcohol and the alcoholic solutions were dissolved in 500 ml. of absolute ether to precipitate the unchanged iron-isonitrile complex. A trace of the iron isonitrile complex was filtered from the reaction mixture and the filtrates were distilled through a fractionating column till all ether was removed; the total residue was 130 ml. The infrared spectrum of this filtrate indicates a strong band at 2130 cm.$^{-1}$, typical for ethyl isonitrile. Ethyl isonitrile was also identified in the filtrate by vapor phase chromatography (see below); 1 ml. of the filtrate contained approximately 0.13 mmole of ethyl isonitrile, or the conversion to isonitrile was approximately 10%.

Identification of ethyl isonitrile. Ethyl isonitrile was prepared from ethyl iodide and silver cyanide according to the method of Davis.[16] The reaction mixture was separated and the ethyl isonitrile was identified by vapor phase chromatography on a Celite column (52°, pressure 25 p.s.i.g.). The retention time for ethyl isonitrile was = 1.75 (min.), propionitrile = 8.53 (min.), hydrogen cyanide = 0.6 (min.), and ethyl alcohol = 3.08 (min.).

The ethyl isonitrile was identified by a strong peak at; 2130 cm.$^{-1}$, as compared to a strong CN stretching frequency to propionitrile at 2230 cm.$^{-1}$ Ethyl isonitrile was hydrolyzed to ethylamine either by 1.0*M* hydrochloric acid or 30% sodium hydroxide as described in detail by Hölzl[3] and Guillemard.[17] The method was specific for isonitriles in the presence of nitriles and hydrogen cyanide.[3] Isonitrile was usually identified in the reaction mixture by at least two of these methods.

Alkylation of hexacyanoferric(II) acid with ethyl alcohol. To 29.6 g. (0.14 mole) of hexacyanoferric(II) acid, freshly dried, was added 465 ml. of absolute ethanol and the reaction mixture was heated in a stainless steel autoclave for 1 hr. at 70°. It was then cooled to 0° and a 10-ml. sample of the supernatant liquor was withdrawn. Hydrolysis of the filtrate with 1.061*N* hydrochloric acid and infrared spectrum indicated complete absence of any isonitrile. To the rest of the filtrate, 18 ml. (0.49 mole) of hydrogen cyanide was added and the reaction mixture was heated for 2 hr. at 120°. The steel vessel was then cooled to 0°, and a blue solid was removed by filtration. The blue residue was then washed with 2 × 65 ml. of ethyl alcohol. (Total filtrates = 570 ml.) The infrared spectrum of the filtrate indicated only one strong band at 2100 cm.$^{-1}$ probably ethyl isonitrile. Attempts to separate ethyl isonitrile from ethyl alcohol by fractional distillation failed. The ethyl isonitrile in the filtrate was identified by hydrolysis of the alcoholic solution with 1.0*N* hydrochloric acid to ethylamine and subsequent preparation of *N*-ethylbenzamide, m.p. 60–70°, by the standard method.[18] This specimen did not lower the melting point of *N*-ethylbenzamide upon admixture. A total of 10.5 g. (40% based on hydrogen cyanide added) of ethyl isonitrile was formed in this reaction. An aliquot of 2.5 ml. of the reaction mixture consumed 0.8332 mmole of acid when hydrolyzed with 1.061*N* hydrochloric acid as outlined above.

Alkylation of hexacyanocobaltic(III) acid with ethyl alcohol. To 109 g. (0.5 mole) of hexacyanocobaltic(III) acid prepared according to the method of Hölzl[3] was added 200 ml. of absolute ethyl alcohol and the reaction mixture was heated for 46 hr. at 100° in a closed stainless steel vessel. The reaction mixture was filtered and an aliquot of the filtrate was analyzed by vapor-phase chromatography as outlined above. The conversion to ethyl isonitrile as calculated from the area of the peak was approximately 9–10%. No *N*-ethylformamide was indicated by vapor-phase chromatography.

Reaction of hexacyanoferric(II) acid with sec-octyl alcohol. *sec*-Octyl alcohol, 20.890 g. (0.16 mole), $[\alpha]_D^{25} = -7.37$ or 71% optically pure,[13] was added to 150 ml. of freshly distilled acetonitrile and 48 g. (0.22 mole) of hexacyanoferric-(II) acid and the reaction mixture was heated for 10 hr. at 120° in a steel vessel under autogenous pressure. After the reaction was over, the green-bluish residue (I) was filtered and the filtrate (II) was distilled under reduced pressure. Distillation of the filtrate (II):

Fraction	Vacuum	Temp.	Grams	n_D^{22}	$[\alpha]_D^{27}$
I	8 mm.	74–77	7.95	1.4191	(−) 3.37
II	8 mm.	77–78	4.075	1.4229	(−) 5.97
III	8 mm.	178–145	0.410	1.4421	
IV	8 mm.	148–150	2.370	1.4487	(−) 4.65
V	1.4 mm.	118–120	0.520		
VI	Residue of distillation		0.117		
			15.477		

Rotations were observed in absolute ethyl alcohol; approximately 20–30 readings were taken for each value in column 6. Fraction I was a mixture of *sec*-octyl alcohol and perhaps a small amount of acetonitrile. Fraction II represented pure *sec*-octyl alcohol. Fraction IV was an amide Infrared spectrum: 3800 (NH), 2925 (—CH_2—), 1655 (—CONH—).

Anal. Calcd. for $C_9H_{19}ON$: C, 68.74; H, 12.17. Calcd. for $C_{10}H_{21}ON$: C, 70.12; H, 12.36. Found: C, 69.52; H, 12.42.

Fraction IV could therefore be either the *N*-*sec*-octylacetamide or *N*-*sec*-octylformamide.

N-sec-Octylacetamide. *N*-*sec*-Octylacetamide was prepared from *sec*-octylamine and acetyl chloride by a known method,[18] b.p. 148–149°/10 mm. $n_D^{22} = 1.4474$. Infrared spectrum: 3800 (NH), 2925 (—CH_2—), 1655 (—CONH—).

The infrared spectrum of *N*-*sec*-octylacetamide was identical with the spectrum of Fraction IV in all details.

N-sec-Octylformamide. *N*-*sec*-Octylformamide was prepared from *sec*-octylamine and chloral in chloroform as the solvent according to the procedure of Blicke and Lu,[19]

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b.p. 145.5–146.5°/9.2 mm.; n_D^{22} = 1.4471. Infrared spectrum: 3800 (NH), 2925 (—CH_2—), 1665 (—CONH—). The infrared spectrum in the finger-print region was distinctly different from that of N-*sec*-octylacetamide.

Hydrolysis of fraction IV. One gram of Fraction IV was heated with 80% sulfuric acid for 4 hr. at 100° and was then allowed to stand over the week end at room temperature. The solution was made alkaline with 30% sodium hydroxide, extracted with ether, dried with magnesium sulfate, and distilled. *sec*-Octylamine was isolated in ∽20% conversion, b.p. 76–80°/20 mm. $[\alpha]_D^{25}$ = (+) 6.6 (5.95% solution in benzene). Purity is thus ∽76%.[14]

Displacement of sec-octyl isonitrile from complex. Complex I residue 2.9 g., 5 ml. of hydrogen cyanide, 5 ml. of methyl alcohol, and 100 ml. of acetonitrile were heated in an autoclave for 8 hr. at 120°. The acetonitrile was distilled, the residue was hydrolyzed with 1*N* hydrochloric acid, and was processed as described above. Only 20 mg. of the *sec*-octylamine was isolated. The 1.1% solution of the *sec*-octylamine in benzene had a rotation of $[\alpha]_D^{25}$ = (+) 3.05. This experiment is not very conclusive because of the small amount of *sec*-octylamine isolated, but it appears that the alkylation proceeds with a concerted displacement.

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[CONTRIBUTION FROM THE DIVISION OF ONCOLOGY, THE CHICAGO MEDICAL SCHOOL]

The Catalytic Hydrogenation of Dibenz[*a,h*]anthracene[1]

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Catalytic hydrogenation of dibenz[*a,h*]anthracene with platinum at atmospheric pressure proceeds as far as 1,2,3,4,1a,4a,5,6,8a,11a,12,13,8,9,10,11-hexadecahydrodibenz[*a,h*]anthracene. Seven intermediate hydrogenated products were isolated, three of them in more than one stereoisomeric form. They were 5,6-dihydro-, 1,2,3,4-tetrahydro-, 5,6,12,13-tetrahydro-, 1,2,3,4,12,13-hexahydro-, 1,2,3,4,8,9,10,11-octahydro-, 1,2,3,4,1a,4a,5,6-octahydro-, and 1,2,3,4,1a,4a,5,6,8,9,10,11-dodecahydrodibenz[*a,h*]anthracene. The yields ranged from 3% to 25% of the reacted dibenz[*a,h*]anthracene.

Following the study of the catalytic hydrogenation of benzo[*a*]pyrene,[2] with the object of investigating the carcinogenic and anti-carcinogenic properties of the products, a similar investigation of the catalytic hydrogenation of dibenz[*a,h*]anthracene was undertaken, with the same objective. A preliminary report of the biological activity of some of the hydrogenation products of dibenz[*a,h*]anthracene has been published.[3]

Some partially hydrogenated derivatives of dibenz[*a,h*]anthracene have been described, although none were prepared under the conditions of this investigation. The 7,14-dihydro compound has been prepared through the corresponding disodio compound[4] and by hydrogenation with nickel under pressure.[5] Cook reported the preparation of an octahydrodibenz[*a,h*]anthracene[6] by reduction with sodium and amyl alcohol, although the structure of the compound was not determined at that time.

An octahydro derivative has also been prepared synthetically by reduction of bistetramethyleneanthraquinone (obtained by cyclization of vinylcyclohexane with 1,4-benzoquinone).[7] This compound, 1,2,3,4,8,9,10,11-octahydrodibenz[*a,h*]anthracene, had a melting point (196–197°) higher than that of Cook's compound (188–190°). One of the octahydrodibenz[*a,h*]anthracenes (IVa) prepared by catalytic hydrogenation (as described below) had a melting point very close to that of the octahydro compound prepared by synthesis,[7] which would be expected to have an absorption spectrum similar to that of anthracene.

The hydrogenations of dibenz[*a,h*]anthracene to be described were carried out under the same conditions as were used for benzopyrene,[2] the catalyst being platinum. Several hydrogenations of dibenz[*a,h*]anthracene were carried out to various stages. Under these conditions, hydrogen was taken up until a hexadecahydro compound was formed, after which no further addition of hydrogen occurred, even after prolonged exposure to the gas. No perhydrodibenz[*a,h*]anthracene could be isolated and, apparently, reduction of the last aromatic ring was very difficult under these conditions. At all intermediate stages in the hydrogenation of dibenz[*a,h*]anthracene a mixture of several partially hydrogenated derivatives was present in the reaction mixture. Unchanged dibenz[*a,h*]anthracene was present after addition of four moles of hydrogen, but not after five moles of hydrogen had been taken up.

A tentative mechanism of addition of hydrogen to dibenz[*a,h*]anthracene (I) is shown in Fig. 1. The hydrogenated compounds were identified from

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[1] This investigation was supported by Grant C-4249 of the National Institutes of Health, U. S. Public Health Service.

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