bomb and hydrogenated under 100 atmospheres pressure at 165° in the presence of 0.93 g. of ruthenium dioxide. Uptake of hydrogen did not proceed to completion because of the oily hydrogenolysis product which coated the catalyst. After filtration from the catalyst, the oily material was extracted with ether and distilled; 16 g. of a product boiling at 55–58° (20 mm.), 153–160° (760 mm.), $n^{25}\text{D}$ 1.4356 was obtained.

Anal. Calcd. for C_9H_{18} (propylcyclohexane): C, 85.63; H, 14.37. Found: C, 85.93; H, 14.63.

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Platinum-catalyzed Exchange of Aromatic Compounds with Deuterium Oxide

By W. G. Brown and J. L. Garnett

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An exchange reaction, using heavy water and catalyzed by active platinum, has been applied to the deuteration of benzoic acid and its sodium salt, bromobenzene, isopropyl benzoate, aniline, nitrobenzene, *p*-nitrobenzoic acid and trimesic acid. Exchange with sodium benzoate involves an apparent induction period, followed by rapid deuteration and eventually complete equilibration with respect to all ring positions. Differences in deuteration rate have been observed for the various compounds. An initial orientation effect occurs in the deuteration of sodium benzoate.

Introduction

A procedure has been devised by Leitch[1] for the preparation of benzene-d_6 which employs the platinum-catalyzed exchange reaction of benzene with deuterium oxide at 110°. In convenience and in freedom from side reactions, the method is superior to the vapor phase exchange on nickel at higher temperatures,[2] and, for similar reasons, it is to be preferred over the older method based upon the exchange of benzene with deuterio-sulfuric acid.[3] The possible extension of the liquid phase platinum-catalyzed exchange reaction to the deuteration of other aromatic compounds was of interest to us, especially with reference to benzene derivatives, *e. g.*, benzoic acid, not readily deuterated by alternative methods. The benzene derivatives used in this series of exchange reactions were benzoic acid, sodium benzoate, bromobenzene, isopropyl benzoate, aniline, nitrobenzene, *p*-nitrobenzoic and trimesic acids.

Experimental

Analytical Procedure for Deuterium.—The Graff and Rittenberg[4] method was used for deuterium analyses. Before combustion, each sample was diluted with non-isotopic material to give an α-value of 0.65–0.70 [α = m.e.D/m.e. (D + H)]. Accuracy to 1% deuterium was achieved in the analytical procedure, the mass spectrometer being calibrated against standard deuterium samples.

Deuteration Procedure.—The general technique adopted for the exchange experiments will be illustrated with reference to benzoic acid and aniline.

Benzoic Acid.—A solution of 130 mg. of sodium benzoate in 390 mg. of deuterium oxide (99.5%) was added to 100 mg. of heavy water containing 12 mg. of catalyst (platinum oxide which had been pre-reduced with deuterium). The Pyrex tube containing the reactants was frozen in a Dry Ice-acetone-bath, vacuum sealed and shaken at 130–135° for the required time. The tube was cooled, opened, the contents reheated to 80° and filtered hot to remove the catalyst. The filtrate was acidified with dilute hydrochloric acid, the precipitate sublimed once, then recrystallized twice from 25% aqueous methanol to yield 80.0 mg. of benzoic acid (deuterium analysis shown in Table I).

Substantially pure benzoic acid-d_5 was prepared in the following manner. Three successive equilibrations of benzoic acid with heavy water were performed and the product after these exchange reactions recrystallized twice from 25% aqueous methanol, thus removing any exchangeable deuterium which had been present in the carboxylic acid group.

Aniline.—A mixture of 392 mg. of aniline (distilled twice before use), 2.2 g. of heavy water and 30 mg. of pre-reduced platinum oxide were shaken in an evacuated tube at 130° for 24 hours. The tube was cooled, opened and 400 mg. of benzene added. The benzene layer was extracted with dilute NaOH to remove traces of phenol, washed well with water, distilled under atmospheric pressure to remove benzene and water, and then under reduced pressure. A second vacuum distillation was performed to provide 300 mg. of deuterated aniline (deuterium analysis shown in Table I). Infrared techniques were used to ensure that all exchangeable deuterium (as N–D) was removed by washing the deuterated aniline with water before the distillation step. The product from the exchange reaction was then C_6D_5-NH_2 (aniline-d_5).

To prepare the tribromo derivative, bromine (0.03 ml.) was added to aniline-d_5 (10 mg.) dissolved in glacial acetic acid (0.2 ml.), the tube shaken for several minutes, diluted with water (0.1 ml.), cooled and centrifuged. The resulting 2,4,6-tribromoaniline, twice recrystallized from aqueous methanol, m.p. 120–121°, contained approximately 40% (based upon infrared C–D intensities) of the deuterium present in the deuterated aniline. Since care was taken to ensure that no enchangeable D was present (as N–D) in the deuterated aniline before bromination, it can be concluded that 40% of the original ring deuterium present was in the *m*-position.

Results and Discussion

Directive effects of substituents, with resultant unequal rates of exchange at non-equivalent ring positions, have already been observed in the nickel-catalyzed exchange reactions of some aromatic compounds. Lauer and Errede[5] reported that the *o*-hydrogens of aniline exchanged more readily than did the *m*- and *p*-hydrogens. Tiers[6] noted differences in the rates of exchange of the ring hydrogens of toluene with heavy water and Bonner[7] has studied the exchange of the ring hydrogens of 2-phenylpropionamide in deuterioethanol with Raney nickel. In both of these instances the *o*-positions proved to be somewhat less reactive than other ring positions. The effects of this kind

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[1] L. C. Leitch, *Can. J. Chem.*, **32**, 813 (1954).

[2] J. A. Dixon and R. W. Schiessler, This Journal, **76**, 2197 (1954).

[3] C. K. Ingold, C. G. Raisin and C. L. Wilson, *J. Chem. Soc.*, 1643 (1936).

[4] J. Graff and D. Rittenberg, *Anal. Chem.*, **24**, 878 (1952).

[5] W. M. Lauer and L. A. Errede, This Journal, **76**, 5162 (1954).

[6] G. V. D. Tiers, Ph. D. Dissertation, The University of Chicago, 1956.

[7] W. A. Bonner, This Journal, **79**, 2469 (1957).

TABLE I

EXCHANGE OF SUBSTITUTED AROMATIC COMPOUNDS WITH DEUTERIUM OXIDE AT 130°

	Wt., g.	D_2O, g.	Platinum oxide, g.	Time of reacn., 130°, hr.	Calcd. α^a	Found α	Reacn., % completion
Sodium benzoate	0.130	0.489	0.012	24	0.915	0.910	99.5
Benzoic acid	.100	.402	.012	12	.891	.731	82.0
Benzoic acid + 0.007 g. K_2CO_3	.112	.370	.012	12	.870	.728	83.7
Aniline	.392	2.20	.029	24	.884	.787	89.1
Bromobenzene	1.495	2.20	.120	24	.822	...	10.0[b]
Isopropyl benzoate	1.500	1.000	.150	72	.476	0.475	99.8
Nitrobenzene	0.550	2.20	.050	24	.908	...	3
p-Nitrobenzoic acid	.500	2.20	.120	24	.936	0	0
Trimesic acid	.500	2.20	.120	24	.939	0	0
Trimesic acid[c] + 0.025 g. K_2CO_3	.500	1.98	.120	24	.933	0	0

[a] α = m.e.D/me. (D + H). [b] This value has been estimated from infrared data, since compounds containing halogen could not be analyzed for deuterium in the mass spectrometer. [c] Although trimesic acid does not exchange under comparable conditions to sodium benzoate, a deuterated hydroxy derivative of the trimesic acid is obtained when potassium carbonate is added to the reaction mixture.

previously noted are of relatively small magnitude and are not such as to suggest any limitation in achieving equilibration at all ring positions.

In this series of experiments, summarized in Table I, wide variations in the extent of ring hydrogen exchange have been observed. Benzoic acid, as such or as the sodium salt, aniline and isopropyl benzoate undergo substantially complete equilibration of all ring hydrogen atoms. Bromobenzene and nitrobenzene exhibit a low degree of exchange and none was observed, despite the use of higher proportions of catalyst, with *p*-nitrobenzoic and trimesic acids.

Isopropyl benzoate, although fully equilibrated with respect to the ring hydrogens, showed no aliphatic C–D absorption in the region 2250 to 2150 cm.$^{-1}$ and upon degradation showed a negligible deuterium content in the isopropyl group, analyzed as isopropyl 3,5-dinitrobenzoate.

A peculiarity was observed in the rate of deuterium uptake by sodium benzoate (*cf.* Table II) in that a slow initial rate, or apparent induction period of about three hours, is followed by a rapid reaction proceeding to near equilibrium in the next three hours.

TABLE II

EXCHANGE OF SODIUM BENZOATE WITH DEUTERIUM OXIDE AT 130°

Sample	Sodium benzoate, g.	D_2O, g.	Platinum oxide, g.	Time, hr.	α, found[a]	Completion %
A	0.130	0.485	0.012	1	0.0012	0.15
B	.130	.491	.012	3	.057	7.5
C	.130	.497	.012	6	.61	79.6
D	.130	.489	.012	12	.73	96.0

[a] α = m.e.D/m.e. (D + H) in benzoic acid. Calculated, for complete exchange of five hydrogen atoms; α, 0.76.

An attempt was made to determine the relative rates of appearance of the *o*-, *m*- and *p*-monodeuterated species by examining the infrared spectra at early stages in the exchange reaction of sodium benzoate in comparison with the spectra of synthetic samples of the monodeuterated benzoic acid.[8] At 0.15% reaction (sample A of Table II) the only detectable change in spectrum as compared with normal benzoic acid is a weak and unresolved peak at 779 cm.$^{-1}$.[9] Pure *o*-deuteriobenzoic acid shows a peak at this wave length, so also does *p*-deuteriobenzoic acid but with one-third the intensity. The latter compound shows a strong peak at 878 cm.$^{-1}$ which is not seen in sample A and it is concluded that the initial rate of exchange is higher with the *o*-position than with the *m*- and *p*- positions.

At 7.5% reaction, the occurrence of peaks at 693 (shoulder), 770 (shoulder), 779 and 878 (both strong) and 1140 cm.$^{-1}$ (shoulder) indicates the presence of both the *o*- and *m*-deuterio species; the observations are inconclusive with respect to the possible presence of the *p*-deuterated acid.

The infrared spectrum of a sample of benzoic acid, deuterated by catalytic equilibration with diluted heavy water at a level calculated to furnish benzoic acid containing 1.54 ring D atoms per molecule, was compared with a material, containing 1.80 ring D atoms per molecule, which was synthesized from randomly labeled benzene.[10] The complete correspondence of all peaks further confirms the presence of all possible species in the acid prepared by direct exchange. In the case of aniline, deuterated by platinum-catalyzed exchange, the uniformity of ring-deuteration is indicated by the retention of 40% of the deuterium upon conversion to the tribromo derivative.

Our results are considered to be generally consistent with the theory of Lauer and Errede[6] to the extent that the exchange and the orientation effects appear to depend upon the geometrical and other factors that would affect attachment of the molecule at a catalytic surface. Thus the adsorption of benzoate ion on the catalyst surface through the carboxyl group evidently places the *o*-positions favorably, but with trimesic acid strong

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[8] We are indebted to G. V. D. Tiers for making these samples available to us. All infrared spectra were performed on a Perkin and Elmer, model 21 instrument. The reference bands for *ortho*, *meta* and *para* species in KBr agreed with the values in solution reported by Tiers and Tiers (G. V. D. Tiers and J. H. Tiers, *J. Chem. Phys.*, **20**, 761 (1952)).

[9] The infrared spectra are reproduced in full elsewhere (Semiannual Report, Argonne Cancer Research Hospital, University of Chicago, September, 1956, p. 99 *et seq.*).

[10] This material was synthesized from benzene, deuterated by the sulfuric acid exchange method, by John F. Neumer.

attachment through all three carboxyl groups must prevent contact of the ortho hydrogens with active sites.

The exchange of side-chain hydrogen atoms observed by Tiers in toluene and by Bonner in phenylacetamide, and the lack of exchange in the aliphatic C–H groups of isopropyl benzoate, are the results to be expected in view of the demonstration by Fukushima and Gallagher[11] that the exchange at saturated carbon atoms of unsaturated steroids is confined to allylic positions.

[11] D. K. Fukushima and T. F. Gallagher, THIS JOURNAL, **77**, 139 (1955).

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[CONTRIBUTION FROM STERLING CHEMISTRY LABORATORY, YALE UNIVERSITY]

The Electron-seeking Demands of Dichlorocarbene in its Addition to Olefins

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The relative reactivity of a number of aliphatic olefins in the addition of dichlorocarbene to form dichlorocyclopropane derivatives has been determined. Reactivity increases with increasing degree of substitution in accord with the hypothesis that dichlorocarbene is an electrophilic molecule. Dibromocarbene shows similar demands complicated perhaps by a steric factor.

The novel reaction of haloform, alkoxide ion and olefins,[1] recently discovered by Doering and Hoffmann, gives 1,1-dihalocyclopropane derivatives. The question may be asked whether the hypothetical intermediate, dihalocarbene, is an electrophilic reagent. A strong affirmative answer already has been given by Hine and Dowell[2] in competition experiments where the relative rates of reaction of dichlorocarbene with chloride, bromide, hydroxide and iodide ions compared to water parallel their nucleophilicities. Skell and Garner[3] have studied the matter by allowing a variety of olefins in pairs to compete for dibromocarbene in the addition reaction. These workers analyzed the products by distillation and were able to arrange a large number of olefins in an order of reactivity which paralleled that shown in bromination and epoxidation.

Independently we carried out a similar investigation allowing dichlorocarbene to choose between olefins offered in pairs. The range of olefins was limited to the lower molecular weights so that the products would be sufficiently volatile to permit convenient analysis by vapor phase chromatography (v.p.c.). The results confirm those of Skell and Garner.

Potassium *t*-butylate is dissolved in the olefin mixture and chloroform is added dropwise at −20 to −10°. The relative quantities of the two products in the reaction mixture is determined immediately by v.p.c. analysis, sensitivity having been determined by calibration with known mixtures of pure products. These sensitivities (perhaps better described as empirical correction factors) are incorporated in the body of the Experimental section and are used to correct the raw analyses. The ratio of the reaction rates is calculated from the expression $k_a/k_b = P_aO_b/P_bO_a$ where P is the mole per cent. of the product and O is the initial mole per cent. of the olefin. Since the starting olefin concentration is about 6–7 times that of the chloroform used, even in unfavorable cases the use of this simplified equation introduces less than a 10% error. As the olefin most frequently used in the

TABLE I

RELATIVE REACTIVITIES OF OLEFINS

	Reactants			
Olefin	$:CCl_2$[a] log	$:CBr_2$[a] log	Br^+[g] log	HO^+[i] log
2,3-Dimethylbutene-2	(1.73)[d]	0.84, 0.97[e]	(1.15)	
2-Methylbutene-2	1.37	.87, .94[e]	(1.02)	0.98
Isobutylene	0.92 (0.89)[b]	.57, .43[e]	(0.74)	−0.15
2-Methylbutene-1	.74			
trans-Pentene-2	(.33)[c]			−0.14
Ethyl vinyl ether	.27			
cis-Pentene-2	.21			
Cyclohexene	.00	.00		0.00
Hexene-1	− .73	(− .71)[e,f]	(0.31)[h]	−1.42
Pentene-1	− .86 (−0.78)[b]	− .78		−1.48

[a] Measured against cyclohexene as the reference standard unless otherwise indicated. [b] Measured in competition with hexene-1 as reference. [c] Measured in competition with *cis*-pentene-2. [d] Measured in competition with 2-methylbutene-2. [e] These data are taken from Skell and Garner[3] and have been adjusted to cyclohexene as standard and are tabulated as the logarithms. [f] Measured in competition with isobutylene. [g] These are the logarithms of the "reduced velocities of bromination at −78°" relative to ethylene taken from Anantakrishnan and Venkataraman.[4] [h] Propene. Calculated from the rates of epoxidation reported by Swern,[5] and referred to cyclohexene as standard.

(*) Manuscript originally received June 7, 1957.

[1] W. von E. Doering and A. K. Hoffmann, THIS JOURNAL, **76**, 6162 (1954).

[2] J. Hine and A. M. Dowell, Jr., *ibid.*, **76**, 2688 (1954).

[3] P. S. Skell and A. Y. Garner, *ibid.*, **78**, 5430 (1956).

[4] S. V. Anantakrishnan and R. Venkataraman, *Chem. Revs.*, **33**, 27 (1943).

[5] D. Swern, *ibid.*, **45**, 1 (1949).