Finally we may point out that our figures do not only disprove this theory but that they also show that during the reaction an exchange of labeled chlorine between Cl^- and ClO_3^- or between Cl^- and ClO_4^- does not occur to an appreciable extent.

We are glad to thank the Foundation for Fundamental Research of Matter (F.O.M.) and the Netherlands Organization for Pure Research (Z.W.O.) for their support of this investigation. Thanks are also due to the personnel of the Philips' cyclotron who performed the necessary irradiations. We also wish to express our gratitude to the Technische Commissie van het Belgisch-Nederlands Cultureel Accoord, who enabled one of us (A. Van den Bosch, Laboratorium voor Physische Chemie, Rijksuniversiteit, Ghent) to take part in this investigation.

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Preparation of N-Alkyl-2-methylcyclohexylamines

BY L. E. CRAIG AND I. J. RESSA

RECEIVED FEBRUARY 2, 1953

Adkins and Cramer[1] found that N-ethylcyclohexylamine is produced in excellent yield when aniline is hydrogenated in ethanol in the presence of a nickel catalyst. This apparent nickel-catalyzed alkylation of an amine with an alcohol was subsequently confirmed[2] by heating cyclohexylamine and ethanol at 200° under hydrogen at 75 atm. and in the presence of the nickel catalyst, N-ethylcyclohexylamine being produced as the main product along with small amounts of cyclohexylamine, N,N-diethylcyclohexylamine and dicyclohexylamine. The reaction was studied as a preparative method with several amines and alcohols, but no appreciable reaction was found to occur with cyclohexylamine, methanol and isopropyl alcohol.

TABLE I

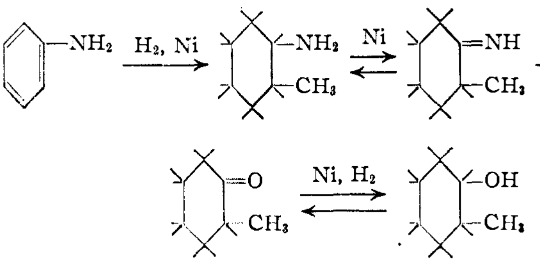
HYDROGENATIONS OF *o*-TOLUIDINE IN ALCOHOL

Alcohol	Alcohol, ml.	*o*-Toluidine, moles	Catalyst, g.	Temp., °C.	Time, hr.	Products (% yield)
CH_3OH	1000	5	50	200	29	2-Methylcyclohexanol (8.8) 2-Methylcyclohexylamine (4.8) N,2-Dimethylcyclohexylamine (6.0) *cis*- (or *trans*)-N,N,2-Trimethylcyclohexylamine (33.5) *trans*- (or *cis*)-N,N,2-Trimethylcyclohexylamine (6.5) Unreacted *o*-toluidine (7.7)
C_2H_5OH	400	2	20	180	16	2-Methylcyclohexanol (15.8) N-Ethyl-2-methylcyclohexylamine (49.1) N,N-Diethyl-2-methylcyclohexylamine (17.1)
$(CH_3)_2CHOH$	200	0.5	5	180	14	N-Isopropyl-2-methylcyclohexylamine (67.8)
n-C_4H_9OH	200	0.5	5	180	10	N-Butyl-2-methylcyclohexylamine (64.3)
$C_4H_9\overset{C_2H_5}{\overset{\vert}{C}}HCH_2OH$	500	1	30	200	9	2-Methylcyclohexylamine (35.4) N-(2-Ethylhexyl)-2-methylcyclohexylamine (14.2) Unreacted *o*-toluidine (9.9)

This paper reports the preparation of N-alkyl-2-methylcyclohexylamines in good yields by ring-hydrogenation of *o*-toluidine in various alcohols. The reaction conditions used and the products obtained are summarized in Table I; the physical properties of the novel 2-methylcyclohexylamines and derivatives are summarized in Table II. The catalyst was a commercially available nickel-on-kieselguhr catalyst, Harshaw Ni-0104T $^1/_8$''. One experiment was carried out with Raney nickel catalyst with results comparable to those with the nickel-on-kieselguhr catalyst, but no other catalysts were investigated.

The hydrogenations in methanol and ethanol produced both N-alkyl- and N,N-dialkyl-2-methylcyclohexylamines, the latter being the main product in methanol. Two isomers, undoubtedly *cis*–*trans* isomers, of N,N,2-trimethylcyclohexylamine were isolated; this is the only case where *cis*–*trans* isomers were isolated, although such isomers of all the 2-methylcyclohexylamines are possible.

The 2-methylcyclohexanol produced in hydrogenations in methanol and ethanol formed constant-boiling mixtures with certain of the amines. It was necessary to remove the 2-methylcyclohexanol before isolation and purification of the products by fractional distillation. It seems probable that the 2-methylcyclohexanol is formed from 2-methylcyclohexylamine and water by nickel-catalyzed reactions of the types



(I)

The formation of the imine is in accord with the mechanism suggested by Winans and Adkins[2] for the formation of secondary amines from primary amines in the presence of hydrogenation catalysts.

As evidence for the over-all reaction I, cyclohexylamine and water at 180° in the presence of the nickel catalyst were found to give cyclohexanol. The addition of a mutual solvent, tetrahydrofuran, was found to be beneficial, 62% of the cyclohexylamine reacting to give cyclohexanol in 84.8% yield.

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[1] H. Adkins and H. I. Cramer, THIS JOURNAL, **52**, 4349 (1930).

[2] C. F. Winans and H. Adkins, *ibid.*, **54**, 306 (1932).

TABLE II

N-ALKYL-2-METHYLCYCLOHEXYLAMINES

Compound	B.p.,[a] °C.	Mm.	n^{25}_D	d^{25}_4	M_D Calcd.	M_D Found	Carbon, % Calcd.	Carbon, % Found	Hydrogen, % Calcd.	Hydrogen, % Found	Nitrogen, % Calcd.	Nitrogen, % Found	Picrate M.p., °C.	Picrate Nitrogen, % Calcd.	Picrate Nitrogen, % Found
N,2-Dimethylcyclohexylamine	162	747	1.4525	0.8497	40.54	40.36	75.52	75.37	13.47	13.32	11.01	11.02			
cis-(or *trans*)-N,N,2-Trimethylcyclohexylamine[b]	170	748	1.4500	.8399	45.35	45.13	76.53	76.70	13.56	13.57	9.92	9.61	157–158	15.13	15.02
trans-(or *cis*)-N,N,2-Trimethylcyclohexylamine[c]	180.5	749	1.4663	.8648	45.35	45.18	76.53	76.43	13.56	13.78	9.92	9.89	210–211 (dec.)	15.13	15.13
N-Ethyl-2-methylcyclohexylamine	177.5	760	1.4504	.8421	45.35	45.04	76.53	76.48	13.56	13.45	9.92	9.93	118–120	15.13	15.03
N,N-Diethyl-2-methylcyclohexylamine	112	50	1.4420	.8227	54.74	54.66	78.00	78.22	13.71	13.54	8.28	8.40			
N-Isopropyl-2-methylcyclohexylamine	186	754	1.4440	.8266	49.78	49.80	77.41	77.39	13.55	13.72	9.03	9.11	149–151	14.58	14.59
	82.4	10													
N-Butyl-2-methylcyclohexylamine	218.4	747	1.4503	.8365	54.74	54.65	78.04	78.13	13.69	13.71	8.27	8.10	143–144	14.06	14.19
	88.2	10													
N-(2-Ethylhexyl)-2-methylcyclohexylamine	135.5	10	1.4513	.8466	72.87	71.59	79.92	79.94	13.86	13.82	6.21	6.23			

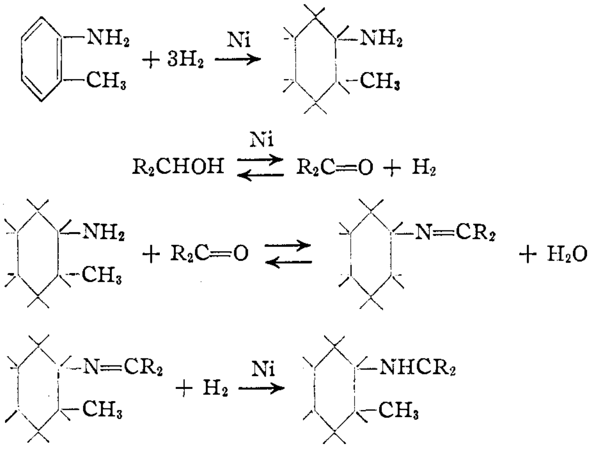
[a] All boiling points are corrected. [b] Methiodide, m.p. 218–219° (dec.). *Anal.* Calcd.: N, 4.94. Found: N, 5.08. [c] Methiodide, m.p. 238–238.5° (dec.). *Anal.* Calcd.: N, 4.94. Found: N, 5.07.

The formation of cyclohexanol in the hydrogenation of aniline was not noted by Adkins and Cramer.[1] In the work described herein, anhydrous alcohols were not used. However, a molecule of water is split out in the alkylation reaction II, and therefore water becomes available for reaction I in any case.

$$RNH_2 + R'OH \xrightarrow{Ni} RNHR' + H_2O \qquad (II)$$

Hydrogenation of *o*-toluidine in isopropyl alcohol and in *n*-butanol produced the corresponding N-alkyl-2-methylcyclohexylamine in good yield. No other products were isolated. The excess alcohol, in each of these cases, was removed at reduced pressure from the acidified reaction product and any 2-methylcyclohexanol would have been removed also. Hydrogenation in 2-ethylhexanol gave 2-methylcyclohexylamine as the main product, although some N-(2-ethylhexyl)-2-methylcyclohexylamine was produced.

The yields obtained suggest that this reaction would be an acceptable preparative method for making various substituted cyclohexylamines by hydrogenation of aromatic amines in alcohols. The reaction probably proceeds by the steps



$$R_2CHOH \overset{Ni}{\rightleftharpoons} R_2C{=}O + H_2$$

The products reported herein are in accord with those formed by reductive alkylation of amines with aldehydes and ketones.[3] That is, amines and formaldehyde readily give the tertiary amine, whereas higher aldehydes give mainly the secondary amine and ketones give only the secondary amine.

Experimental

Hydrogenation of *o*-Toluidine.—The hydrogenations summarized in Table I were carried out in an Aminco rocker-type bomb. The catalyst was Harshaw Ni-0104T 1/8″, which is a prereduced, stabilized nickel-on-kieselguhr pelleted catalyst supplied by the Harshaw Chemical Company. The *o*-toluidine, alcohol and catalyst were charged into the bomb, the bomb flushed with nitrogen and then with hydrogen, and hydrogen introduced to 2500 p.s.i.g. The temperature was raised to 180–200° with shaking, the hydrogen pressure rising to 3000–3500 p.s.i.g. In some cases it was necessary to add more hydrogen during the course of the hydrogenation. The theoretical amount of hydrogen had been absorbed in the times indicated in Table I. After cooling, the catalyst was removed by filtration and the products isolated as described below.

In the first reactions with methanol and ethanol, most of the alcohol was removed by distillation, the residue treated

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(3) R. Adams, "Organic Reactions," Vol. IV, John Wiley and Sons, Inc., New York, N. Y., 1948, p. 174.

with a large volume of water, and the mixture extracted exhaustively with low boiling petroleum ether. In the distillation of the residue from these extracts, constant-boiling azeotropes of 2-methylcyclohexanol and certain of the products were obtained. The azeotrope of 2-methylcyclohexanol and N,N,2-trimethylcyclohexylamine (about 60% 2-methylcyclohexanol) had a b.p. of 162° (736 min.) (cor.), n^{25}_{D} 1.4570, the azeotrope with N,N-diethyl-2-methylcyclohexylamine (about 40% 2-methylcyclohexanol) had a b.p. of 192° (cor.), n^{25}_{D} 1.4500. In order to avoid these azeotropes, an excess of hydrochloric acid was added to the residue from the petroleum ether extracts, the 2-methylcyclohexanol removed by steam distillation, and the amines isolated by making the solution basic, extracting, and fractionally distilling.

The higher alcohols were removed by distillation under reduced pressure after adding an excess of acid to the reaction product. The residue was then made basic, the resulting mixture extracted with ether, and the products isolated by fractional distillation. All distillations were carried out in a 6 ft. × 13 mm. Podbielniak column except the product from 2-ethylhexanol which was distilled through a 3 ft. × 13 mm. Podbielniak column. The products isolated and yields are summarized in Table I.

Cyclohexanol from Cyclohexylamine.—A mixture of 50 g. (0.5 mole) of cyclohexylamine, 200 ml. of water and 5 g. of Harshaw Ni-0104T $^1/_8''$ was placed in an Aminco bomb and, after flushing with nitrogen and venting, heated for 10 hours at 180° (no hydrogen was used). The catalyst was removed by filtration and the reaction product extracted exhaustively with low boiling petroleum ether. The extracts were dried and the solvent removed by distillation. Analysis[4] of the residue indicated that it contained 42.8% alcohol calculated as cyclohexanol, 38.6% primary amine calculated as cyclohexylamine, and 7.8% secondary amine calculated as dicyclohexylamine. This would indicate that cyclohexanol was produced in 50% yield, based on reacted cyclohexylamine.

In another experiment carried out under the same conditions, except that 100 ml. of tetrahydrofuran was added as a solvent for the reaction, analysis of the product indicated that 62% of the cyclohexylamine reacted to give cyclohexanol in 84.8% yield. Cyclohexanol was isolated by extracting an acidified aliquot of the reaction product with ether and distilling (b.p. 157–158°) (uncor.), n^{26}_{D} 1.4631[5] and further identified by its 3,5-dinitrobenzoate, m.p. 112–113°.[6]

Acknowledgment.—The authors are indebted to Mr. L. J. Lohr for the distillations and to Dr. S. Siggia and Mr. L. J. Fraunefelder for analyses.

(4) S. Siggia, J. G. Hanna and I. R. Kervenski, *Anal. Chem.*, **22**, 1295 (1950); S. Siggia and I. R. Kervenski, *ibid.*, **23**, 117 (1951).

(5) Reported b.p. 161°, K. K. Kelley, THIS JOURNAL, **51**, 1400 (1929); reported n^{25}_{D} 1.4642, G. S. Hiers and R. Adams, *ibid.*, **48**, 2385 (1926).

(6) Reported m.p. 112–113°, T. Reichstein, *Helv. Chim. Acta*, **9**, 799 (1926).

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Oxidations with Ruthenium Tetroxide

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RECEIVED APRIL 4, 1953

Osmium tetroxide has been used widely in organic chemistry as a catalyst in oxidations[2] and particularly for the hydroxylation[3] of olefins. The latter reaction is usually carried out by mixing stoichiometric quantities of the olefin and osmium tetroxide in an inert solvent such as ether, with or without traces of pyridine, and proceeds in good yield to the corresponding *cis*-glycol *via* a cyclic osmate ester which has to be cleaved.[3] Osmium tetroxide is expensive and very poisonous, and it seemed of interest, therefore, to investigate the behavior of the corresponding ruthenium derivative, since ruthenium appears immediately above osmium in the periodic table. Ruthenium tetroxide has been prepared a number of times,[4] but its behavior toward organic compounds has not been investigated except for the observation[4] that it is reduced rapidly by alcohol, acetaldehyde and the like. Ruthenium is more readily available than osmium and there exist *a priori* two reasons why ruthenium tetroxide might be preferred to the osmium analog. Although its vapors cause irritation when inhaled, it is not poisonous to the eyes[4,5] in contrast to this very serious danger with osmium tetroxide. Furthermore, recovery problems are simplified by the fact that combustion of ruthenium dioxide in air will not yield the volatile tetroxide in contrast to the analogous osmium derivative and organic impurities can thus be removed readily. In view of the fact that the present investigation had to be interrupted,[1] we should like to report briefly our observations on the behavior of ruthenium tetroxide with some organic compounds.

The much greater oxidizing action of ruthenium tetroxide as compared to osmium tetroxide was already demonstrated in initial qualitative experiments when a search was made for suitable solvents in which the oxidations could be conducted. Thus ether, benzene and pyridine, solvents which have been found very useful in the case of osmium tetroxide,[3] reacted violently and instantaneously with ruthenium tetroxide and thus proved completely useless. Of the common organic solvents, only carbon tetrachloride and chloroform were satisfactory[6] and the former was employed throughout our experiments. In view of the very high vapor pressure of ruthenium tetroxide, the solid usually has to be stored over potassium hydroxide in an ice cooled desiccator and it was found advantageous, therefore, to keep the reagent in carbon tetrachloride solution in which it was stable for a period of over one year. The ruthenium tetroxide content was established readily in an aliquot portion by reduction with an organic compound to the insoluble solvated ruthenium dioxide and reduction of the latter with hydrogen to ruthenium metal which could be weighed.

Since phenanthrene reacts slowly (2–7 days) with osmium tetroxide[3] in benzene solution to afford in good yield the osmate ester which upon cleavage leads to the crystalline 9,10-dihydrophenanthrene-9,10-diol, this example was selected first for comparison purposes. When a carbon tetrachloride solution of ruthenium tetroxide was added to an ice-cold solution of phenanthrene, a black pre-

(1) American Platinum Works Predoctoral Fellow at Wayne University, 1952.

(2) *Inter al.*, K. A. Hofmann, *Ber.*, **45**, 3329 (1912); N. A. Milas and S. Sussman, THIS JOURNAL, **58**, 1302 (1936).

(3) *Cf.* R. Criegee, *Ann.*, **522**, 75 (1936); R. Criegee, B. Marchand and H. Wannowius, *ibid.*, **550**, 99 (1942).

(4) First prepared by C. Claus, *J. prakt. Chem.*, **79**, 28 (1860); the most recent reference is that by F. S. Martin, *J. Chem. Soc.*, 2683, 3055 (1952).

(5) W. M. Latimer and J. H. Hildebrand, "Reference Book of Inorganic Chemistry," The Macmillan Co., New York, N. Y., 1940, p. 418.

(6) This observation was also made by Martin (ref. 4) who measured the partition coefficient of ruthenium tetroxide between water and carbon tetrachloride and found it to be 59 in favor of the latter.