before use and had appropriate physical properties. Pentyne, hexyne, and heptyne were purchased from Farchan Research Laboratories and were used without further purification. Pyridine was reagent grade, purchased from Merck, stored over solid potassium hydroxide and distilled before use. All solutions in pyridine were made up in an atmosphere of CO_2-free nitrogen. Carbon tetrachloride was analytical reagent grade, purchased from Mallinckrodt, and used without further purification. Tetramethylsilane was a gift of Minnesota Mining and Manufacturing Co.

N.m.r. spectra were obtained on Varian model 4300B and 4311 high-resolution spectrometers operating at 40.000 and 56.442 megacycles, respectively. Side-band frequencies accurate to ±0.1 c.p.s. were read from a Hewlett-Packard counter. The τ-values in Table I were obtained by interpolation and are reproducible with a precision of ±0.02 p.p.m. Sweep rates were approximately 3 c.p.s. per sec.

Near infrared spectra of phenylacetylene–pyridine–carbon tetrachloride mixtures were obtained on a Beckman DK-2 spectrophotometer equipped with a quartz prism and a germanium filter to remove stray light of higher frequency. The photometric accuracy of this machine was determined by verifying Beer's law with known solutions. It was found to be about ±0.5% at optical densities around 1.0. The resolution and frequency accuracy were studied by examining the spectrum of ammonia vapor in the region around 3300 cm.$^{-1}$. Frequencies of sharp bands were found to be reproducible with a precision of ±1 cm.$^{-1}$; but the resolution, as judged by the height and shape of the bands, was not good.

Acknowledgment.—We are pleased to acknowledge the financial support of the du Pont Co. through grant-in-aid, and also that of the Graduate School of the University of Minnesota. We are greatly indebted to Dr. G. V. D. Tiers and Mr. G. Filipovich of the Minnesota Mining and Manufacturing Co. for their help in obtaining and interpreting n.m.r. spectra, and to Dr. Tiers, also, for a helpful discussion of this manuscript.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, VANDERBILT UNIVERSITY, NASHVILLE 5, TENN.]

Isomerization of Aldoximes to Amides under Substantially Neutral Conditions[1]

BY LAMAR FIELD, PATRICIA BARNETT HUGHMARK, SUSAN HOLROYD SHUMAKER AND W. STANLEY MARSHALL

RECEIVED NOVEMBER 21, 1960

Ten aldoximes were isomerized to amides in good yields, according to the equation $RCH{=}NOH \rightarrow RCONH_2$. Reaction was effected by heating the oxime in a solvent with as little as 0.2 mol. % of nickel acetate tetrahydrate as a catalyst. Generality was demonstrated by applying the reaction to a saturated and to an unsaturated acid-sensitive aliphatic oxime and to aromatic aldoximes; the aromatic oximes could contain electron-donating or -withdrawing substituents, even though certain of these were in the *ortho* position and others lend sensitivity toward acidic catalysts. The reaction was unsatisfactory only with 2,4-dihydroxybenzaldoxime and with 9-anthraldoxime (which gave the nitrile). Isomerization of aldoximes with small amounts of nickel acetate thus affords a promising means of characterizing oily oximes and of converting aldehydes to amides, under substantially neutral conditions. Isomerization can be effected also with certain other compounds of metals and with nickel.

While studying the hydrogenation of aldoximes with Raney nickel as catalyst, Paul found that amides were formed.[2] Using several aldoximes, he was able to show that the form ordinarily available could be isomerized effectively to a single amide, with Raney nickel as catalyst, according to the equation $RCH{=}NOH \rightarrow RCONH_2$. Ketoximes did not react. More recently, he isomerized furfuraldoxime also with a nickel–boron catalyst.[3] Amides result in low yield in hydrogenation of certain oximes with reduced copper at 200° but, since ketoximes react, the isomerization probably differs from that of Paul.[4]

Reactions of this type have not attracted the attention they merit from both the standpoint of their theoretical interest and their promise for synthesis and characterization. Only Caldwell and Jones have capitalized on them, in isomerizing some oily unsaturated oximes to solid amides.[5] Our interest was attracted to such reactions because of the obvious applications of this simple means of isomerizing aldoximes to amides under substantially neutral conditions.

In our hands, reaction of benzaldoxime with Raney nickel in a number of experiments gave no worse than fair results and frequently quite good ones. Nevertheless, the number of variables inherent in the heterogeneous bulk reaction of an oxime and a metal clearly will lead to difficulty in obtaining reproducibly good results; some of these variables are suggested parenthetically in the description in the Experimental of a process based on Paul's. Furthermore, often there is some inconvenience in obtaining Raney nickel of standard activity. In an effort to improve the utility of the isomerization, we sought first to determine the most effective catalyst and next to use the most promising in a homogeneous mixture.

A reasonably reproducible procedure was developed for isomerizing benzaldoxime to benzamide with nickel and then was used for evaluating other possible catalysts. Table I shows that several substances effectively catalyze this isomerization. Other substances tried gave only highly colored oils which did not crystallize in 2–3 months. These included ferric chloride and ferric oxide, cobaltous carbonate, anhydrous cobaltous chloride and cupric chloride, silver oxide, yellow mercuric oxide, and iron powder ("by reduction"); cupric acetate monohydrate gave pale blue solid with an m.p. exceeding 235°.

[1] Based on the M.A. Thesis of Patricia Barnett, June, 1956, the M.S. Thesis of Susan Holroyd, June, 1960, and the A.B. Honors Research of W.S.M. We wish to thank Professors D. E. Pearson and M. M. Jones for helpful suggestions.

[2] R. Paul, (a) *Compt. rend.*, **204**, 363 (1937); (b) *Bull. soc. chim. France*, [5] **4**, 1115 (1937).

[3] R. Paul, *Ind. Eng. Chem.*, **44**, 1006 (1952).

[4] S. Yamaguchi, *Bull. Chem. Soc. Japan*, **1**, 35 (1926) [*C. A.*, **21**, 75 (1927)]; *Mem. Coll. Sci. Kyoto Imp. Univ.*, **9A**, 33 (1925) [*C. A.*, **19**, 3261 (1925)].

[5] A. G. Caldwell and E. R. H. Jones, *J. Chem. Soc.*, 599 (1946).

TABLE I

POTENTIAL CATALYSTS FOR ISOMERIZATION OF BENZALDOXIME TO BENZAMIDE

Potential catalyst	Temperature,[a] °C. Of exothermic reaction	Of heating for 1 hr.	Yield, %	M.p., °C.
Nickel acetate (tetrahydrate)	[b]	185–190	75	126–128
Nickel carbonate	164–240	184–189	72	126.5–128
Raney nickel	[b]	180–185	58–63[c]	124.5–128[c]
Cupric oxide	102–236	120–125	60	126–127.5
Basic cupric carbonate[d]	86–160	106–111	56	126–128
Nickel metal, powd.	185–245	205–210	53	125–128
Nickelous oxide	190–234	210–215	24	124–126.5
Cobaltic oxide	186–203	205–210	23	123–126

[a] Legends related to temperature are explained in the Experimental. [b] No exothermic reaction observed in this instance. [c] Range for 3 experiments. [d] $CuCO_3 \cdot Cu(OH)_2$.

The results of Table I suggest that benzaldoxime can form a necessary intermediary complex ion with the catalyst only if the oxime can react as an acid. Hence, certain metals, their oxides or weak-acid salts may suffice, but a salt of a strong acid (cupric chloride) does not.

Many of the reactions performed to this point gave small amounts of a high melting solid. Elementary analysis, hydrolysis and identity with authentic material showed this substance to be N,N′-benzylidene-bis-benzamide, $C_6H_5CH(NHCOC_6H_5)_2$. It presumably resulted from condensation of benzamide with the oxime, or with benzaldehyde, which Paul suggested may form along with ammonia and nitrogen from decomposition of the oxime.[2]

Of the possibilities presented by the results of Table I, nickel acetate (tetrahydrate) seemed most promising. The use of this catalyst in a homogeneous liquid system next was considered, since reaction of nickel acetate and an oxime in bulk no doubt would be subject to the erratic behavior and difficulty of control experienced with Raney nickel.

Catalysis by a metal salt of isomerization of an aldoxime to an amide appears to have been observed first by Comstock, who found that benzamide resulted when benzaldoxime and cuprous chloride were heated in benzene or toluene.[6] Comstock's isomerization was not general and the aldehyde often was the principal product.

Subsequently, Bryson and Dwyer observed isomerization of furfuraldoxime to furamide during a study of coördination compounds of the oxime with salts of nickel and other metals.[7] Evidently interested chiefly in the inorganic aspects of the reaction, Bryson and Dwyer did not explore synthetic possibilities, but did state that 0.2 g. of oxime gave 0.1 g. of amide. Their comprehensive study of the complex metallic derivatives involved in the process showed that tris-furfuraldoxime nickel could decompose to the bis compound and furamide, and that a bis compound could catalyze isomerization of the oxime *via* transformation to a tetrakis compound which decomposed to furamide and the bis compound. Bryson and Dwyer suggested that the reaction is a "*trans* Beckmann rearrangement." Since usually only β-aldoximes form coördination compounds with metallic salts, they considered that an α-oxime isomerized to the β-form as a preliminary to formation of an amide.

In our search for a liquid system for use with nickel acetate, preliminary experiments showed xylene to be satisfactory. Its use is convenient because amides usually crystallize nicely from it. Changes in the volume of solvent seemed to have little effect. Relatively large amounts of nickel acetate were used at the outset, but the amount was reduced when most had to be removed before crystallization of the amide and when too much catalyst actually appeared to be deleterious. The essential role of the catalyst was proved by failure to isolate any amide in its absence. It is noteworthy that as little as 0.2 mol. % of catalyst resulted in amide in 67% yield, although about 2 mol. % seemed optimum. Ordinarily, five hours was allowed for reaction.

Not all of these features were incorporated in the first determinations of the generality of the isomerization with nickel acetate. In Table II, which demonstrates the generality, an early procedure is referred to as procedure B. Procedure A, ultimately developed, is simpler and more economical. It probably can be substituted for B, but procedure B is specified in Table II and described in the Experimental since A and B may not always be interchangeable.

A little piperidine is used in procedure A because it effected improvement with *m*-nitrobenzaldoxime. The piperidine may act either by converting the oxime to a more nucleophilic anion which forms a coördination compound more readily, or by catalyzing conversion to amide of an intermediary coördination compound; Bryson and Dwyer used weak bases in formation and conversion of their nickel–oxime coördination compounds.[7]

With *p*-hydroxybenzaldoxime, procedure B produced amide in only 20% yield (Cellosolve as solvent resulted in 12%). In water, however, amide was obtained in 60% yield. Procedure C, with water as solvent, therefore is included in the Experimental.

Procedure C gave poorer results than A with benzaldoxime (use of less catalyst than specified in procedure C may have been a partial cause). Procedure C unexpectedly gave poorer results than A with salicylaldoxime also, probably because of adverse chelation effects as well as a reduced amount of catalyst. Since salicylaldoxime probably does not typify water-soluble aldoximes, however, we are inclined to suggest procedure A for oximes soluble in xylene but sparingly so in water and procedure C for oximes rather soluble in water. Procedure B may be advantageous if piperidine is undesirable for some reason with oximes which otherwise seem adapted to procedure A.

Table II shows that isomerization of aldoximes to amides is quite general. Thus, reaction succeeded with two aliphatic oximes, one of which is unsaturated. Caldwell and Jones obtained an amide from citronellaloxime in 50% yield.[5] The yield of 71% obtained with nickel acetate suggests that

---

(6) W. J. Comstock, *Am. Chem. J.*, **19**, 485 (1897).

(7) A. Bryson and F. P. Dwyer, *J. Roy. Soc. N. S. Wales*, **74**, 455, 471 (1940).

TABLE II

ISOMERIZATION OF ALDOXIMES TO AMIDES USING NICKEL ACETATE TETRAHYDRATE

Aldehyde used for oxime	M.p., °C. (n^{25}_{D}) of oxime	Procedure	Crude amide Yield, %	Crude amide M.p., °C.	Crude amide Solv. for recrystn.[a]	First crop, recrystd. Yield, %	First crop, recrystd. M.p., °C.	M.p. reported °C.[b]	Yield, all recrystd. crops, %
Acetaldehyde	42–43	B[c]			B	73	80–81[d]	81	
Citronellal	(1.4720)	A[e]	71	79.5–80.5	HP(2:1)	46	82–83	84–85	62
Benzaldehyde	28–33	A[f]			B	86	127.5–129[d]	128	91
		C[g]	68		B	44	123–126.5		
p-Hydroxybenzaldehyde	74–75	C[h]	60	161–162				162	
		B	20	159.5–160.5					
Salicylaldehyde	60–61	A[f]			B	60	136.5–138.5	139–140	
		C[i]	21	131.5–134.5					
Piperonal	105–107	A	90	159.5–163	W	76	167–168.5	169	81
p-Dimethylaminobenzaldehyde	141.5–143	A[j]	95	191.5–203	BE(1:1)	66	208–209	207–208	83
o-Chlorobenzaldehyde	74–75	A	86[k]	137.5–139.5	B	69	142–143.5	142	76
m-Nitrobenzaldehyde	121–122	B[l]	79	139 5–142	EW	74	141.5–142.5	142–143	
p-Nitrobenzaldehyde	132–133	B[m]			EW	63	200.5–201.5	201.5	

[a] B, benzene; E, 95% ethanol; H, hexane; P, pentane; W, water.

[b] Taken mostly from standard references.

[c] Modified. Oxime (0.084 mole) and 0.90 g. of catalyst were heated in 150 ml. of xylene at reflux for 15 hr. "Crude amide" was obtained by cooling and filtration and repeating this process after removal of most of the xylene.

[d] Undepressed by an authentic sample.

[e] No amide appeared when the xylene solution was cooled. All but 3–4 ml. of solvent was removed (reduced pressure) and "crude amide" then was obtained by filtration.

[f] *Ca.* 45 ml. of xylene was removed by distillation before collection of "crude amide" to improve the yield.

[g] Modified. Oxime (0.05 mole) and 0.3 g. of catalyst were heated in 50 ml. of boiling water for 15 hr.; the organic phase was extracted with ether, dried, and concentrated. Use of more catalyst might improve the yield.

[h] When 1 g. of oxime and 1.8 g. of catalyst were heated in 15 ml. of boiling water for 14 hr., recrystallization of combined crops of "crude amide" gave *p*-hydroxybenzamide in 65% yield, m.p. 161–162°.

[i] Modified. Oxime (0.05 mole), 1 ml. of piperidine and 0.25 g. of catalyst were heated in 50 ml. of boiling water for 5 hr. Oily product was extracted (ether) and crystallized after drying and removal of solvent. Use of more catalyst might improve the yield.

[j] Reaction was incomplete after 5 hr. (m.p. of an evaporated aliquot, 121–125°). The mixture therefore was heated for 5 hr. more before collection of "crude amide."

[k] Includes a second crop of 10%, m.p. 138–141.5°, obtained after removing 20 ml. of xylene from the mother liquor.

[l] A similar experiment but with addition of 1 ml. of piperidine (and slightly more catalyst[m]) resulted in a crude yield of 93%, m.p. range (all crops) 134–140°; recrystallization of combined crops gave 85%, m.p. 142–143°.

[m] Second portion of catalyst, 0.9 g. rather than 0.45 g.

this catalyst may have an advantage in yield relative to Raney nickel, as well as in other features already mentioned. The reaction succeeded also with aromatic aldoximes substituted with either electron-donating or -withdrawing substituents, even though the substituent is in a hindering *ortho* position.

Aldoximes have been isomerized to amides by means of acidic catalysts. Various aliphatic aldoximes with phosphorus pentachloride gave both of the amides one might anticipate from a conventional Beckmann rearrangement, one being a substituted formamide.[8] An aldoxime may be effectively converted to an amide by polyphosphoric acid (*n*-heptaldoxime to *n*-heptamide in 92% yield), but not invariably (benzaldoxime to benzamide in 25–40% yield, depending on whether *syn*- or *anti*-oxime was used).[9] A hot solution of boron trifluoride in acetic acid converts both *syn*- and *anti*-*p*-chlorobenzaldoxime to *p*-chlorobenzamide in 95–99% yield, the *syn*-oxime presumably isomerizing to the *anti* which is transformed into the amide.[10] Boron trifluoride in acetic acid converted various aldoximes into amides in excellent yields. Only tar resulted with piperonaldoxime, however. The probable value of nickel acetate in isomerizing acid-sensitive aldoximes, suggested in the instance of citronellaloxime, was confirmed by isomerization of piperonaldoxime in 90% yield.

The attempt to isomerize salicylaldoxime (Table II) was of interest because of the possibility that *o*-hydroxyl might typify groups which could interfere with normal conversion to an amide by adverse chelation in the presumed intermediary nickel coördination compound. Fortunately, the reaction occurred fairly satisfactorily, although a somewhat low yield (especially in water) suggests that chelation effects may not be insignificant. Boron trifluoride in acetic acid produced salicylamide in 47% yield.[10]

In two instances of those cited in Table II, identity of the amide was established by mixture m.p.; in the others, presumption of identity is reasonable from the agreement of melting points with reported values.

Only two aldoximes gave unsatisfactory results in attempts to isomerize them to the amide with nickel acetate. 9-Anthraldoxime gave at most trace amounts of the amide. The major product was 9-cyanoanthracene (43%), as evidenced by the infrared spectrum and identity with presumably authentic material. 2,4-Dihydroxybenzaldoxime, submitted to procedure A, except with water instead of xylene as solvent (either 5 or 15 hr.), gave only an intractable mixture.

Hoffenberg and Hauser suggested that isomerization of aldoximes with boron trifluoride in acetic acid might proceed in part by dehydration of the oxime to the nitrile, which subsequently was hydrolyzed.[10] It was of interest, therefore, to determine whether this pathway was likely to be im-

---

(8) W. R. Dunstan and T. S. Dymond, *J. Chem. Soc.*, **65**, 206 (1894).

(9) E. C. Horning and V. L. Stromberg, *J. Am. Chem. Soc.*, **74**, 5151 (1952); *anti*-benzaldoxime hydrochloride gave amide in 80% yield.

(10) D. S. Hoffenberg and C. R. Hauser, *J. Org. Chem.*, **20**, 1496 (1955).

portant in the reaction with nickel acetate. Accordingly, nickel acetate tetrahydrate was heated in distilling xylene until no more water was removed. Benzaldoxime then was added and removal of water continued. Under these conditions, presence of water in sufficient concentration for sufficient time to effect hydrolysis of a nitrile is quite unlikely. Isolation of benzamide in 64% yield thus strongly suggests that a nitrile is not involved and, by implication, that a nickel–oxime complex isomerizes directly (the rather low yield in this experiment can be attributed to volatilization of acetic acid, apparently necessary for proper reaction, along with the water). Bryson and Dwyer found no furonitrile in their study of furfuraldoxime and concluded that it was not involved in their isomerization.[7]

In the various isomerizations described, the oxime was used as commonly obtained. No attempt was made to delineate composition in terms of *syn, anti* isomers because of the probable important but unknown influence of the conditions used in changing the composition during the reaction.

Experimental[11]

Oximes.—According to the procedure of Pearson and Bruton for ketoximes,[12] a cold solution of sodium hydroxide (1.5 moles) in water (180 ml.) was added to hydroxylamine hydrochloride (2 moles) in water (300 ml.). Aldehyde (1 mole) was added slowly, then enough ethanol for homogeneity at the b.p. After 1 hr. of reflux, followed by cooling, solids were separated by filtration and oils by removing ethanol, extracting with ether or benzene, and distilling.

Isomerizations of Benzaldoxime in Absence of Solvents. (a) With Raney Nickel.—In initial experiments resembling some of Paul,[2] the water of a commercial Raney nickel (Raney Catalyst Co., Chattanooga, Tenn.) was replaced with absolute ethanol by decantation, and 1 ml. of nickel suspension was taken as 0.6 g. Benzamide was extracted from reaction mixtures with ethanol.

After 7 months at 25°, 3.33 g. of oxime and 0.5 g. of nickel gave benzamide in 83% yield, m.p. 125–128°; after 2 weeks, only an oil was isolated. After many preliminary experiments, the best procedure for effecting rearrangement reproducibly in a short time seemed to be to heat 1 g. (0.017 g. atom) of nickel and 6.1 g. (0.05 mole) of oxime with stirring under reflux (a water condenser was better than an air condenser) in an oil-bath, so that the bath temperature increased *ca.* 3°/min. When the temperature of the mixture reached 160° (exothermic reaction[2] occurred, if at all, at *ca.* 160°), it was increased quickly to 180° (at *ca.* 195° lower yields of less pure product resulted) and was there maintained for 1 hr.; benzamide was extracted in 77% yield, m.p. 120–126°. Although yield and purity of the amide were influenced by numerous factors, the procedure simply of heating an oxime with Raney nickel probably often will succeed fairly well; thus in 18 experiments, yields of 53–83% were obtained, with the poorest m.p. range being 93–115°.

(b) With Other Inorganic Catalysts.—Potential catalysts were evaluated essentially by generalizing the procedure of (a). Benzaldoxime (0.05 mole) and the catalyst (0.017 mole) were heated in an oil-bath. The bath temperature was increased at 3°/min. until the temperature of the mixture exceeded that of the bath (reaction usually at 70–190°, if at all). The bath was removed and reaction allowed to continue until the temperature had dropped to that at which exothermic reaction first began; the first temperature of the "Temperature of exothermic reaction" (Table I) refers to the temperature at which exothermic reaction began and the second refers to the maximum temperature attained by the mixture while heat was evolved. The mixture then was heated for 1 hr. at 20–25° above the temperature at which exothermic reaction had begun (see Table I). If no exothermic reaction occurred, the mixture was simply heated at *ca.* 190–200° (temp. of mixture) for 1 hr. Results appear in Table I in decreasing order of effectiveness.

(c) **Isolation of N,N'-Benzylidene-bis-benzamide.**—In 7 of 37 reactions summarized under (a) and (b), small amounts of high melting sparingly soluble solid resulted. These identical products (mixture m.p.), combined and recrystallized, gave colorless needles with a constant m.p. of 225.5–227°.

Anal. Calcd. for $C_{21}H_{18}N_2O_2$: C, 76.34; H, 5.49; N, 8.48. Found: C, 76.47; H, 5.66; N, 8.03.

Hydrolysis gave benzoic acid (m.p. 118–121°). An authentic sample,[13] m.p. 226–228.5°, did not depress the m.p.

Isomerizations of Benzaldoxime with Nickel Acetate in Xylene. (a) Variation in the Amount of Nickel Acetate.—Nickel acetate tetrahydrate was heated with benzaldoxime (0.05 mole) for 5 hr. in refluxing xylene (50 ml.; a saturated solution of catalyst contained *ca.* 0.3 g.). Results are given in Table III. The reaction solution usually was green until reaction was complete and then became light yellow or light brown, suggesting that if the green color persists in extensions of the reaction, refluxing should be continued.

TABLE III

RELATION BETWEEN YIELD OF BENZAMIDE AND AMOUNT OF NICKEL ACETATE TETRAHYDRATE

Mmoles of nickel acetate tetrahydrate	Catalyst, mol. %[a]	Yield, %	M.p., °C.
2.8	5.6	77	124–127.5
1.2	2.4	87	125–128
0.6	1.2	87	123–128
0.12	0.2	67[b]	127–128
0.026	0.05	0[c]	.....

[a] The term mol. % for present purposes is defined as (no. of moles of catalyst/no. of moles of oxime) 100. [b] Other less pure crops, 3%. [c] Exact repetition, but without catalyst, of another reaction which had given amide in 83% yield also resulted in no amide.

(b) Other Variations.—With 2.8 mmoles of catalyst in the procedure of (a), reduction in the volume of xylene by one-half had negligible effect (81%, m.p. 125–127.5°). With 1.2 mmoles of catalyst, reduction in the time of reflux by one-half reduced the yield (74%, m.p. 125–128°) and doubling it had little effect (84%, m.p. 125–127.5°).

(c) Isomerization with Removal of Water.—Nickel acetate tetrahydrate (0.7 g., 3 mmoles) was heated in 40 ml. of vigorously refluxing xylene until no more water seemed to be trapped in a Dean–Stark tube (1 hr.). Oxime (0.05 mole) in 10 ml. of xylene then was added and vigorous reflux was continued, with vigorous stirring, for 5 hr. Water distilled, especially during the first 2 hr.; the distillate contained acetic acid. Benzamide resulted in 64% yield after recrystallization (m.p. 124–128°); a similar experiment gave a yield of 65%.

Preferred Methods of Isomerization.—Variations from standard procedures, sometimes made because of special properties of the various representative substances involved, are described in footnotes to Table II for possible application in other situations.

(a) **Procedure A.**—A mixture of 0.1 mole of the aldoxime, 0.498 g. (2 mmoles, 2 mol. %) of finely ground nickel acetate tetrahydrate and 2 ml. of piperidine in 60 ml. of xylene was stirred and heated at the reflux temperature for 5 hr. and then was allowed to cool to room temperature (occasionally, as noted in Table II, part of the solvent was distilled to improve the yield). "Crude amide," with the yield and m.p. given in Table II, then was separated by filtration. Recrystallization gave a "first crop" and such subsequent crops as seemed worth collecting; "yield, all recrystd. crops" refers to the total amount thus collected.

When 9-anthraldoxime was submitted essentially to procedure A, 9-cyanoanthracene resulted in 43% yield,

---

[11] Melting points are corrected and boiling points are uncorrected. Analyses were by Galbraith Laboratories, Knoxville, Tenn., and Micro-Tech Laboratories, Skokie, Ill. "Xylene" refers to an ordinary grade of *p*-xylene.

[12] D. E. Pearson and J. D. Bruton, *J. Org. Chem.*, **19**, 957 (1954).

[13] E. Hoffmann and V. Meyer, *Ber.*, **25**, 212 (1892).

m.p. 185–190° (depressed by the oxime). Recrystallization gave nitrile with a constant m.p. of 179.5–180°, which did not depress the m.p. of an authentic sample[14] and had an identical infrared spectrum (absorption at 2222 cm.$^{-1}$).

(b) **Procedure B.**—The aldoxime (0.05 mole) and nickel acetate tetrahydrate (0.90 g., 3.6 mmoles, 7 mol. %) were stirred in 150 ml. of xylene at the reflux temperature for 5 hr., after which the mixture was filtered while hot, if solid was present. The mixture then was cooled and amide which crystallized was removed. More catalyst (0.45 g.) was added to the filtrate and heating with stirring was continued for 10 hours (sometimes it was convenient to remove amide after 5 hr. of this period). The mixture then was concentrated to *ca.* 50 ml. and amide which separated was removed. The combined crops ("Crude amide") were recrystallized.

(c) **Procedure C.**—A mixture of 0.12 mole of aldoxime and 1.80 g. (7.2 mmoles, 6 mol. %) of nickel acetate tetrahydrate in 150 ml. of water was heated at the reflux temperature for 5 hr. Solid which appeared on cooling was removed; the filtrate was heated for 17 hr. more and then was concentrated in stages until further crops of amide seemed unlikely. All crops then were combined and recrystallized if necessary.

---

[14] J. S. Meek and J. R. Dann, *J. Am. Chem. Soc.*, **77**, 6677 (1955).

[CONTRIBUTION NO. 2646 FROM THE GATES AND CRELLIN LABORATORIES OF CHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, CALIF., AND THE DEPARTMENT OF CHEMISTRY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY CAMBRIDGE 39, MASS.]

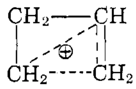
Small-Ring Compounds. XXXIII. A Study by Nuclear Magnetic Resonance of the Extent of Isotope-position Rearrangement in the Vapor-phase Photochlorination of *methyl*-^{13}C-Cyclopropane[1]

BY E. RENK, PAUL R. SHAFER,[2] W. H. GRAHAM, R. H. MAZUR AND JOHN D. ROBERTS

RECEIVED DECEMBER 14, 1960

Vapor-phase photochlorination of *methyl*-^{13}C-cyclopropane was found to yield cyclopropylcarbinyl-α-^{13}C chloride and allyl-γ-^{13}C-carbinyl chloride. Within the experimental error of the analytical method (nuclear magnetic resonance spectroscopy), no other ^{13}C-position isomers of the chlorides were formed.

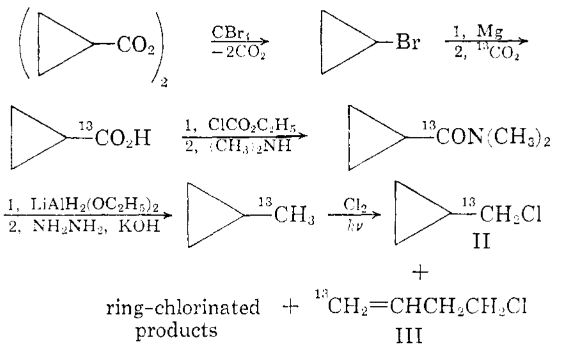
Very considerable isotope-position rearrangement attends carbonium ion-type reactions of isotopically labeled cyclopropylcarbinyl and cyclobutyl derivatives.[3] These rearrangements seem best accounted for by assuming that rapidly equilibrating non-classical cationic intermediates are involved, such as I.[3b−e]



I

It is of considerable theoretical and practical importance to know whether or not similar intermediates and rearrangements occur in the interconversion[4] of cyclopropylcarbinyl and allylcarbinyl derivatives in reactions generally considered to proceed by way of free-radical and carbanion mechanisms. A typical free-radical reaction of interest in this connection is the vapor-phase photochlorination of methylcyclopropane, which yields roughly equal quantities of cyclopropylcarbinyl and allylcarbinyl chlorides along with lesser amounts of ring-chlorinated products.[4a] Some preliminary results on the photochlorination of *methyl*-^{14}C-cyclopropane[5] indicated that the cyclopropylcarbinyl and allylcarbinyl chlorides might have been formed with considerable shuffling of ^{14}C. However, the work was very much hampered by the lack of a suitable method to locate ^{14}C in cyclopropylcarbinyl chloride without incurring risk of additional isotope-position rearrangement. With the advent of n.m.r. spectroscopy, it has become possible to study isotope-position rearrangements in compounds of this type using ^{13}C or ^{2}H as tracers[2c,4b] without need for chemical degradation. In the present study of the chlorination of methylcyclopropane, ^{13}C was chosen as the tracer since the ^{2}H might be expected to lead to large kinetic isotope effects on the chlorination reaction, which could seriously change the product ratios.

The reactions used and the results of this study follow.



The chlorination products were separated by preparative vapor-phase chromatography (v.p.c.) and the positions of the ^{13}C determined by analysis of the effect of the ^{13}C on the proton spectra (Fig. 1)

---

[1] Supported in part by the Office of Naval Research, the Petroleum Research Fund of the American Chemical Society, and the National Science Foundation. Grateful acknowledgment is hereby made to the donors of the Petroleum Research Fund.

[2] National Science Foundation Faculty Fellow, 1959–1960.

[3] (a) J. D. Roberts and R. H. Mazur, *J. Am. Chem. Soc.*, **73**, 3542 (1951); (b) R. H. Mazur, W. N. White, D. A. Semenow, C. C. Lee, M. S. Silver and J. D. Roberts, *ibid.*, **81**, 4390 (1959); (c) M. C. Caserio, W. H. Graham and J. D. Roberts, *Tetrahedron*, **11**, 171 (1960); (d) E. Renk and J. D. Roberts, *J. Am. Chem. Soc.*, **83**, 878 (1961); (e) E. F. Cox, M. C. Caserio, M. S. Silver and J. D. Roberts, *ibid.*, **83**, in press (1961).

[4] (a) J. D. Roberts and R. H. Mazur, *ibid.*, **73**, 2509 (1951); (b) M. S. Silver, P. R. Shafer, J. E. Nordlander, C. Rüchardt and J. D. Roberts, *ibid.*, **82**, 2646 (1960).

[5] Unpublished work by R. H. Mazur at the Massachusetts Institute of Technology, 1950–1951.