[CONTRIBUTION FROM THE MERCK SHARP & DOHME RESEARCH LABORATORIES, DIVISION OF MERCK & CO., INC.]

High Pressure Studies: Oximes of Hindered Ketones

BY WILLIAM H. JONES, E. W. TRISTRAM AND WILLIAM F. BENNING

RECEIVED OCTOBER 13, 1958

Highly hindered, unreactive ketones react with hydroxylamine at pressures of about 9500 atmospheres to give good yields of the corresponding oximes. Qualitative rate studies showed a marked positive effect of pressure on reaction rate which is interpreted to mean that the rate-determining step involves the formation of a highly polar activated complex from neutral or much less polar reactants.

Hydrostatic pressure may produce pronounced effects on the rate and course of liquid phase reactions. For reactions which proceed by an ionic mechanism, a rationale for these effects was not evident until the recent work of Hamann[1] who demonstrated that in polar media those "reactions in which the transition state is more highly ionic, and hence more extensively solvated, than the initial state are greatly accelerated by pressure; those in which the transition state is less ionic and less solvated than the initial state are retarded by pressure.[1a]" The positive pressure effect is caused by a binding of the solvent molecules to the more highly charged activated complex with a resulting decrease in the volume of the system. The basic relationship between pressure and rate was originally proposed by van't Hoff[2]

$$\left(\frac{\ln k}{p}\right)_T = \frac{-\Delta V^{\ddagger}}{RT}$$

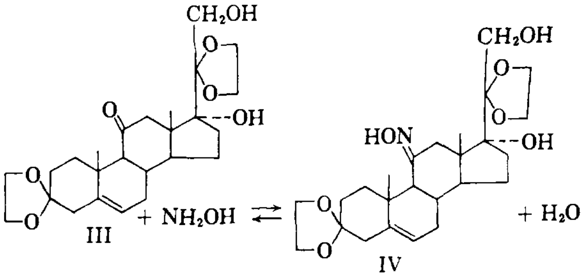
where, according to modern theory, $\Delta V^{\ddagger}$ is the change in volume per mole when the activated complex is formed from the reactants. The effect of pressure on the equilibrium constant follows an analogous relationship.

The effect of pressure on addition reactions of carbonyl compounds such as the formation of oximes, hydrazones, semicarbazones, etc., which are ionic reactions exhibiting general acid catalysis,[3] has not been studied. It was hoped that the rate-determining step might involve the formation of a charged complex, despite conflicting conclusions in the literature[3-6] on this point, and therefore the reactions might be accelerated by pressure. Also since certain oximes would provide a convenient route to some desired amines, we have investigated the reaction of several hindered ketones with hydroxylamine.

Di-*t*-butyl ketone (hexamethylacetone) (I) is a classic example of a sterically hindered carbonyl compound uncomplicated by other functional groups or extraneous electrical effects. Although this ketone will undergo addition reactions with a few small molecules like methyl Grignard reagent and hydrogen, the common carbonyl derivatives have never been prepared despite repeated attempts to do so.[7] When hexamethylacetone was treated with hydroxylamine at a pressure of about 140,000 p.s.i., however, a 70% yield of pure crystalline oxime was obtained. As expected, the less hindered pentamethylacetone (II) was even more reactive under the same conditions, giving a 96% yield of oxime in a shorter time.

Catalytic reduction of hexamethylacetone oxime gave 2,2,4,4-tetramethyl-3-aminopentane in good yield. This amine possessed a high order of activity in a ganglionic blocking assay.

11-Ketosteroids also possess a very unreactive carbonyl group. Attempts to prepare an oxime (IV) from 3,20-bis-ethylenedioxy-5-pregnene-17α, 21-diol-11-one (cortisone-3,20-bis-dioxolane) (III) by standard procedures at atmospheric pressure gave poor yields of oxime in difficultly-separable mixtures. Low solubility of the steroid made it necessary to employ a complex solvent mixture of ethanol, water and pyridine. With this mixture and using an additional buffer of sodium acetate, it was possible to obtain a 74% yield of crystalline oxime by operating at 134,000 p.s.i. pressure.



In order to obtain a clearer picture of the effect of pressure on these reactions, qualitative rate studies were made. The results of the kinetic experiments are presented in Tables I and II and in Fig. 1.

Experimental[8]

High Pressure Apparatus.—The 12H Series equipment of the Harwood Engineering Co. was used for all high pressure experiments. The reactor, designed for operation to 200,000 p.s.i., had the following dimensions: 8" o.d. × 30" long, void space 1" i.d. × 12" long. It was fitted with conventional Bridgman closures at both ends. Pressures were generated with an A2.5J pressure intensifier driven by

---

[1] (a) J. Buchanan and S. D. Hamann, *Trans. Faraday Soc.*, **49**, 1425 (1953); (b) H. G. David and S. D. Hamann, *ibid.*, **50**, 1188 (1954); (c) S. D. Hamann and W. Strauss, *ibid.*, **51**, 1684 (1955); (d) H. G. David, S. D. Hamann and S. J. Lake, *Australian J. Chem.*, **8**, 285 (1955); (e) S. D. Hamann, "Physico-Chemical Effects of Pressure," Academic Press, Inc., New York, N. Y., 1957.

[2] van't Hoff, "Vorlesungen uber theorstische und physikalische Chemie," Vol. I, Braunschweig, 1901, p. 236.

[3] J. Hine, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1956, pp. 246–251.

[4] P. D. Bartlett, Chapter 1 in H. Gilman's, "Organic Chemistry," Vol. III, John Wiley and Sons, Inc., New York, N. Y., 1953, pp. 117–118.

[5] L. P. Hammett, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1940, pp. 330–336.

[6] G. H. Stempel, Jr., and G. S. Schaffel, THIS JOURNAL, **66**, 1159 (1944); R. P. Cross and P. Fugassi, *ibid.*, **71**, 223 (1949).

[7] A. Haller and E. Bauer, *Compt. rend.*, **150**, 582 (1910); Bruzau, *Ann. chim.*, [11] **1**, 257 (1934); J. B. Conant and A. H. Blatt, THIS JOURNAL, **51**, 1235 (1929); N. C. Cook and W. C. Percival, *ibid.*, **71**, 4141 (1949); F. C. Whitmore, "Organic Chemistry," D. Van Nostrand Co., Inc., New York, N. Y., 1951, p. 223.

[8] All melting and boiling points are uncorrected.

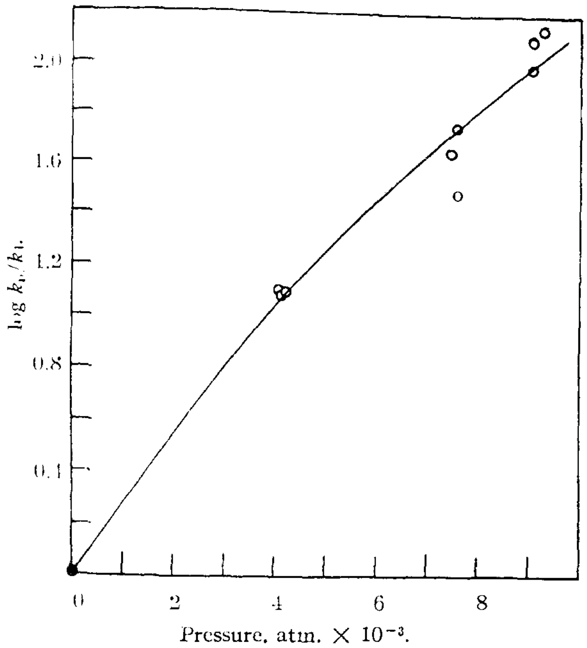


Fig. 1.—Effect of pressure on rate of formation of cortisone-3,20-bis-dioxolane 11-oxime.

a 20,000 p.s.i. Milton Roy pump, and measured with a manganin cell using a special Foxboro Null Balance Indicator, an AC bridge designed for use with the cell and calibrated in pressure units.

Reaction mixtures were confined in a collapsible sample holder fabricated from a stainless steel bellows (Flexonics Corporation, Maywood, Ill.), 0.75" o.d. × 11.5" long, which was closed at both ends with brass screw caps containing flat Teflon gaskets. The sample holder was placed inside a closely fitting thin-walled stainless steel tube which permitted linear compression while preventing kinking of the bellows. This entire assembly was then immersed in the reactor, a lead-free gasoline (Amoco) serving as the hydraulic fluid. The capacity of the sample holder was approximately 60 ml.

TABLE I

RATE OF FORMATION OF CORTISONE-3,20-BIS-DIOXOLANE 11-OXIME AT 75°

Solvent system: ethanol–water–pyridine in 1:1.3:2.1 proportion by weight; concentrations: hydroxylamine hydrochloride, 0.28 molal; sodium acetate, 0.72 molal.

Initial molal concn. of steroid	Press., atm.	Time, sec. × 10^{-3}	Reaction,[a] %	$k_1 \times 10^6$,[b] sec.$^{-1}$	k_p[c]/k_1
0.013	1	79.2	10	1.3	1
.022	4130	21.6	27	15	12
.022	4200	31.2	26	10	7.7
.022	4100	36.0	34	12	9.2
.022	7600	7.20	24	38	29
.013	7430	21.6	69	54	42
.043	7640	21.6	76	70	54
.013	9180	3.60	46	170	130
.042	9380	10.8	86	180	140
.021	9180	10.8	80	150	120
.022	9170	21.6	94	130	100

[a] Determined by infrared assay. [b] Pseudo-first-order rate constant. [c] Ratio of rate at given pressure to rate at atmospheric pressure.

Materials.—Pentamethylacetone and hexamethylacetone were prepared by successive methylations of pinacolone using methyl iodide and sodium amide following the procedure of Haller and Bauer.[9] The products were separated by fractionation through an 18 in. Nester and Faust (Exton, Pa.) spinning band column. The fractions used had the properties: pentamethylacetone, b.p. 136.5–137°, $n^{25}D$ 1.4043; hexamethylacetone, b.p. 155.5–157°, $n^{25}D$ 1.4183. The identity and purity of the fractions were further established by vapor phase chromatography and nuclear magnetic resonance spectrography.

TABLE II

RATE OF FORMATION OF HEXAMETHYLACETONE OXIME AT 75°

Solvent: ethanol–water in 1.3:1 proportion by weight; concentrations: hydroxylamine hydrochloride, 0.17 molal; sodium acetate, 0.23 molal.

Initial molal concn. of ketone	Press., atm.	Time, sec. × 10^{-3}	Reaction,[a] %	$k_2 \times 10^6$,[b] kg. solvent/mole-sec.	k_p[c]/k_1
0.110	1	432	10	0.15[d]	1
.119	6600	57.6	49	85	570
.100	9130	88.9	85	190	1300

[a] Determined by iodimetric titration of hydroxylamine. [b] Pseudo-second-order rate constant. [c] Ratio of rate at given pressure to rate at atmospheric pressure. [d] Since there was no measurable reaction at atmospheric pressure within the limit of error of the assay (10%), this is an assumed maximum rate to provide an arbitrary basis for comparison.

Cortisone-3,20-bis-dioxolane[10] was purified by chromatography on a basic alumina column which was eluted with a 1:1 benzene–chloroform mixture. The best material melted at 232–237°, showed a negative α-ketol test with 2,3,5-triphenyltetrazolium chloride, and exhibited only end absorption in the ultraviolet spectrum.

Kinetic Measurements with Cortisone-3,20-bis-dioxolane.—In the reaction rate experiments with cortisone-3,20-bis-dioxolane, molal concentration units were employed rather than the more customary molar units since it was not practicable to estimate accurately the decrease in the volume of the solutions caused by liquid compression. In all runs the reactor was preheated to 75 ± 1°. The reactants and solvents were weighed, mixed and the solution was placed in the sample holder. The sample holder was also heated to 75° and placed in the reactor, which was then sealed and pressurized. The time required to pressurize the system was about 5 min. which was very small compared with the reaction times. Uncertainty in pressure measurement was estimated to be ±10%.

All reaction mixtures contained the same initial concentrations of hydroxylamine, 0.28 molal, and sodium acetate, 0.72 molal. The initial concentration of 11-keto-steroid was varied from 0.013 to 0.043 molal. The three-component solvent system of ethanol–water–pyridine was always in the same proportion of 1.0:1.3:2.1 by weight.

At the end of the reaction time, the system was quickly vented down to atmospheric pressure. The sample holder was removed and the contents were rinsed out with 25 ml. of methanol and 25 ml. of water. To prevent any hydrolysis of the dioxolane groups during work-up, the mixture was made alkaline (*p*H 11–12) with 30% sodium hydroxide. All the steroids in the mixture were precipitated quantitatively by dilution with 100 ml. of water followed by evaporation of alcohol and pyridine *in vacuo* at 40°. The total steroids were filtered, washed well with water and dried over potassium hydroxide at 80° for three hours *in vacuo*.

The composition of the steroid mixture was determined by a quantitative infrared spectrographic analysis using a Perkin-Elmer model 12C spectrophotometer. The analysis depended on the degree of absorption at the carbonyl frequency of 5.88 μ. The composition of the mixture was then read directly from a standard curve prepared by measuring the absorption of pure reference samples of the starting 11-keto-steroid, the 11-oxime, and of a number of known mixtures of the two compounds. The analysis was estimated to have an accuracy of ±1%.

In addition to the sources of error given above, there was a slight but indeterminate amount of decomposition of hydroxylamine during all runs. It is estimated that the rate constants given in Table I may be in error by as much as 25%.

---

(9) A. Haller and E. Bauer, *Compt. rend.*, **150**, 582 (1910).

(10) R. Antonucci, *et al.*, *J. Org. Chem.*, **18**, 70 (1953).

Kinetic Measurements with Aliphatic Ketones.—A different analytical procedure was used to determine the extent of reaction of pentamethylacetone and hexamethylacetone with hydroxylamine. The amount of unreacted hydroxylamine was found directly by iodimetric titration. All reaction mixtures had the same initial concentrations of hydroxylamine, 0.17 molal, and sodium acetate, 0.23 molal. The initial concentrations of ketone were about 0.1 molal. The solutions were prepared as follows: a weighed sample of ketone was placed in a tared 50-ml. volumetric flask. Then 15 ml. of an 0.5 *M* standard solution of hydroxylamine hydrochloride in 95% ethanol and 20 ml. of an 0.5 *M* aqueous sodium acetate solution were added. The solution was diluted to 50 ml. with 95% ethanol and weighed. In each run a blank solution was prepared.

The solution was then transferred to the sample holder and pressure runs were carried out as previously described. After the sample had been removed from the pressure vessel, a 5-ml. aliquot was diluted with 20 ml. of water, and 2 g. of reagent anhydrous dibasic sodium phosphate (Merck) and 2 ml. of starch indicator solution were added. The resulting solution was titrated with a 0.05 *N* standard iodine solution. The appearance of a blue color which persisted for 30 seconds was taken as the end-point. The blank solutions were titrated by exactly the same procedure. The tendency of the blue color to fade, and slow and variable decomposition of hydroxylamine introduce error in this analytical procedure which was estimated to be as much as 10%. Runs with both ketones at atmospheric pressure showed no detectable reaction even after 120 hours at 58°.

3,20-Bis-ethylenedioxy-5-pregnene-17α-21-diol 11-Oxime (Cortisone-3,20-bis-dioxolane 11-Oxime).—To a solution of 3.0 g. (0.043 mole) of hydroxylamine hydrochloride and 6.0 g. (0.073 mole) of sodium acetate in 15 ml. of water was added 3.0 g. (0.0067 mole) of cortisone-3,20-bis-dioxolane. The mixture was diluted with 15 ml. of ethanol and 25 ml. of pyridine, heated to 75° and transferred to a collapsible sample holder. The capped sample holder was placed in the pressure vessel which was sealed, heated to 75° and pressurized to 134,000 p.s.i. These conditions were maintained for about 16 hours (overnight). The system was then cooled to room temperature, and the pressure was released. The reaction mixture was rinsed out of the sample holder with 25 ml. of water and 25 ml. of methanol. The combined mixture was then made alkaline (*p*H 11–12) by adding 30% sodium hydroxide, and diluted with 100 ml. of water. Most of the alcohol and pyridine was removed by evaporation *in vacuo* at 40°. The crystalline product, cortisone-3,20-bis-dioxolane 11-oxime, was filtered, washed with water and dried *in vacuo* over potassium hydroxide at room temperature. The product weighed 2.3 g. (74%), m.p. 245–248°. A portion of the product was recrystallized three times from methanol containing a trace of pyridine, m.p. 258–261° dec., $[\alpha]^{25}\text{D}$ +1.2° (*c* 0.8, in chloroform). The infrared spectrum was entirely consistent with the oxime structure, the ultraviolet spectrum exhibited no λ_{max} and the α-ketol test with 2,3,5-triphenyltetrazolium chloride reagent was negative.

Anal. Calcd. for $C_{25}H_{37}NO_7$: C, 64.77; H, 8.05; N, 3.02. Found: C, 64.62; H, 7.94; N, 3.09.

Hexamethylacetone Oxime.—Three grams (0.021 mole) of hexamethylacetone, 2.2 g. (0.032 mole) of hydroxylamine hydrochloride and 5.4 g. (0.04 mole) of sodium acetate trihydrate were dissolved in a water–ethanol mixture. The total volume of solution was brought to 50 ml. with ethanol. The reaction mixture was transferred to a collapsible sample holder, placed in the pressure vessel, heated to 75° and pressurized to 140,000 p.s.i. for 20 hours. At the end of the reaction period the sample holder was removed, emptied, and rinsed with water and ethanol. The white crystalline oxime was filtered, washed with water and dried; weight 2.3 g. (70%), m.p. 156.5–158.5°. Concentration of the above filtrate to remove alcohol gave only a trace of additional product. A portion of the oxime was recrystallized from petroleum ether (Skellysolve B, b.p. 60–71°) to constant m.p. 157.5–158.5°.

Anal. Calcd. for $C_9H_{19}NO$: C, 68.74; H, 12.18; N, 8.91. Found: C, 68.50; H, 11.98; N, 8.59.

2,2,4,4-Tetramethyl-3-aminopentane.—To a solution of 0.90 g. (0.0057 mole) of hexamethylacetone oxime in 30 ml. of glacial acetic acid was added 0.5 g. of platinum oxide catalyst. The mixture was hydrogenated at room temperature and an initial hydrogen pressure of 40 p.s.i.g. The theoretical amount of hydrogen was absorbed in three hours. The catalyst was removed by filtration and the filtrate was treated with 1.0 ml. of concentrated hydrochloric acid. The solution was concentrated to dryness by evaporation *in vacuo* from the frozen state. The white crystalline residue of 2,2,4,4-tetramethyl-3-aminopentane hydrochloride was recrystallized three times from an ethanol–ether mixture. The yield was 0.70 g. (69%) of product which did not melt below 300°.

Anal. Calcd. for $C_9H_{22}ClN$: C, 60.14; H, 12.34; N, 7.79. Found: C, 59.97; H, 12.10; N, 7.37.

Pentamethylacetone Oxime.—Three grams (0.023 mole) of pentamethylacetone and the sodium acetate and hydroxylamine hydrochloride were dissolved in an ethanol–water mixture exactly as described for hexamethylacetone. The mixture was pressurized to 140,000 p.s.i. at 75° for 16 hours. A yield of 3.15 g. (96%) of pentamethylacetone[11] oxime, m.p. 140–141°, was obtained.

Discussion of Results

The *p*H and total acid concentration were the same in all rate experiments. In the runs listed in Table I the concentration of hydroxylamine was large compared with the steroid concentration, and it also remained essentially constant. Therefore pseudo-first-order rather than second-order rate constants were calculated. The pseudo-second-order rate constants shown in Table II were necessitated by the more nearly equivalent concentrations of hydroxylamine and ketone.

The rate date presented in Tables I and II and in Fig. 1 are subject to large experimental errors. Nevertheless they suffice to show clearly the great effect that pressure exerts on the rate of oxime formation. When the rate of an ionic reaction is increased by pressure to the extent observed in the present work, it may be stated, on the basis of the results obtained by Hamann[1] and more recently by by Laidler,[12] that such a reaction proceeds by the formation of a highly polar activated complex from neutral or much less highly charged reactants. The decrease in volume ($\Delta V^{\ddagger}$), calculated from the slope of the linear portion of the curve in Fig. 1, is about −20 ml./mole. This volume change may be considered to be the sum of two terms: $\Delta V_1^{\ddagger}$ which represents the change in volume of the molecules themselves when they form the transition state, and $\Delta V_2^{\ddagger}$ which is the change in volume of the solvent caused by interaction with the transition state complex. $\Delta V_1^{\ddagger}$ for reactions of this type have been calculated to be only from −5 to −10 ml./mole. Therefore the $\Delta V_2^{\ddagger}$ term, the decrease in volume of the solvent accompanying the solvation of a charged complex, accounts for the great acceleration in rate by pressure.

It might be suggested that this effect of pressure on oxime formation is due merely to the increase in acidity of the solutions at high pressure since it is known[10] that increasing pressure greatly increases the extent of ionization of weak acids, which were present in the buffered system employed. However, previous workers have shown[13] that although the rate of oxime and semicarbazone formation increases with increasing acidity, it rises to a maxi-

---

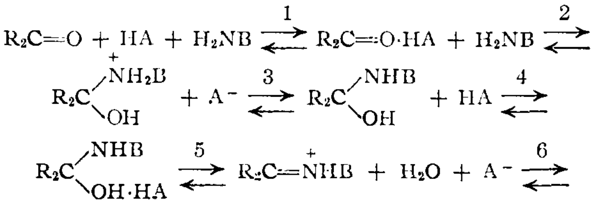
[11] J. U. Nef, *Ann.*, **310**, 316 (1900).

[12] C. T. Burris and K. J. Laidler, *Trans. Faraday Soc.*, **51**, 1497 (1955).

[13] E. Barrett and A. Lapworth, *J. Chem. Soc.*, **93**, 85 (1908); J. B. Conant and P. D. Bartlett, THIS JOURNAL, **54**, 2881 (1932); F. H. Westheimer, *ibid.*, **56**, 1962 (1934).

mum and then decreases as the reactive base (NH_2OH) is converted to its unreactive conjugate acid (NH_3^+OH). Furthermore, in no case did the effect of acidity ever increase the rate by as much as one order of magnitude. Therefore, since the effect of pressure on this reaction is very much greater than one could reasonably expect from mere increase in acidity, we conclude that the rate-determining step in the formation of these oximes proceeds by formation of a highly polar activated complex from uncharged reactants. Any proposed mechanism of oxime formation should be examined in the light of this observation.

It was suggested by Bartlett[4] that carbonyl addition reactions of this type have some such mechanism as



$$R_2C{=}O + HA + H_2NB \overset{1}{\rightleftarrows} R_2C{=}O{\cdot}HA + H_2NB \overset{2}{\rightleftarrows}$$

$$R_2C\begin{matrix}\overset{+}{N}H_2B\\ OH\end{matrix} + A^- \overset{3}{\rightleftarrows} R_2C\begin{matrix}NHB\\ OH\end{matrix} + HA \overset{4}{\rightleftarrows}$$

$$R_2C\begin{matrix}NHB\\ OH{\cdot}HA\end{matrix} \overset{5}{\rightleftarrows} R_2C{=}\overset{+}{N}HB + H_2O + A^- \overset{6}{\rightleftarrows}$$

$$R_2C{=}NB + H_2O + HA$$

and that steps 2 or 5 are rate determining rather than other steps which involve simple proton transfers. Hine[3] proposed a similar mechanism. Hammett[5] and others[6] suggest the converse; that the rate-determining step is a proton transfer or at least involves the participation of charged intermediates in the formation of a charged or neutral activated complex.

The large acceleration of rate by increasing pressure demonstrated in the present work supplies strong evidence that either step 2 or 5 is in fact rate determining as suggested by Bartlett. Furthermore, recent work by Jencks[14] provides evidence that step 5 rather than 2 is rate determining since with more reactive carbonyl compounds at atmospheric pressure the equilibria as far as step 3 were shown to be practically instantaneous. Thus the pressure effect on rate with hindered carbonyl compounds is compatible with Jencks' conclusions.

The technique of carrying out liquid phase ionic reactions at high pressure not only enables one to prepare compounds which are difficult to obtain by more conventional methods, but also provides a useful approach to the study of reaction mechanisms.

Acknowledgment.—We are indebted to Mr. R. W. Walker for the development and performance of the quantitative infrared spectrographic analyses, and to Mr. R. N. Boos for microanalytical data.

[14] W. P. Jencks, Abst. 134th Amer. Chem. Soc. Meeting, Chicago, Ill., Sept. 7-12, 9P (1958).

RAHWAY, N. J.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, POLYTECHNIC INSTITUTE OF BROOKLYN]

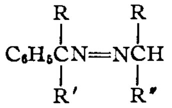
Azo Compounds. XXIX. Decomposition Study of α-Alkyl- and α,α-Dialkylbenzylazoalkanes[1]

BY C. G. OVERBERGER AND A. V. DIGIULIO[2]

RECEIVED SEPTEMBER 15, 1958

The four unsymmetrical benzylazoalkanes, α-phenylethylazoisopropane (I), α-cumylazoisopropane (II), α,α-diethylbenzylazo-3-pentane (III) and α,α-methylisobutylbenzylazo-2-(4-methylpentane) (IV) were decomposed in diphenyl ether. First-order kinetics were observed and the E_A and $\Delta S^{\ddagger}$ were determined in each case. Similar rates were obtained in the presence of benzoquinone. Comparisons between I, II, III and IV are made as well as with azo-bis-isopropane, and 1-azo-bis-1-phenylalkanes. Differences in reactivity are discussed in terms of hyperconjugation and "B"-strain. Additional evidence has been obtained that indicates that in the thermal decomposition of azo compounds, probably both radicals assist in the elimination of nitrogen in the rate-determining step.

In previous work Overberger and co-workers[3a,b,c,d,e] prepared a number of symmetrical aliphatic azonitriles and investigated the effect of structure on the rate of decomposition to nitrogen and two free radicals. The purpose of this present work was to extend the study of the effects of structure on the homolytic dissociation of unsymmetrical aliphatic azo compounds particularly where the two radicals attached to the azo linkage were of considerable difference in stability. It was anticipated that a study of this type of azo compound would shed some light on the problem as to whether both carbon–nitrogen bonds were ruptured simultaneously[4,5] in the rate-determining step or occurred in a stepwise manner[6,7] in the thermal decomposition of unsymmetrical azoalkanes and arylazoalkanes. The unsymmetrical benzylazoakanes of the general structures[1,25] were decomposed thermally



$$C_6H_5\overset{\overset{R}{|}}{\underset{\underset{R'}{|}}{C}}N{=}N\overset{\overset{R}{|}}{\underset{\underset{R''}{|}}{C}}H$$

I, R = R″ = CH_3, R′ = H
II, R = R′ = R″ = CH_3
III, R = R′ = R″ = C_2H_5
IV. R = CH_3, R′ = R″ = iC_4H_9

and then rates of decomposition studied.

---

[1] This is the 29th in a series of papers concerned with the preparation and decomposition of azo compounds. For the previous paper in this series see C. G. Overberger and A. V. DiGiulio, THIS JOURNAL, **81**, 1194 (1959).

[2] This paper comprises a portion of a thesis presented by A. V. DiGiulio in partial fulfillment of the requirements for the degree of Doctor of Philosophy to the Graduate School of the Polytechnic Institute of Brooklyn.

[3] (a) C. G. Overberger, M. T. O'Shaughnessy and H. Shalit, THIS JOURNAL, **71**, 2661 (1949); (b) C. G. Overberger and M. B. Berenbaum, *ibid.*, **73**, 2618 (1951); (c) C. G. Overberger and H. Biletch, *ibid.*, **73**, 4880 (1951); (d) C. G. Overberger and A. Lebovits, *ibid.*, **76**, 2722 (1954); (e) C. G. Overberger, W. F. Hale, M. B. Berenbaum and A. B. Finestone, *ibid.*, **76**, 6185 (1954).

[4] H. C. Ramsperger, *ibid.*, **51**, 2134 (1929).

[5] S. G. Cohen and C. H. Wang, *ibid.*, **77**, 3628 (1955).

[6] M. Page, H. O. Pritchard and A. F. Trotman-Dickenson, *J. Chem. Soc.*, 3878 (1953).

[7] G. L. Davies, D. H. Hey and G. H. Williams, *ibid.*, 4397 (1956).