

mixture was stirred for the time at the temperature indicated in Table II. The product was distilled into a Dry Ice trap at reduced pressure (15–20 mm). The infrared spectrum of each product reported was identical with that of an authentic sample.

Photochemically Induced Reduction of Halides.—To a 50-ml Pyrex tube fitted with a glass stopper was added 0.05 mol of halide, 0.075 equiv of polymer (4.6 g), and 0.038 equiv of bis-*n*-butyltin oxide (22.8 g). The reaction mixture was irradiated in a Rayonet photochemical reactor for the time indicated in Table II. Transfer of the reaction mixture to a 50-ml flask followed by distillation at reduced pressure (15–20 mm) gave pure product. The infrared spectrum of each product reported was identical with that of an authentic sample.

Reduction of 4-Methylcyclohexanone.—To a 100-ml three-necked flask equipped with a Hershberg stirrer, condenser and addition funnel was added 30 g of di-*n*-butyltin oxide (0.12 mol) and 35 ml of toluene. While stirring at 25°, there was added dropwise a mixture of 11.2 g of ketone (0.1 mol) and 18 g of silicone polymer (0.3 equiv). After addition was complete, the reaction mixture was stirred at 25° for 3 hr. Distillation at reduced pressure gave a mixture of *cis*- and *trans*-4-methylcyclohexanol: bp 55° (20 mm); yield 75% based on starting ketone.

Registry No.—Tri-*n*-butyltin hydride, 688-73-3; 1,1-dibromo-*trans*-2,3-dimethylcyclopropane, 3591-58-0; 7,7-dibromobicyclo[4.1.0]heptane, 2415-79-4; 4-methylcyclohexanone, 589-92-4.

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Nitrile Oxides. XII. Cycloaliphatic and Aliphatic Stable Nitrile Oxides¹

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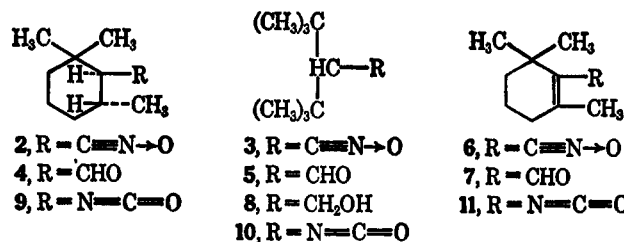
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Simple aliphatic nitrile oxides are extremely unstable and isomerize even at 0° in dilute solutions within seconds or, at best, minutes to the corresponding dialkylfurazan oxides (furoxans, 1,2,5-oxadiazole 1-oxides).^{2,3} Only recently a few representatives of aliphatic nitrile oxides have been obtained as monomers by working at temperatures of approximately -40°.⁴ Trimethylacetone nitrile oxide [1, (CH₃)₃C—C≡N→O] is the only member of the series reported so far to be stable enough to be distilled *in vacuo* and to require several days at room temperature to dimerize completely.^{2,4,5} In the light of our recent success in completely stabilizing aromatic and heterocyclic nitrile oxides by controlled steric hindrance,⁶ the relative stability of 1 may be attributed to the bulky *t*-butyl group. Aromatic and heterocyclic nitrile oxides are

adequately protected against dimerization by two methyl groups in *o,o'* position to the CNO group, but the limited lifetime of 1 indicated that a higher degree of steric hindrance than that provided by one *t*-butyl group would be necessary for the stabilization of an aliphatic or cycloaliphatic nitrile oxide, probably because of the greater conformational freedom of these structures.

These speculations were confirmed by the preparation of the strongly hindered nitrile oxides, *trans*-2,2,6-trimethylcyclohexylfulmide (2) and di-*t*-butylacetone nitrile oxide (3). Both compounds proved indefinitely stable at 25°. The parent carbon skeleton structures of 2 and 3 were chosen for their accessibility. The synthesis of both 2 and 3 started with the known aldehydes 4⁷ and 5,⁸ which were converted into the oximes and then dehydrogenated by the recently described improved procedure.⁹ The remarkable degree of steric protection provided by the 2,2,6-trimethylcyclohexane moiety was impressively demonstrated by the preparation of 2,2,6-trimethylcyclohexen-1-ylfulmide (6) from the corresponding aldehyde 7 (*β*-cyclocitral). Compound 6 is the first known unsaturated nitrile oxide. Generally, ethylenic double bonds react quite readily with the nitrile oxide function, but their reactivity decreases sharply with increased substitution.^{2a,10} No intermolecular reaction of the CNO and the ethylenic group of 6 could be enforced.



In spite of the crowded vicinity of the CNO group in 2, 3, and 6, they reacted as easily as unhindered nitrile oxides with a number of typical dipolarophiles and nucleophiles. Heating the nitrile oxides for 5 hr to 125–130° rearranged them neatly to the corresponding isocyanates 9–11 which were characterized by subsequent reaction with aniline to give the corresponding *N*-phenylureas. Data on the obtained products are listed in Table I.

Experimental Section¹¹

***trans*-2,2,6-Trimethylcyclohexylfulmide (2).**—*trans*-2,2,6-Trimethylcyclohexane-1-aldehyde (IV) was obtained by the hydrogenation of the ethylene acetal of *β*-cyclocitral with platinum oxide in acetic acid.⁷ The oxime of IV is best prepared by the following method. The aldehyde (5 g) was dissolved in methanol (100 ml) and a solution of hydroxylamine hydrochloride (5 g) and sodium carbonate (3.5 g) in water (15 ml) was added. The reaction mixture was heated to reflux for 5 hr, poured into water (500 ml), and extracted with ether. The ethereal extracts were dried over anhydrous sodium sulfate, the solvent was removed *in vacuo*, and the residue was fractionated. The fraction

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(11) Melting points were determined with the Fisher-Johns melting point apparatus and are uncorrected. Microanalyses were by Galbraith Laboratories, Knoxville, Tenn. Molecular weights were determined by the osmometric method; the applied solvent is indicated in parentheses.

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TABLE I
 ADDITION PRODUCTS FROM THE NITRILE OXIDES 2, 3, AND 6

No.	Registry no.	Reactants	Compound	Yield, %	Mp, °C	Formula ^a
1	19202-80-3	2 + phenylacetylene	3-(2,2,6-Trimethylcyclohexyl)-5-phenylisoxazole	78	90	C ₁₈ H ₂₈ NO
2	19203-44-2	3 + phenylacetylene	3-Di- <i>t</i> -butylmethyl-5-phenylisoxazole	80	108	C ₁₈ H ₂₈ NO
3	19221-86-4	6 + phenylacetylene	3-(2,2,6-Trimethylcyclohexen-1-yl)-5-phenylisoxazole	82	59	C ₁₈ H ₂₁ NO
4	19202-81-4	2 + malononitrile	3-(2,2,6-Trimethylcyclohexyl)-4-cyano-5-aminoisoxazole	86	156	C ₁₈ H ₁₉ N ₃ O
5	19206-27-0	3 + malononitrile	3-Di- <i>t</i> -butylmethyl-4-cyano-5-aminoisoxazole	95	295	C ₁₈ H ₂₁ N ₃ O
6	19206-28-1	6 + malononitrile	3-(2,2,6-Trimethylcyclohexen-1-yl)-4-cyano-5-aminoisoxazole	61	138	C ₁₈ H ₁₇ N ₃
7	19202-82-5	2 + aniline	2,2,6-Trimethylcyclohexanoylanilide oxime	77	170	C ₁₆ H ₂₄ N ₂ O
8	19206-29-2	3 + aniline	Di- <i>t</i> -butylacetanilide oxime	76	135	C ₁₈ H ₂₆ N ₂ O
9	19206-30-5	6 + aniline	2,2,6-Trimethylcyclohexen-1-oylanilide oxime	77	159	C ₁₆ H ₂₂ N ₂ O
10	19206-31-6	3 + water	Di- <i>t</i> -butylacetohydroxamic acid	100	154	C ₁₆ H ₂₁ NO ₂
11	19206-32-7	6 + water	2,2,6-Trimethylcyclohexen-1-oyl-hydroxamic acid	76	180	C ₁₆ H ₁₇ NO ₂
12	19202-83-6	9 + aniline	N-(2,2,6-Trimethylcyclohexyl)-N'-phenylurea	100	209	C ₁₈ H ₂₄ N ₂ O
13	19206-33-8	10 + aniline	N-(Di- <i>t</i> -butylmethyl)-N'-phenylurea	100	236	C ₁₈ H ₂₆ N ₂ O
14	19206-34-9	11 + aniline	N-(2,2,6-Trimethylcyclohexen-1-yl)-phenylurea	100	178	C ₁₆ H ₂₂ N ₂ O

^a Supporting combustion data on C, H, and N ($\pm 0.3\%$) were obtained for all the compounds listed.

distilling at 62–64° (0.1 mm) (4 g, 73%) solidified quickly (mp 44°) and was the pure oxime. *Anal.* Calcd for C₁₀H₁₉NO: C, 70.96; H, 11.32; N, 8.28. Found: C, 70.98; H, 11.34; N, 8.33.

The oxime (0.05 mol) was dehydrogenated to the nitrile oxide with N-bromosuccinimide and sodium methoxide as previously described.⁹ After dilution of the reaction mixture with water, it was extracted three times with 50-ml portions of *n*-pentane. The combined solvent extracts were dried over anhydrous sodium sulfate, the solvent was removed *in vacuo* and the residue was fractionated on a 10-cm Vigreux column. The fraction boiling at 31° (0.001 mm) was the pure II (70%). It did not solidify on prolonged storage at –20°: d_4^{20} , 0.9739, n_D^{20} , 1.4690. *Anal.* Calcd for C₁₀H₁₇NO: C, 71.81; H, 10.25; N, 8.38; mol wt, 167. Found: C, 71.84; H, 10.43; N, 8.32; mol wt, 170 (chloroform).

Di-*t*-butylacetoneitrile Oxide (3).—In our first attempts to prepare 3 from the aldehyde 5, we used samples of 5 as obtained according to the literature,⁸ but obtained specimens of the nitrile oxide which did not crystallize and which gave poor analytical results, although the presence of considerable amounts of 3 could be demonstrated by the preparation of the crystalline derivatives 2, 5, 8, and 10 of Table I. According to Newman, *et al.*,⁸ the aldehyde is prepared by chromic acid oxidation of a crude 2,2-di-*t*-butylethanol (8), containing unknown isomeric alcohols which are apparently carried over through the subsequent steps. Since the aldehyde 5 cannot be separated efficiently from these by-products and neither its oxime nor the nitrile oxide 3 are thermally stable enough to be subjected to a long fractionated distillation, we purified the precursor 8 by filtration of the solid portion of crude 8 at –20° and subsequent recrystallizations from petroleum ether (bp 35–40°) at –20°, until a melting point of 54–55° was attained.

The aldehyde 5 (7 g), obtained from pure 8 by the described procedure, was dissolved in ethanol (250 ml) and refluxed for 18 hr with a solution of hydroxylamine hydrochloride (9 g) and potassium hydroxide (9 g) in water (25 ml). After dilution of the reaction mixture with 250 ml of water, the pH was adjusted to 4 and the major part of the ethanol distilled off. The residue was again diluted with water (250 ml) and extracted with ether. After removal of the solvent, the ethereal extracts left an oil, which, on fractionation, gave di-*t*-butylacetaldoxime boiling at 73–75° (0.35 mm) and soon solidifying (mp 30°), yield 72%. *Anal.* Calcd for C₁₆H₂₁NO: C, 70.12; H, 12.36; N, 8.18. Found: C, 70.31; H, 12.48; N, 8.27.

Other procedures, recommended in literature for the conver-

sion of aldehydes into oximes, proved unsatisfactory with the highly hindered 5.

Conversion of the oxime of 5 into the nitrile oxide went smoothly by the procedure described above. The nitrile oxide 3 boiled at 55–56° (0.2 mm) and solidified completely on cooling, mp 24–24.5°, yield 77%. *Anal.* Calcd for C₁₀H₁₉NO: C, 70.96; H, 11.32; N, 8.28; mol wt, 169. Found: C, 71.04; H, 11.35; N, 8.29; mol wt, 170 (benzene).

2,2,6-Trimethylcyclohexen-1-ylfulmide (6).—The starting material for 6, the aldehyde 7 (β -cyclocitral), was obtained from commercially available citral by the most recently recommended method,⁷ while for the preparation of its oxime an older procedure was found most satisfactory.¹² The pure oxime (mp 84°) was converted as described above in 81% yield into the nitrile oxide 6, a colorless liquid of unpleasant odor, boiling at 48–49° (0.03 mm). Compound 6 did not solidify on prolonged storage at –20°: d_4^{20} , 0.9962, n_D^{20} , 1.5103. *Anal.* Calcd for C₁₀H₁₅NO: C, 72.69; H, 9.15; N, 8.48; mol wt, 165. Found: C, 72.73; H, 9.20; N, 8.62; mol wt, 168 (acetone).

Addition Reactions of the Nitrile Oxides.—The isoxazoles 1–3 (Table I) were obtained by mixing the nitrile oxides with a 10% excess of phenylacetylene and allowing the reaction to proceed overnight at 25°. After removal of the excess phenylacetylene *in vacuo*, the solid residue was recrystallized once from aqueous methanol to yield an analytically pure product.

Addition of malononitrile was effected by refluxing for 15 min equal molecular quantities of the compounds (5 mmol) in methanol (5 ml) in presence of sodium methoxide (1 mmol).¹³ The compounds 4–6 of Table I separated on dilution with water and were purified by one recrystallization from methanol–water.

The anilide oximes 7–9 of Table I were prepared by heating the nitrile oxide (2 mmol) and aniline (3 mmol) in benzene (2 ml) to reflux for 30 min. Solvent and excess aniline were then removed by vacuum steam distillation, leaving finally a solid residue which was recrystallized once from petroleum ether.

For the hydrolysis to the hydroxamic acid, the previously described procedure for mesitohydroxamic acid was used.¹⁴ After one recrystallization compounds 10 and 11 of Table I were analytically pure.

The crude isocyanates 9–11 (2 mmol), obtained as described above, were mixed with a solution of aniline (2.2 mmol) in benzene (2 ml) and heated on the steam bath for 30 min. On

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cooling the mixed ureas 12-14 of Table I crystallized out and were purified by one recrystallization from ligroin (bp 60-70°).

Registry No.—2, 19202-78-9; 2 oxime, 19202-79-0; 3, 19203-41-9; 3 oxime, 19203-42-0; 6, 19203-43-1.

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Relative Rate Constants for Hydrogen Abstraction by Methyl Radicals from Substituted Toluenes^{1,2}

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Atom abstraction is the most common reaction which radicals undergo, and hydrogen is the most commonly transferred atom.^{4a} For this reason, it is important to amass data which can lead to mechanistic insights into the factors influencing this process. Recently, extensive studies have been reported of hydrogen abstraction by the phenyl and *p*-nitrophenyl radicals in solution.⁵ There are extensive data on the methyl radical in the gas phase,⁶ however, until recently the only data on hydrogen abstraction by methyl radicals in solution were the very limited data of Edwards and Mayo.^{7a} Recently, Mayo^{7b} himself, as well as other authors, have emphasized the importance of repeating this work. Some data have recently been published by Szwarc⁸ and by Berezin and Dobish.⁹ In this communication we present data on the Hammett correlation for the reaction of methyl with substituted toluenes. We conclude that methyl is a slightly electrophilic radical; the Hammett equation for abstraction from toluenes by methyl radicals gives a value of ρ^+ of about -0.1 . Surprisingly, this is very near the value which correlates data for abstraction by the phenyl radical.⁵ We briefly discuss our attempts to obtain relative rate

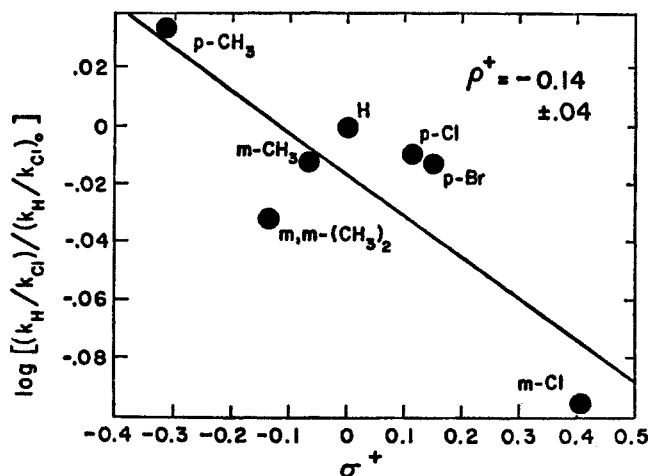
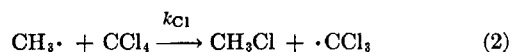
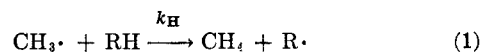


Figure 1.—The Hammett plot for the reaction of methyl radicals with substituted toluenes. The line shown is that given in eq 5 in the text.

constants for hydrogen abstraction from aliphatic hydrogen donors. For these solvents, the relative values of k_H are solvent dependent.

We have used the experimental design originated by Edwards and Mayo in which 0.1 *M* solutions of acetyl peroxide are allowed to decompose in a mixed solvent consisting of carbon tetrachloride and a hydrogen donor, and the ratio of CH₄ and CH₃Cl in the products is related to k_H/k_{Cl} (eq 1 and 2). Edwards and Mayo



used a complex gas separation procedure to obtain their analyses. We have used a technique in which 5 to 10 μl of the reaction solution is placed in a capillary tube, which is deaired, and sealed, and placed in a 100° bath, and allowed to react. The capillary is then crushed in the gas stream of an Aerograph Model 202-1 gas chromatograph using a Hewlett-Packard "Solid Sample Analyzer." A $\frac{1}{8}$ in. \times 10 ft column of Porapac allows separation and analysis of the following components: CO₂, CH₄, CH₃Cl, C₂H₆, methyl acetate, carbon tetrachloride, and chloroform. The molar response of the gases was determined using both known amounts of the pure gases and standard mixtures made up on a vacuum line.¹⁰

In agreement with Edwards and Mayo,^{7a} we find that some CH₄ is produced even when 0.1 *M* acetyl peroxide is allowed to decompose in pure CCl₄, and a correction must be applied in the mixed solvents for this methane.⁵ We have calculated k_H/k_{Cl} values using eq 3 where

$$k_H/k_{Cl} = \frac{\text{CH}_4/\text{CO}_2 - M_0}{\text{CH}_3\text{Cl}/\text{CO}_2} R_0 \quad (3)$$

$R_0 = X_{\text{CCl}_4}/X_{\text{RH}}$ (X is the mol fraction^{8c}) and $M_0 = (\text{CH}_4/\text{CO}_2)_0$ is the amount which must be subtracted to correct for the methane which does not arise from reaction 1. Using three values of R_0 and toluene as the hydrogen donor, the value of k_H/k_{Cl} is most nearly constant if M_0 is taken as 3.5% relative to CO₂ as 100.¹¹

(10) Our analytical results have been confirmed for a number of runs by mass spectrographic analysis.

(11) Edwards and Mayo,^{7a} found M_0 to be 0.035 mmol/mol of peroxide decomposed, or approximately 2.7% of the CO₂ yields, by a different method.

(1) Reactions of Radicals. 22.

(2) Supported in part by U. S. Public Health Service Grant GM-11908-03.

(3) (a) Postdoctoral Fellow supported by a grant from the Air Force Office of Scientific Research, AFOSR(SRC)-OAR, 1964-1966. (b) National Science Foundation College Teacher Research Participant, 1966-1968.

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