at 5-10°. The white solid product is insoluble in water; no extraction is necessary.

Anal. Calcd for $C_2Cl_2N_4O_8$: C, 8.61; Cl, 25.42; N, 20.09. Found: C, 8.65, 8.80; H, 0.11, 0.20; Cl, 25.22, 25.38; N, 19.95, 20.02.

Hexanitroethane (XII).—To a vigorously stirred slurry of 19.6 g (0.069 mole) of X in 50 ml of methylene chloride was added dropwise 100 ml of cold (−10°) concentrated sulfuric acid, maintaining the temperature at −10–0° during the addition. To this solution was added slowly the nitration mixture consisting of 35 ml of concentrated sulfuric acid and 35 ml of white fuming nitric acid ($d = 1.52$). After the nitrating mixture was added, the reaction temperature was raised to 50° and maintained for about 30 min. The methylene chloride layer was separated, dried over anhydrous magnesium sulfate, and evaporated under reduced pressure. Cooling afforded 19 g (92%) of XII, mp 150° (dec).

Hexanitroethane is also obtained by the nitration of dipotassium trinitropropionaldehyde.[20]

Potassium Dinitromethane (XIII).—A solution of 5 g (0.059 mole) of piperidine in 10 ml of methanol was slowly added to a solution of 2 g (0.01 mole) of I in 10 ml of methanol-water solution (80:20) at 5°. The solution was allowed to stand for 2 hr and then a solution of 5 g (0.05 mole) of potassium acetate in 10 ml of 60% methanol was added. The yellow precipitate which formed was immediately collected, washed with methanol, and the crude product was crystallized from water, giving 83.3% of XIII, mp 225° (dec). This product was identical with an authentic sample of XIII prepared from 2,2-dinitropropanediol by the method of Feuer and co-workers.[17]

XIII is also obtained as a product of the reaction of I with ammonia, sodium methoxide, potassium acetate, and potassium phthalimide under similar reaction conditions.

Other Salts of *sym*-Tetranitroethane.—An ion-exchange column of approximately 280 ml of Dowex 50-X8 was washed with sulfuric acid, followed by sodium hydroxide (twice), according to established procedure to charge the column with sodium ion. A solution of 50 g (0.182 mole) of dipotassium tetranitroethane in water was allowed to flow slowly through the column. When the column eluate was colorless, the collected solution of disodium tetranitroethane (XIV) was evaporated on a rotary evaporator. The residue was finally dried *in vacuo* over P_2O_5. The yield of the dihydrate of XIV was 47 g (93%).

Anal. Calcd for $Na_2C_2N_4O_8 \cdot 2H_2O$: C, 8.28; H, 1.39; N, 19.32. Found: C, 8.44; H, 1.47; N, 19.56.

Drying the dihydrate above at 60° over P_2O_5 in a drying pistol *in vacuo* produced the monohydrate of XIV.

Anal. Calcd for $Na_2C_2N_4O_8 \cdot H_2O$: C, 8.83; H, 0.7; N, 20.59. Found: C, 8.88; H, 1.44; N, 20.70.

The melting point (for both mono and dihydrate) was 295° (experimental). The dilithium tetranitroethane (XV) was prepared by an analogous procedure from a lithium ion charged ion-exchange column. Drying the residue at room temperature over P_2O_5 *in vacuo* produced the dihydrate of XV. The berylium and calcium salts of tetranitroethane were also prepared by this technique. The hydrates of salts of tetranitroethane are not stable for storage for long periods of time at room temperature, as contrasted to the dipotassium salt which appears to be stable indefinitely.

Anal. Calcd for $Li_2C_2N_4O_8 \cdot 2H_2O$: C, 9.31; H, 1.56; N, 21.73. Found: C, 8.88, 9.04; H, 1.49, 1.63; N, 21.34, 21.50.

***sym*-Tetranitroethane (XVI).**—Solutions of *sym*-tetranitroethane may be prepared by suspending X in an anhydrous organic solvent (preferably alkanes or halogenated alkanes) and introducing dry hydrogen chloride slowly at −15 to −20°. After yellow salt disappears the white precipitate (KCl) is filtered off, leaving a colorless solution of XVI. If this solution is allowed to warm to 10°, it turns yellow and produces bubbles. The infrared spectrum showed principal bands at 1610 (*asym*-NO_2) and 1310 cm^{-1} (*sym*-NO_2). The nmr (60 Mc) spectrum in carbon tetrachloride showed a single peak at $\delta = 7.12$ ppm.

Acknowledgment.—The authors appreciate the encouragement and the many helpful suggestions given during the course of this study by Dr. H. M. Kindsvater, Dr. Milton Frankel, Mr. Marion Hill, and Professor H. Feuer.

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[20] J. A. Gallaghan and W. L. Reed, U. S. Patent 3,101,379 (Aug 20, 1963); *Chem. Abstr.*, **60**, 1588c (1964).

Electron Spin Resonance Studies of a Stable Arylnitroso-Olefin Adduct Free Radical[1]

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An extremely stable alkenylaryl nitroxide has been prepared and studied by esr techniques. The free radical is formed by what appears to be a novel pseudo Diels-Alder reaction between nitrosobenzene and its derivatives with an olefin such as 2,3-dimethyl-2-butene. The N^{14} and proton hyperfine interactions have been used to interpret the esr spectra. Assignments of hyperfine coupling constants have been confirmed in part by deuterium substitution and are consistent with published results on similar radicals. The effect of substitution in the aromatic entity on N^{14} coupling constants has been considered, and correlations similar to those observed by other workers with substituted nitrobenzene anion radicals have been found. The kinetics of the formation of these nitroxides have been studied in some detail using esr techniques. The reaction was found to be over-all second order. The structure of the adduct free radical has been essentially confirmed by separation and identification of reduction products. A reaction mechanism is proposed.

The study of organic free radicals containing nitrogen using esr techniques has received considerable attention in recent years. Nitrobenzene anion radicals have been the object of considerable interest in this regard. Weissman, *et al.*,[2] observed the spectrum of the anion radical prepared by reduction of nitrobenzene with metallic sodium. Spectra were observed on similar systems by Geske and Maki[3] using constant potential electrolysis directly inside the esr microwave cavity as the means of radical generation.

In contrast, the nitroxide-type odd electron compounds have received somewhat less systematic attention by workers in the field. This type of free radical was first reported in 1914 by Weiland and Offenbacker.[4] The esr spectrum of di-*p*-anisylnitric oxide free radical was observed in 1950 by Holden, *et al.*[5] Diphenylnitric oxide radical was first observed by Hoskins in 1956 using

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[1] Presented at the Sixteenth Annual Southeastern Regional Meeting of the American Chemical Society, Charleston, W. Va., Oct 1964.

[2] T. E. Chu, G. E. Pake, D. E. Paul, J. Townsend, and S. I. Weissman, *J. Phys. Chem.*, **57**, 504 (1953).

[3] David H. Geske and August H. Maki, *J. Am. Chem. Soc.*, **82**, 2671 (1960); A. H. Maki and D. H. Geske, *J. Chem. Phys.*, **33**, 825 (1960).

[4] H. Weiland and H. Offenbacker, *Ber.*, **47**, 2111 (1914).

[5] A. N. Holden, C. Kittle, F. R. Merritt, and W. A. Yager, *Phys. Rev.*, **77**, 147 (1950).

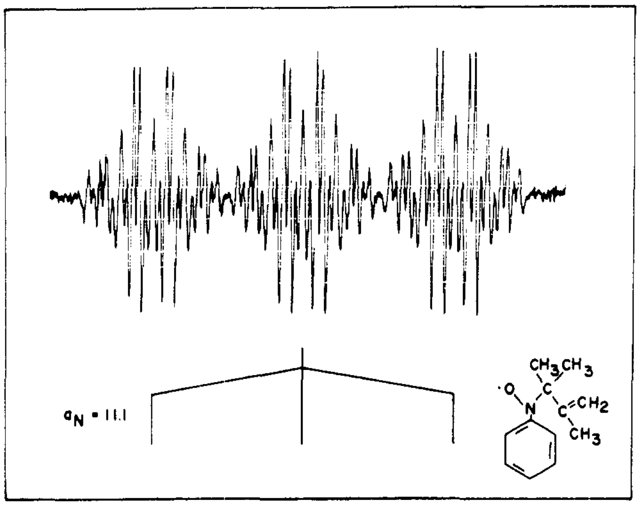

Figure 1.—Esr second derivative spectrum of the nitrosobenzene–2,3-dimethyl-2-butene adduct free radical. N^{14} interaction and proposed structure are given below spectrum, field increasing to the left.

esr techniques.[6] Baird and Thomas reported the esr spectra of a variety of nitroxides prepared by oxidation of the corresponding amines.[7a] These included not only the diaryl type mentioned above but also aryl, alkylaryl, alkyl, and dialkyl types. (Recently a series of *t*-butylphenyl nitroxides was reported by Rassat.[7b,c]) Other reports of this type of free radical have also appeared.[8–12] In most cases the nitroxides have been generated by oxidation of the appropriate primary or secondary amine.

In this work the electron spin resonance observed in our laboratory of a series of extremely stable alkenylarylnitroxides will be reported. These radicals are prepared by a novel condensation reaction between phenylnitroso compounds and an olefin. The spectra have been interpreted in terms of N^{14} and proton hyperfine interactions. Isotopic substitution of deuterium in the parent free radical has provided an unambiguous assignment of the *ortho* and *para* proton interactions. The coupling constants appear to be consistent with literature reports on similar free radicals.

The effect of both electron-donating and -withdrawing groups upon hyperfine coupling constants has been shown. These substituent effects are reminiscent of those obtained by other workers with nitrobenzene anion radicals.[13,14] Although not the primary object of this work, considerable data have been collected for correlating the effect of substituents on the distribution of π-electron spin density. Similar correlations have been made on nitrobenzene anion radicals.[15]

The identity of the odd electron entity has also been confirmed by chemical techniques. Based on product identification and reaction kinetics, which were also studied by esr, a mechanism for the reaction is postulated.

Experimental Section

Reagents.—Solvents used in this work were reagent grade and not further purified. The olefin principally used, 2,3-dimethyl-2-butene, was obtained from Phillips Petroleum. It contained only one component by gas chromatographic analysis and was not further purified. Other olefins used were obtained from Phillips Hydrocarbons or Matheson Coleman and Bell. 2-Methyl-2-pentene was prepared by isomerization of 2-methyl-1-pentene.[16]

Nitrosobenzene was prepared from nitrobenzene according to the procedure suggested in *Organic Syntheses*.[17] This involves reduction to the hydroxylamine with zinc dust and ammonium chloride, followed by oxidation with dichromate in sulfuric acid. After recrystallization from heptane a product melting at 65–66° was isolated (lit.[17] mp 64–67°). The nitroso compounds listed below, all previously reported in the literature, were prepared from the corresponding nitro compound by a similar technique:[18] *o*-chloronitrosobenzene;[19] *m*-chloronitrosobenzene;[19] *p*-chloronitrosobenzene;[19] *p*-nitrosotoluene;[20] *o*-nitrosotoluene;[20] *p*-nitrosoanisole.[21] Two new compounds which were also prepared by the nitro reduction oxidation technique are *p*-nitrosodiphenyl ether, mp 31–32° (*Anal.* Calcd for $C_{12}H_9NO_2$: C, 72.4; H, 4.52; N, 7.03. Found: C, 70.3; H, 4.56; N, 7.06.), and *p*-nitrosoacetophenone, mp 108–109° (*Anal.* Calcd for $C_8H_7NO_2$: C, 64.4; H, 4.70; N, 9.40; Found: C, 64.4; H, 4.81; N, 9.53.).

Nitrosobenzene-2,4,6-d_3 was prepared by oxidation of the corresponding amine with Caro's reagent.[22] The intermediate was prepared according to the procedure of Best and Wilson.[23] The nitroso compound, following recrystallization from heptane (mp 63–64°) was estimated by nmr to have three atoms of deuterium per molecule.

N-*t*-butylaniline was prepared by the alkylation of aniline with isobutylene according to the procedure of Olin.[24]

Esr Spectrometer.—The esr spectrometer employed was the commercially available *x*-band Varian V-4502 instrument. It operates in TE_{102} mode, and employs a 9-in. magnet with 100 kc/sec in addition to low-frequency (20–400 cps) field modulation. The variable-temperature accessory, a modification of the Varian equipment, was employed for operation above ambient temperatures.

Fremy's salt (peroxylamine disulfonate) was used as a reference standard for measurement of hyperfine coupling constants. The constant used for field calibration with peroxylamine disulfonate was $a_N = 13.0$ gauss.[25] The measurements were made by obtaining the spectra of the nitroxide and the calibration standard at the same instrumental conditions. Data from at least three repeat scans were averaged prior to calculating coupling constants. No attempt was made to determine *g* values accurately; however, in all cases they were near the free spin value of 2.0023.

To better detect the small hyperfine interactions and facilitate spectral interpretation, the second derivative presentation of the esr signal was normally employed. This was accomplished

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(6) R. H. Hoskins, *J. Chem. Phys.*, **25**, 788 (1956).

(7) (a) J. C. Baird and J. R. Thomas, *ibid.*, **35**, 1507 (1961); (b) H. Lemaire, Y. Marechal, R. Ramasseul, and A. Rassat, *Bull. Soc. Chim. France*, **372** (1965); (c) H. Lemaire and A. Rassat, *J. Chim. Phys.*, **61**, 1580 (1964).

(8) H. G. Thom, B. E. Wahler, and G. Schoffa, *Z. Naturforsch.*, **13a**, 552 (1958).

(9) K. Ulbert and V. Trkal, *Collection Czech. Chem. Commun.*, **25**, 1215 (1960).

(10) A. K. Hoffman and A. T. Henderson, *J. Am. Chem. Soc.*, **83**, 4671 (1961); G. M. Coppinger and J. D. Swalen, *ibid.*, **83**, 4900 (1961).

(11) A. J. Buchachenko, *Opt. i Spectroskopiya*, **13**, 795 (1962).

(12) (a) E. G. Rozantsev, Yu. G. Mamedov, and M. B. Neiman, *Izv. Akad. Nauk SSSR, Otd. Khim. Nauk*, **1962**, 2250; (b) M. B. Neiman, E. G. Rozantsev, and Yu. G. Mamedov, *Nature*, **196**, 472 (1962); (c) E. G. Rozantsev and M. B. Neiman, *Tetrahedron*, **20**, 131 (1962); (d) E. G. Rozantsev and A. B. Shapiro, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1123 (1964).

(13) A. H. Maki and D. H. Geske, *J. Am. Chem. Soc.*, **83**, 1852 (1961).

(14) P. C. Kolker and W. A. Waters, *Proc. Chem. Soc.*, **55** (1963).

(15) Philip H. Rieger and George K. Fraenkel, *J. Chem. Phys.*, **39**, 609 (1963).

(16) F. C. Whitmore, H. E. Whitmore, and N. C. Cook, *J. Am. Chem. Soc.*, **72**, 51 (1950).

(17) George H. Coleman, Chester M. McCloskey, and Frank A. Stuart, *Org. Syn.*, **25**, 80 (1945).

(18) Some of the nitroso compounds (chloro derivatives) were contaminated with the corresponding azoxy compound; however, this impurity had no effect on esr spectra of the olefin adduct free radical.

(19) R. E. Lutz and Marion R. Lytton, *J. Org. Chem.*, **2**, 68 (1937).

(20) E. Bamberger, *Ber.*, **28**, 245 (1895).

(21) A. Baeyer and E. Knorr, *ibid.*, **35**, 3034 (1902).

(22) A. Schors, A. Kraaijeveld, and E. Havenga, *Rec. Trav. Chim.*, **74**, 1243 (1955).

(23) A. P. Best and C. L. Wilson, *J. Chem. Soc.*, 239 (1946).

(24) J. F. Olin, private communication.

(25) J. Q. Adams and J. R. Thomas, *J. Chem. Phys.*, **39**, 1904 (1963).

by modulating the magnetic field at two frequencies (100 kc/sec and 400 cps) while sweeping through the spectrum.

Free-Radical Preparation.—The free-radical solutions were prepared by dissolving the appropriate phenylnitroso compound in benzene (other solvents such as cyclohexane or excess olefin can also serve as a medium for the reaction). The olefin, usually in considerable excess, was added to this solution so that the reaction proceeded at a relatively rapid rate. To avoid any dipole-dipole broadening from excessive radical concentrations, and yet obtain spectra of sufficient intensity for good signal–noise ratio, the solutions were normally 0.01 to 0.05 M in nitroso compound.

Free radicals can be observed immediately upon mixing and placing these solutions in the esr sample cavity. The signal intensity increases with time as the reaction proceeds.

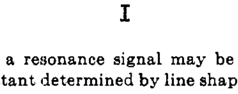
The initially observed signals were quite broad with only the large interaction with N^{14} being apparent. A pronounced sharpening of the spectra, with commensurate improvement in resolution, occurred when the samples were held at elevated temperatures (75–100°) in the sealed esr sample tubes. Elimination of O_2 from the sample solution also improved resolution somewhat. The actual conditions required to obtain the best resolved spectra vary from compound to compound. Optimum spectra were obtained by heating each sample and repeatedly scanning its spectrum until the best possible resolution was achieved.

Reaction Rate Measurements.—Reaction rates could be conveniently studied directly in the esr sample cavity by repeatedly scanning the spectrum at a constant set of instrumental conditions. The first derivative signal height is proportional to the free-radical concentration if the line widths remain constant.[26,27] No attempt was made to determine absolute free radical concentrations. These rate measurements were determined at different temperatures by employing the variable temperature probe. Rate constants were determined by making the appropriate plot of esr signal intensity at infinite time minus the signal intensity at time t, *i.e.*, $([N\cdot]_\infty - [N\cdot]_t)$, against time. It was also possible to determine the decay rates of these free radicals by a similar technique.

Esr Results.—In all the spectra observed a pronounced threefold symmetry was found; *i.e.*, the hyperfine pattern appearing at the center of the spectra also appeared at equal intervals at higher and lower fields. Since the intensity of each pattern was identical, the threefold symmetry was assumed to come about as a result of an interaction of the unpaired electron with the N^{14} nucleus for which $I = 1$. Similar threefold symmetry and N^{14} coupling constants have been observed with other reported nitroxides.[5-12]

The additional hyperfine structure observed results from interaction of the unpaired electron with the nuclear moment of the ring protons and to a lesser degree with other proton(s) in the molecule. Assignment of the interaction to specific protons is based on various factors which will become more obvious when all the spectra are considered. In all cases, the interaction with the *ortho* and *para* protons is much larger than with the *meta*-protons. The *meta*-proton interaction is often not obvious since it is complicated by a small interaction with the aliphatic protons. As a result, assignment of *meta* coupling constants is by no means unambiguous. The data in Table I were arrived at on the basis of this analysis.

In each of the following examples cited, the radical generated resulted from the reaction of the indicated nitrosoaromatic with 2,3-dimethyl-2-butene in benzene. (The reason for using this olefin in the majority of the studies will be discussed below.) Based on the evidence to follow, the structure of these nitroxides fits the following formula.



I

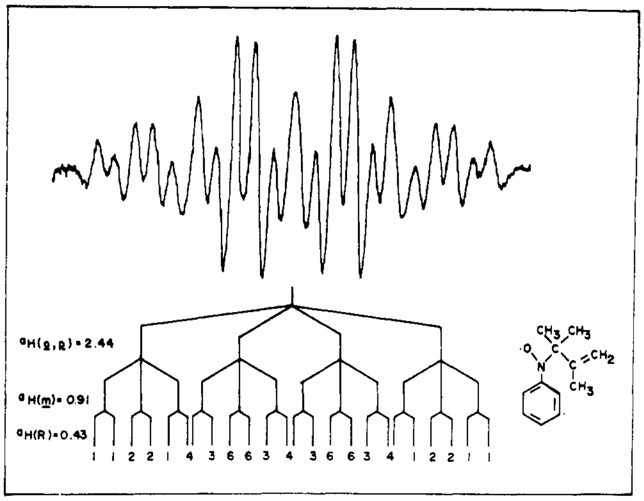


Figure 2.—Expanded-scale second derivative spectrum of the central subpattern of the nitrosobenzene–2,3-dimethyl-2-butene adduct free radical. Calculated coupling constants and relative intensities are indicated, field increasing to the left.

In Figure 1 through 5, esr spectra of some of the radicals are presented as the second derivative of the absorption *vs.* the magnetic field increasing to the left.

Nitrosobenzene.—The spectrum obtained from the parent compound, shown in Figure 1, demonstrates the characteristic threefold symmetry. Coupling to the *ortho* and *para* protons ($a_{H(o,p)} = 2.44$ gauss) is equivalent within the resolution obtainable; therefore, each of the three sub-patterns appears as a quartet which is further split to a lesser degree by the *meta* protons. The other interaction of 0.43 gauss cannot be definitely assigned to a particular molecular position. Although the $a_{H(R)}$ interaction is indicated in Figure 2 as resulting from only one proton, it can only be said definitely that an odd number of spin $^1/_2$ nuclei are responsible. (Careful inspection of the wings did not reveal any additional lines.)[28]

***o*-Chloronitrosobenzene.**—This spectrum was of considerable interest in that no hyperfine structure could be resolved, other than that resulting from interaction with the N^{14} nucleus. No structure from the chlorine nuclear moment would be expected; however, its presence undoubtedly contributes to the broader lines and hides the smaller proton interactions.

***m*-Chloronitrosobenzene.**—Together with the always-present threefold symmetry, the spectrum would suggest the presence of three equivalent nuclei of spin $^1/_2$ and a fourth proton with somewhat smaller interaction. This can be explained on the basis that the *ortho* and *para* protons are equivalent, resulting in a trio of quartets which are further split into doublets, presumably by the *meta* proton. The somewhat greater line widths again occur as a result of a small interaction with the chlorine nuclear moment.

***p*-Chloronitrosobenzene.**—The spectrum obtained from the *p*-chloro derivative shown in Figure 3 is what one might expect, considering the availability of two pairs of equivalent protons in the π-electron system. The larger interaction presumably arises from the *ortho* protons. Some of the spectral lines within each subpattern were not resolved.

***m,p*-Dichloronitrosobenzene.**—This spectrum was quite similar to that obtained from the *m*-chloro derivative except that

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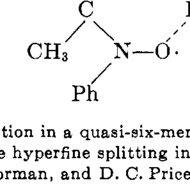
[26] The intensity of a resonance signal may be approximated by $I = KW^xh$, where K is a constant determined by line shape, W is the peak separation of the derivative, and h is its amplitude. The value of x varies from 1 to 2 depending on the modulation amplitude employed. Therefore, the free radical concentration is proportional to signal height at constant line width and modulation amplitude.

[27] Over-modulation of the magnetic field was employed here to avoid resolution of the complete hyperfine pattern.

[28] Subsequent to the original preparation of this paper, it was suggested that consideration be given the possibility of this doublet splitting being the result of through-space coupling to a single proton as is indicated below.



This type of 1,6 interaction in a quasi-six-membered cyclic system has been suggested to explain the hyperfine splitting in certain iminoxy radicals: B. C. Gilbert, R. O. C. Norman, and D. C. Price, *Proc. Chem. Soc.*, 234 (1964).

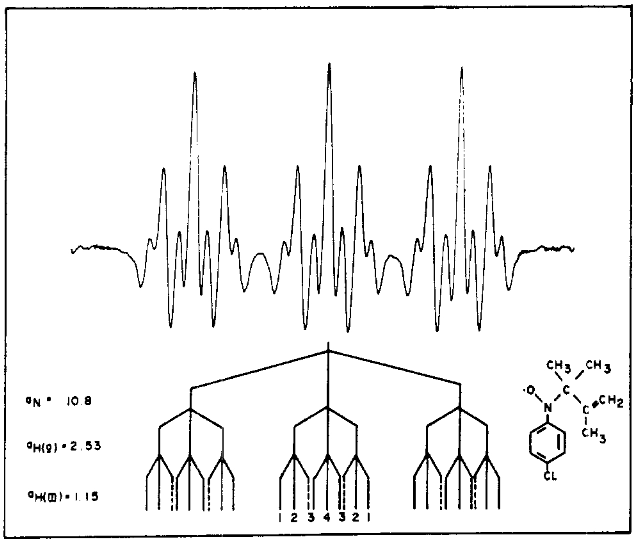


Figure 3.—Esr second derivative spectrum of the *p*-chloronitrosobenzene–2,3-dimethyl-2-butene adduct free radical. Calculated coupling constants, relative intensities, and proposed structure appear below spectrum, field increasing to the left.

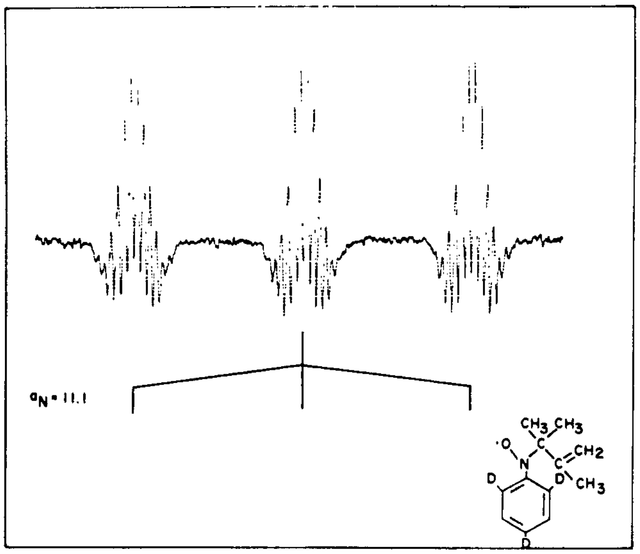


Figure 4.—Esr second derivative spectrum of the nitrosobenzene-2,4,6-d_3–2,3-dimethyl-2-butene adduct free radical. N^{14} interaction and proposed structure are given below spectrum, field increasing to the left.

only two equivalent spin $^1/_2$ nuclei were indicated. This resulted in three equivalent trios, each having intensity ratios of 1:2:1. Again somewhat broad lines are observed, obscuring any structure resulting from the other available ring proton.

p-**Nitrosotoluene.**—A slight departure from the threefold symmetry occurred in this case, as a result of overlap of the high and low field sub-patterns with the central subpattern. This comes about as a result of a fairly large interaction (2.53 gauss) with five equivalent protons. If one assumes equivalency of the methyl protons *para* to the nitrogen and the ring protons *ortho* to the nitrogen, such a hyperfine pattern would be expected. Further structure as a result of interaction with the remaining two ring protons could explain the additional lines. This spectrum was not dissimilar to the analogous *p*-nitrotoluene anion radical reported by Maki and Geske.[13]

TABLE I

OBSERVED COUPLING CONSTANTS FOR THE ADDUCT FREE RADICALS FROM SUBSTITUTED NITROSOBENZENE AND 2,3-DIMETHYL-2-BUTENE

Aryl group	Coupling constants in gauss				
	a_N	$a_{H(o)}$	$a_{H(p)}$	$a_{H(m)}$	$a_{H(other)}$
Ph	11.1	2.44	2.44	0.91	$a_{H(R)} = 0.43^a$
2,4,6-d_3-Ph	11.1	...	...	0.84	$a_{D(o,p)}, a_{H(R)} = 0.42^b$
o-ClPh	12.7	*c*	*c*	*c*	
m-ClPh	10.6	2.56	2.56	0.94	
p-ClPh	10.8	2.53	...	1.15	
m,p-Cl_2Ph	10.5	2.62	...	*c*	
o-CH_3Ph	12.3	...	...	...	$a_{H(x)} = 0.68^{d,e}$
p-CH_3Ph	11.2	2.53	...	1.08	$a_{H(p\text{-}CH_3)} = 2.53$
p-CH_3COPh	10.0	2.44	...	1.07	
p-PhOPh	10.9	2.36	...	1.06	$a_{H(x)} = 0.37^e$
p-CH_3OPh	11.5	2.20	...	1.17	

[a] Interaction with an odd number of equivalent protons. [b] Equal interaction with three deuterons ($I = 1$) and an odd number of equivalent protons. [c] Interaction not resolved. [d] The spectrum suggests an interaction with seven approximately equivalent protons. [e] Not assigned.

o-**Nitrosotoluene.**—A large N^{14} interaction was observed with this compound as was the case with the other *ortho* substituted derivative. Assignments for the additional structure in each of the three subpatterns cannot be definitely made due to the poor resolution. The spectra could be explained in terms of an equal but small (0.7 gauss) interaction with an odd number (at least seven) of approximately equivalent protons. This may encompass some R group protons as well as the *ortho, para,* and *o*-methyl protons. Although this seems unlikely in view of the data reported on *ortho*-substituted nitrobenzene anion radicals, the combined effect of an *ortho* substituent and a very bulky R group on the nitrogen could result in a large steric factor and thus considerable redistribution of the spin density.

p-**Nitrosoacetophenone.**—The compound gave a hyperfine pattern almost equivalent to the *p*-chloro isomer. The only significant difference was a somewhat smaller interaction with the N^{14} nucleus. This would be expected considering the larger positive Hammett σ constant[29] (electron-attracting affinity) for the acetyl group in the *para* position.

p-**Nitrosodiphenyl Ether.**—The hyperfine structure in this case is again characteristic of the other *para*-substituted compounds reported in that each of the three identical subpatterns is composed of a triplet further split to a lesser degree by two other equivalent protons. Additional structure with splitting of 0.4 gauss was resolved, for which a definite assignment cannot be made. The spectrum would suggest that it arises from an odd number of essentially equivalent protons.

p-**Nitrosoanisole.**—The spectrum of this radical is also consistent with the other *para*-substituted compounds discussed in that interaction with two pairs of equivalent protons is evident. The larger interaction is attributed to the protons *ortho* to the nitrogen and the smaller to the *meta* protons. Additional structure is apparent but only partially resolved. The somewhat greater N^{14} interaction observed, compared with I, is consistent with the electron-donating capacity of the methoxy group.

Nitrosobenzene-2,4,6-d_3.—Isotopic substitution was employed so that the assignment of coupling constants to the *ortho* and *para* position would be unambiguous and also to obtain better values for the *meta* and/or alkenyl group proton interactions. As can be seen in Figure 4, the N^{14} coupling constant is identical with that reported for the undeuterated case (I). The absence of the *ortho–para* proton interactions in this spectrum confirms the previous assignment. An expanded scale spectrum of the central subpattern is given in Figure 5. (Although originally overlooked by this author, it was pointed out by a referee that more detailed interpretation of this spectrum would be complicated by interaction with the *ortho* and *para* deuterons ($I = 1$) since $a_D = 0.153\ a_H$.) Based on the 2.44-gauss *ortho–para* interaction one would expect $a_{D(o,p)}$ to be about 0.37 gauss which is quite close to the measured value of 0.42 gauss. If one assumes an additional interaction of approximately 0.4 gauss with one proton (as observed in I) the experimental spectra can be rationalized.

Proof of Structure.—Although in solution these radicals have extreme stability,[30] attempts to isolate them in a pure state were unsuccessful. Structure proof was, therefore, carried out in-

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(29) L. P. Hammett, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1940, p 188.

(30) Little decay of the free-radical intensity of I in benzene occurs over a period of several months at room temperature.

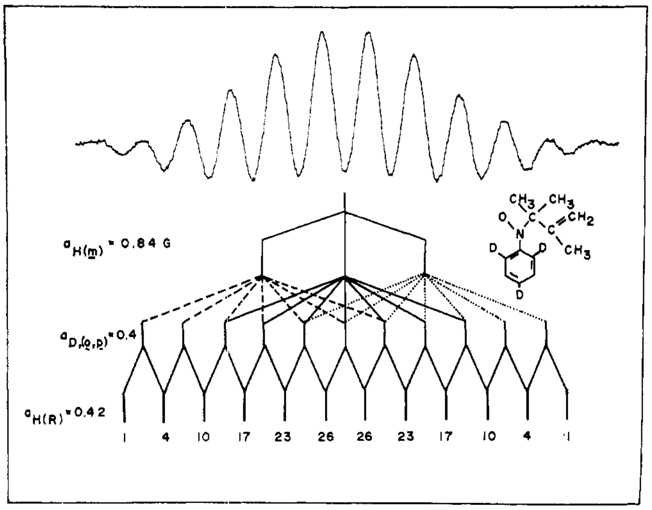
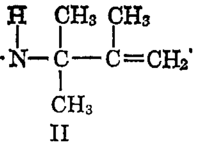


Figure 5.—Expanded-scale second derivative spectrum of the central subpattern of the nitrosobenzene-2,4,6-d_3–2,3-dimethyl-2-butene adduct free radical. Calculated coupling constants and relative intensities appear below spectrum, field increasing to the left.

directly. Reduction of a benzene solution of the nitroxide, I, with sodium and *n*-butanol resulted in a 38% yield of N-(1,1,2-trimethyl-2-propenyl)aniline, which was isolated by preparative gas chromatography. *Anal.* Calcd for $C_{12}H_{17}N$: C, 82.2; H, 9.86; N, 7.99; Found: C, 82.2; H, 9.77; N, 8.48. Both the infrared and nmr spectra were consistent with the proposed structure. In the nmr there were two equivalent alkyl CH_3 groups (δ = 1.40), one CH_3 group on a double bond (δ = 1.72), one aromatic NH (δ = 3.43), and two nonequivalent olefin protons (δ = 4.88, δ = 4.97). The chemical shift of the olefin protons and the lack of splitting of the C_1 methyl protons confirms the presence of the terminal methylene group.



$C_6H_5-NH-C(CH_3)_2-C(CH_3)=CH_2$

II

Reduction of a benzene solution of the nitroxide, I, with hydrogen over Pt-C at 120° and 400 psi of H_2, resulted in a 55% yield of N-(1,1,2-trimethylpropyl)aniline (III). (This saturated derivative could be separated from II by gas chromatography.) Its structure was consistent with the infrared and nmr spectra.

To confirm unequivocally the six-carbon side-chain structure, III was prepared by an alternate reaction and isolated by preparative gas chromatography. This procedure involved the condensation of aniline with 2,3-dimethyl-2-butene over an acid clay at 100° according to Olin.[24] The N-substituted derivative was isolated and found to have an identical infrared spectrum with that of III from reduction of the adduct free radical, I.

An alternate proof of structure was the preparation of the free radical, I, from the corresponding amine, II, by oxidation with hydrogen peroxide in the presence of sodium tungstate in methanol. (Russian workers have reported the use of this system to oxidize amines to the corresponding nitroxides.[12b,d]) A benzene solution of the free radical obtained in this manner was found to have an esr spectrum identical with I, prepared from nitrosobenzene and 2,3-dimethyl-2-butene. A comparison of the spectra are shown in Figure 6. Although the degree of resolution is slightly different, the coupling constants are found to be identical.

Also shown in Figure 6 is the esr spectrum of the radical prepared by a similar oxidation of N-(1,1,2-trimethylpropyl)-aniline, III. The observed N^{14} and proton coupling constants are significantly different from those observed with I and consistent with the absence of unsaturation in the alkyl group.

Lemaire and co-workers[31] reported the esr spectrum of phenyl-*t*-butyl nitroxide prepared from phenylmagnesium bromide and nitro-*t*-butane. This author was able to prepare a free radical by the oxidation of N-*t*-butylaniline which had an identical spectrum with that reported by Lemaire (a_N = 12.3 gauss; $a_{H(o,p)}$ = 1.80 gauss; a_m = 0.90 gauss). (The disagreement in N^{15} coupling constants must be the result of the difference in solvents.) Therefore, by analogy the assumption that II and III are indeed oxidized to the corresponding nitroxides would appear valid.

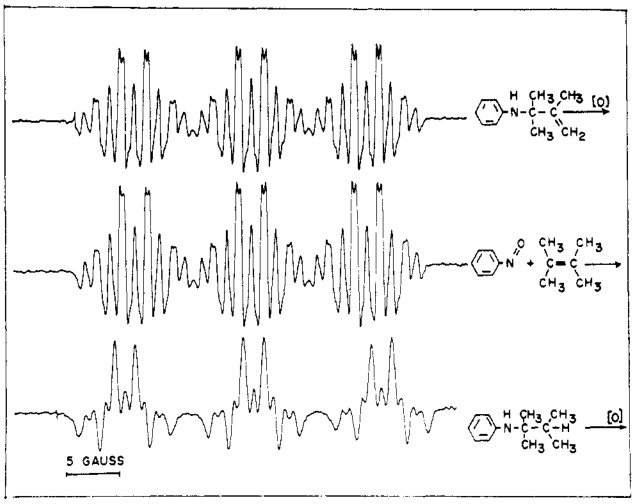


Figure 6.—Esr second derivative spectrum of benzene solution of nitroxyl radicals prepared as indicated, field increasing to the left.

Reaction Kinetics.—The kinetic study of the reaction between nitrosobenzene and 2-methyl-2-pentene,[32] which should be characteristic of all these reactions, indicated that the reaction was over-all second order. As shown in Table II, column 4, the rate constants were found to be nearly equivalent when either reactant was in excess. At equal concentration of both reactants a second-order radical formation occurred; however, since the units of concentration were arbitrary a direct comparison of the rates could not be made.

TABLE II

Concn, *M*		Reaction rates at 23°	
PhNO	$CH_3C(CH_3)=CHCH_2CH_3$	k_1, sec^{-1}	k_2',[a] sec^{-1} M^{-1}
0.0391	0.355	4.38×10^{-4}	1.24×10^{-3}
0.173	0.0178	2.18×10^{-4}	1.26×10^{-3}

[a] k_2' is calculated by dividing k_1 by the concentration of the excess reagent.

Similar radical formation kinetics were also observed with a number of other olefins including 2,3-dimethyl-2-butene, cyclohexene, 1-phenyl-2-butene, and 2-octene. The rates of formation and estimated free radical yield with the various olefins were quite variable. Greater reaction rates did not necessarily result in a higher yield of free radicals.

Measurement of the rate of formation of I at a series of temperatures between 10 and 70° provided an activation energy for this reaction of 10 ± 1 kcal/mole.

Concerning the yield of this reaction, an approximate determination of free-radical concentration was made by comparison of the signal intensity with that of DPPH under the same conditions. Nitrosobenzene and 2,3-dimethyl-2-butene were found to form the free radical, I, to the extent of approximately 40% of theory. Considering the inherent errors involved in this type of measurement the results are probably good to no better than ±20%. However, they are sufficiently accurate to point out that this reaction takes place to a significant degree.

Discussion

Hyperfine Structure.—The hyperfine structure observed on some of the alkenylaryl nitroxides is of

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[31] H. Lemaire, A. Rassat, and A. M. Rovat, *Bull. Soc. Chim. France,* 1980 (1963).

[32] This olefin was used in the earlier part of this work before 2,3-dimethyl-2-butene was obtained.

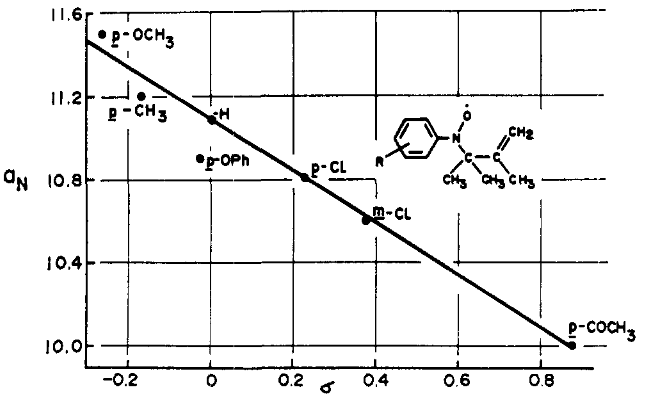


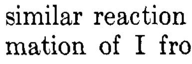
Figure 7.—a_N (gauss) *vs.* Hammett σ for *meta-* and *para*-substituted alkenylaryl nitroxides of I.

considerable interest. Not only is the electronic effect of the substituent on the magnitude of a_N quite apparent, but a steric factor also appears to come into play. In this regard, the *o*-chloro derivative of I will be considered. In Table I, it will be noted that this derivative has a much larger N^{14} coupling constant than either the electronically similar *para* or *meta* derivative. This anomaly can be qualitatively explained by considering the steric effect of the *ortho* substituent. The chlorine atom inhibits free rotation about the nitrogen–carbon bond. This steric interference reduces the interaction between the unpaired electron and the π-electron cloud of the phenyl group. A larger interaction with the N^{14} nuclei and a smaller interaction with the ring protons result. The same argument can be used to explain the larger value of a_N observed for the *o*-methyl derivative. Geske and Ragle[33] made similar observations with the *o*-methyl substituted nitrobenzene anion radicals.

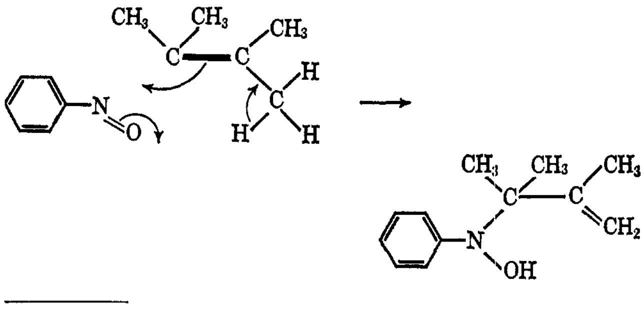
As indicated in Figure 7, reasonably good correlation exists between the magnitude of the N^{14} interaction and the Hammet σ constants[29] for the *meta* and *para* derivatives investigated. Such a dependency was also observed by Maki and Geske on the nitrobenzene anion radical[13] and by Rassat, *et al.*, on *t*-butylphenyl nitroxides.[7c] This behavior is to be expected since the magnitude of a_N indirectly reflects, in a qualitative sense, the over-all electron distribution which is quite dependent upon the relative electron affinity of the substituent group.

Assignment of the ring-proton coupling constants for these free radicals is not unambiguous in most cases. As a result of the deuterium substitution experiment the assignment of *ortho* and *para* interaction constants is well substantiated, at least in the case of the parent radical, I, and by analogy in the other cases. In contrast the assignment of *meta* coupling constants is somewhat less definite. In general the assignments proposed in all cases are consistent with the results of Baird and Thomas[7] as well as those of others working with similar radicals.[3,13]

Since it was desirable to obtain spectra with as little complexity as possible, 2,3-dimethyl-2-butene was primarily used as the olefin in these studies. Considering the addition reaction which appears to be taking place, this symmetrical olefin could result in only a single species. In addition, the proposed product would contain no α protons which might further complicate the spectra. Earlier studies with 2-methyl-2-pentene resulted in spectra which were much more difficult to interpret. It is quite likely that two radical species were present in that case: one with α protons, the other without. Further studies with other olefins should be undertaken.

Reaction Mechanism.—The chemistry of nitroso compounds has been the subject of two reviews in recent years.[34,35] The reactions of nitrosobenzene with certain substituted ethylenes was thought to result in four-membered rings, 1,2-oxamines.[36] Hepfinger and co-workers[37] have since shown that the products isolated in these cases are hydroxylamines or nitrones,  $\underset{R'}{R-\underset{|}{C}}=\underset{\overset{\downarrow}{O}}{N}-Ph$. Other reports, in the most part by Alessandri, indicate that the reactions with carbon–carbon double bonds, including internal olefins, result in the formation of nitrones.[38-40] As a result of the work herein reported it would appear that nitroxides may have also been formed in many of the reactions cited in the literature; however, they further react upon workup, resulting in a variety of products. It may be significant that the early workers in this area did not get good yields, and always reported azoxybenzene as a byproduct. Hamer and Macaluso have recently reported similar results.[41] Attempts by the author to isolate the addition products of nitrosobenzene and 2-methyl-2-pentene were unsuccessful, however, a considerable amount of azoxybenzene was recovered.

Nitroso compounds are known to undergo a Diels–Alder addition to dienes resulting in a six-membered heterocycle. The major studies in this area were done by Arbuzov,[42] Wichterle,[43] and their co-workers, and more recently by Kresze and Schulz.[44] A somewhat similar reaction appears to be taking place in the formation of I from nitrosobenzene and 2,3-dimethyl-2-butene. The proposed reaction scheme given below is supported by the second-order kinetics which were observed. (This mechanism is roughly analogous to the



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[33] D. H. Geske and J. L. Ragle, *J. Am. Chem. Soc.*, **83**, 3532 (1961); D. H. Geske, J. L. Ragle, M. A. Bambenek, and A. L. Balch, *ibid.*, **86**, 987 (1964).

[34] B. G. Gowenlock and W. Luttke, *Quart. Rev.* (London), **12**, 321 (1958).

[35] Y. Ogata, *Yuki Gosei Kagaku Kyokai Shi*, **19**, 438 (1961).

[36] C. K. Ingold and S. D. Weaver, *J. Chem. Soc.*, 1456 (1924).

[37] N. F. Hepfinger, C. E. Griffin, and B. L. Shapiro, *Tetrahedron Letters*, 1365 (1963); N. F. Hepfinger and C. E. Griffin, *ibid.*, 1361 (1963).

[38] A. Angeli, L. Alessandri, and R. Pegna, *Atti. Accad. Naz. Lincei*, **19**, I, 650 (1910).

[39] L. Alessandri, *ibid.*, **24**, I, 62 (1915).

[40] L. Alessandri, *Gazz. Chim. Ital.*, **54**, 426 (1924).

[41] Jan Hamer and A. Macaluso, *Tetrahedron Letters*, 381 (1963).

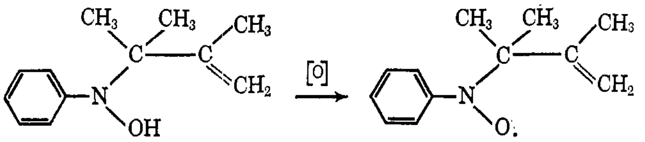
[42] Yu. A. Arbuzov and T. A. Pisha, *Doklady Akad. Nauk SSSR*, **116**, 71 (1957).

[43] O. Wichterle, V. Gregor, A. Dubansky, and V. Seidl, *Chem. Listy*, **51**, 605 (1957).

[44] G. Kresze and G. Schulz, *Tetrahedron*, **12**, 7 (1961).

mechanism recently discussed by Hill and Rabinovitz[45] for the addition of olefins to dienophiles.)

The hydroxylamine which is initially formed, being quite reactive, is readily oxidized by unreacted nitrosobenzene (which would account for the low yield based on nitrosobenzene)[46] or oxygen to the corresponding



nitroxide. Although further study would be necessary to establish this mechanism definitely, it appears to be consistent with all the facts.

The hydroxylamine intermediate has not been isolated and unequivocally identified; however, the following observations lend support to its presence. While attempting to reduce a benzene solution of I with hydrogen over Pt–C, it was found that, after a short reaction period, the esr spectrum disappeared, whereas upon standing in air a similar esr signal reappeared and increased in intensity with time. Increasing the reaction temperature and time period resulted in a product which did not revert to the free radical upon exposure to air. Preparative gas chromatography on the initial solution after partial reduction resulted in the isolation of a component which had the characteristic infrared bands one would expect to find in the corresponding hydroxylamine. These observations strongly indicate that the hydroxylamine is an intermediate.

Acknowledgments.—The author wishes to thank Drs. M. J. S. Dewar and W. H. Urry for their suggestions with regard to this work. Also, A. B. S. thanks Dr. G. R. Wilder for his assistance in obtaining evidence to support the proposed free radical structure together with his suggestions and comments. Lastly, the author is indebted to Mr. D. D. Mullins who prepared most of the nitroso compounds used in this study.

[45] R. K. Hill and M. Rabinovitz, *J. Am. Chem. Soc.*, **86**, 965 (1964).

[46] One mole of nitrosobenzene could reduce 2 moles of hydroxylamine in which event the maximum free-radical yield would be 67% based on nitrosobenzene.

Synthesis and Chemistry of 4-Amino-4,6-dideoxy Sugars. I. Galactose[1]

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Received March 25, 1966

The synthesis of 4-amino-4,6-dideoxy-D-galactose, Ia, and its N-methyl and N,N-dimethyl homologs is described starting from methyl-α-D-glucopyranoside.

The recently described synthesis of amosamine[2] marked the first synthesis of a 4-amino-4,6-dideoxy hexose, a new class of carbohydrate. The increasing frequency of isolation of class members from natural sources[1] emphasizes their fundamental biological importance. Accordingly, we have initiated a program of synthesis of several member amino sugars so that the scope and mechanism of their biological activity may be the more rapidly elucidated. Further, a successful synthetic program would also result in an expanded knowledge of the fundamental chemistry of carbohydrates, and, in particular, chemistry of the 4-carbon site of hexoses.

4-Amino-4,6-dideoxy-D-galactose, Ia, is naturally occurring being found in the cell extracts of *Escherichia coli* strain Y10.[1] This amino sugar is also an anticipated constituent of thirteen other bacterial types and strains.[1] The N-alkyl homologs of Ia have not been found in nature to date.

4-Amino-4,6-dideoxy-D-galactose (Thomosamine).[3]—The starting material for Ia was methyl 2,3-di-O-benzyl-α-D-glucopyranoside which was made from methyl-α-D-glucopyranoside by known procedures[4] in 60% over-all yield for the three steps. Subsequent dimesylation afforded IIa in 98% yield. Selective displacement of the primary 6-mesyloxy group with iodide ion was smoothly effected in refluxing 2-butanone affording IIb in 85% yield. At 105° in acetone some displacement of the 4-mesyloxy function occurred giving, in addition to IIb, 11% of a diiodo derivative, most probably a mixture of C-4 epimers.[5]

Reduction of the 6-iodo group was conveniently done on a large scale with lithium aluminum hydride in tetrahydrofuran solvent. To obtain convenient reaction times it was necessary to use excess hydride and this resulted in reductions at sites other than position 6. Thus, from reduction of IIb for 6 hr in refluxing tetrahydrofuran there was obtained 82% of the desired 6-deoxy-4-mesylate IIc. An infrared spectrum of the mother liquors was devoid of mesylate absorption ($\nu_{\mathrm{SO_2}}$ 8.50 μ) and indicated the presence of a hydroxyl group. Remesylation of the mother liquors afforded additional IIc indicating the presence in the original reaction mixture of about 12% of the 4-hydroxy compound IIIa which arose from O–S cleavage by hydride. Also, from chromatography of the remesylation there was obtained as a liquid 3% of the 4,6-dideoxy derivative IIIb and about 1% of starting 6-iodo-4-mesylate IIb. In all, then, conversion of IIb to IIc could be effected in a yield of 94%.

Introduction of the nitrogen function was effected by displacement with azide ion of the 4-mesyloxy group. Subsequent lithium aluminum hydride reduction of the

[1] A preliminary account of a portion of this work has appeared: C. L. Stevens, P. Blumbergs, D. H. Otterbach, J. L. Strominger, M. Matsuhashi, and D. N. Dietzler, *J. Am. Chem. Soc.*, **86**, 2937 (1964).

[2] Paper II of this series: C. L. Stevens, P. Blumbergs, F. A. Daniher, D. H. Otterbach, and K. G. Taylor, *J. Org. Chem.*, **31**, 2822 (1966), and references therein cited.

[3] The name thomosamine is proposed for this amino sugar in honor of Olin E. Thomas, vice-president and treasurer of Wayne State University.

[4] (a) K. Freudenberg and E. Plankenhorn, *Ber.*, **73B**, 621 (1940); (b) D. J. Bell and J. Lorber, *J. Chem. Soc.*, 453 (1940).

[5] Treatment of IIc under similar conditions afforded a mixture of epimeric iodides: C. L. Stevens, K. G. Taylor, and J. A. Valicenti, *J. Am. Chem. Soc.*, **87**, 4579 (1965).