a series of appropriately substituted compounds have been compared in a common solvent under conditions such that the extent of ionization was considerable. For instance, in *t*-butyl alcohol solution containing excess potassium *t*-butoxide the rates of oxidation are: *p*-nitrotoluene > 2,4-dinitrotoluene > 2,4,6-trinitrotoluene; *p*-nitrodiphenylmethane > *p*,*p*'-dinitrodiphenylmethane >> 2,2',4,4'-tetranitrodiphenylmethane (stable); *p*-nitrotriphenylmethane > tris-(*p*-nitrophenyl)-methane; phenylacetonitrile > *p*-nitrophenylacetonitrile; thiophenol >> *p*-nitrothiophenol (stable); while in dimethyl sulfoxide–*t*-butyl alcohol mixtures (80–20), aniline >> *p*-nitroaniline (stable), and *p*-nitrocumene > 2,4-dinitrocumene. Under conditions wherein ketones are oxidized readily in basic solution, many *β*-dicarbonyl compounds are stable,[5] presumably due to the fact that the second carbonyl group stabilizes the enolate anion more than the radical and thereby decreases the ease with which reaction 1 will occur. In a similar manner we have observed that in dimethyl sulfoxide–*t*-butyl alcohol solutions (80–20%) in the presence of a two-fold excess of potassium *t*-butoxide, the relative rates of oxygen absorption are

$CH_3C_6H_4NO_2\text{-}p > CH_2(C_6H_4NO_2\text{-}p)_2 > CH(C_6H_4NO_2\text{-}p)_3$ (all in *t*-butyl alcohol)
$CH_3COCH_3 > CH_2(COCH_3)_2$, $CH_2(CH_3CO)CO_2C_2H_5$
$CH_3COC_6H_5 > CH_2(COC_6H_5)_2$ (stable)
$CH_2(C_6H_5)CO_2C_2H_5 > CH(C_6H_5)(CO_2C_2H_5)_2$ (stable)
$CH_3SO_2CH_3$, $CH_2(SO_2CH_3)_2$, $CH(SO_2CH_3)_3$ (all stable)
$CH_3COC_6H_5 > CH_2(NO_2)COC_6H_5$ (stable)
$CH_2(C_6H_5)COC_6H_5 > CH(C_6H_5)(CN)COC_6H_5$ (stable)

In aliphatic series one usually expects radical stabilities of tert. > sec. > prim. whereas carbanion stabilities are usually prim. > sec. > tert. Thus, other factors being equal, the conversion of a tert.-carbanion to a tert.-radical should always occur more readily than the conversion of a prim.-carbanion to a prim.-radical. In every appropriate case we know of this relationship holds. Thus, in *t*-butyl alcohol solution 2,4-dinitrocumene is oxidized more readily than 2,4-dinitrotoluene. In dimethyl sulfoxide–*t*-butyl alcohol mixtures (80–20) these relative rates are observed

$(CH_3)_2CHCOCH(CH_3)_2 > CH_3CH_2COCH_2CH_3 > CH_3COCH_3$
$(CH_3)_2CHSO_2CH(CH_3)_2 > CH_3CH_2SO_2CH_2CH_3 \gg CH_3SO_2CH_3$ (stable)
$(CH_3)_2CHCN > CH_3CH_2CN > CH_3CN$
$(CH_3)_2CHCO_2C_2H_5 > CH_3CH_2CO_2C_2H_5 \gg CH_3CO_2C_2H_5$ (stable)
$(CH_3)_2CHCOC_6H_5 > CH_3CH_2COC_6H_5 > CH_3COC_6H_5$[6]
$(CH_3)_2CHNO_2 > CH_3CH_2NO_2 > CH_3NO_2$[6]

Substitution of a phenyl group for a hydrogen atom does not have a consistent effect on the ease of oxidation of the resulting carbanion. The phenyl group is recognized to be important in stabilizing both radicals and carbanions and one might expect these effects to cancel in regard to the ease of occurrence of reaction 1. However, in most cases the phenyl-substituted compound oxidizes more readily than the unsubstituted compound, indicating that in general the phenyl group stabilizes a radical more than a carbanion. The following relative rates of oxidation have been observed in dimethyl sulfoxide–*t*-butyl alcohol (80–20) containing excess potassium *t*-butoxide

$(C_6H_5)_2CHCN > C_6H_5CH_2CN > CH_3CN$
$p\text{-}NO_2C_6H_5CH_3 > p\text{-}NO_2C_6H_5CH_2C_6H_5 > p\text{-}NO_2C_6H_5CH(C_6H_5)_2$ (all in *t*-butyl alcohol)
$(C_6H_5)_2CHCO_2C_2H_5 > C_6H_5CH_2CO_2C_2H_5 \gg CH_3CO_2C_2H_5$ (stable)
$C_6H_5CH_2COCH_2C_6H_5 > CH_3COCH_3$
$C_6H_5CH_2SO_2CH_2C_6H_5 \gg CH_3SO_2CH_3$ (stable)
$C_6H_5COCH(C_6H_5)_2 > C_6H_5COCH_2C_6H_5 > C_6H_5COCH_3$
$C_6H_5CH_2OH > (C_6H_5)_2CHOH > CH_3OH$
$CH_3NO_2 \gg C_6H_5CH_2NO_2$ (stable)

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[5] W. E. Doering and R. M. Haines, *J. Am. Chem. Soc.*, **76**, 482 (1954).

[6] These series were oxidized in the presence of deficient base. The oxidations are more rapid in deficient base than in the presence of excess potassium *t*-butoxide (see ref. 3c).

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THE FORMATION OF RADICAL-ANIONS BY ELECTRON TRANSFER BETWEEN ANIONS AND THEIR UNSATURATED ANALOGS IN DIMETHYL SULFOXIDE SOLUTION[1,2]

Sir:

We have shown in a previous publication[3] that electron transfer between carbanions and organic electron acceptors (*π*), such as the nitroaromatics, often occurs readily.

$$R\colon^- + \pi \longrightarrow \pi\cdot^- + R\cdot \longrightarrow \text{products}$$

Experimentally this irreversible process is not as conveniently studied as the reversible electron transfer reaction between a dianion and its unsaturated analog.

$$\pi^= + \pi \rightleftarrows 2\pi\cdot^- \text{ or } \pi H^- + \pi \rightleftarrows 2\pi\cdot^- + H^+$$

It is known that in basic solution electron transfer occurs between hydroquinones and quinones[4] and between benzoin and benzil.[5] Dianions prepared from alkali metals and an olefin will in certain cases react with more of the olefin to produce radical-ions. Such reactions have been observed for stilbene,[6a] tetraphenylethylene[6b] and cyclooctatetraene.[6c] Calculations indicate that in the alkali metal adducts of aromatic hydrocarbons[7] the radical-anion is favored over a mixture of dianion and unreacted hydrocarbon.[7] It is also recognized that dianions, obtained by the addition

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[1] Reactions of Resonance Stabilized Anions. V.

[2] This work was supported by a grant from the National Science Foundation and the Petroleum Research Fund, administered by the American Chemical Society. Grateful acknowledgment is hereby made to the donors of the Petroleum Research Fund as well as to the National Science Foundation.

[3] G. A. Russell and E. G. Janzen, *J. Am. Chem. Soc.*, **84**, 4143 (1962).

[4] T. H. James and A. Weissberger, *ibid.*, **60**, 98 (1938); L. Michaelis, M. P. Schubert, R. K. Reber, J. A. Kuck and S. Granick, *ibid.*, **60**, 1678 (1938); J. H. Baxendale and H. R. Hardy, *Trans. Faraday Soc.*, **49**, 1433 (1953); H. Diebler, M. Eigen and P. Matthies, *Z. Naturforsch.*, **16B**, 629 (1961).

[5] A. Weissberger, H. Mainz and E. Strasser, *Ber.*, **62**, 1942 (1929); A. Weissberger, *ibid.*, **65**, 1815 (1932); L. Michaelis and E. S. Fletcher, *J. Am. Chem. Soc.*, **59**, 1246 (1936); J. L. Ihrig and R. G. Caldwell, *ibid.*, **78**, 2097 (1956).

[6] (a) D. E. Paul, D. Lipkin and S. I. Weissman, *ibid.*, **78**, 116 (1956); (b) J. F. Garst and R. S. Cole, Abstracts of Papers, 142nd Meeting of the Am. Chem. Soc., Atlantic City, 1962, p. 5-Q; (c) T. J. Katz and H. L. Strauss, *J. Chem. Phys.*, **32**, 1873 (1960).

[7] N. S. Hush and J. Blackledge, *ibid.*, **23**, 514 (1955); C. J. Hoijtink, E. DeBoer, P. H. van der Heij and W. P. Weijland, *Rec. trav. chim.*, **75**, 487 (1956).

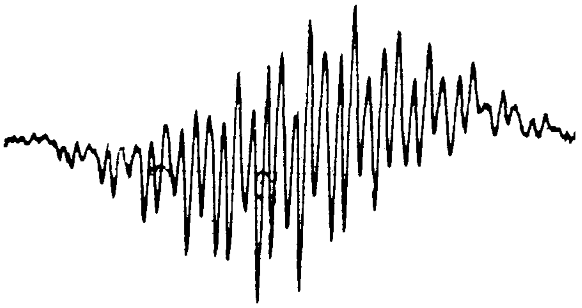

Fig. 1.—Radical-anion produced by electron transfer between azobenzene (0.01 *M*) and hydrazobenzene (0.01 *M*) in dimethyl sulfoxide (80)–*t*-butyl alcohol (20) containing 0.02 *M* potassium *t*-butoxide.

of alkali metals to olefins or aromatics, will undergo electron-transfer with ketones to give ketyl radical anions.[8] The electrolytically produced dianion of dinitrodurene undergoes electron transfer with dinitrodurene[9a] while possibly the dianion formed by alkali metal reduction of phenanthradene undergoes electron transfer with phenanthradine.[9b]

We have investigated the formation of radical-anions by use of a 1:1 mixture of an unsaturated compound and its dihydro derivative in the presence of potassium *t*-butoxide in dimethyl sulfoxide solution.[10] The observation of the formation of radical-ions must depend on the ability of the base and solvent system to ionize the dihydro compound (πH_2) as well as the ease of electron transfer. By virtue of the unique properties of dimethyl sulfoxide we have been able to observe many electron transfer reactions in the presence of potassium *t*-butoxide which cannot be observed in conventional solvents. Experiments were performed using a Varian V-4500 100 kc. e.p.r. spectrometer equipped with a flow system. Solutions (0.02 *M*) were saturated with thoroughly deoxygenated nitrogen before mixing. The solvent was dimethyl sulfoxide (80%)–*t*-butyl alcohol (20%) containing potassium *t*-butoxide equivalent to the potentially ionizable hydrogen atoms.

Electron transfer was observed in these systems: acridan–acridine, 1,2-dihydro-2,3-diphenylquinoxaline – 2,3 - diphenylquinoxaline, 9,9′ - bifluorene–Δ - 9,9′ - bifluorene, 9,10 - dihydroanthracene–anthracene, hydrazobenzene – azobenzene, furoin–furil, fluoren - 9 - ol – fluoren - 9 - one, xanthen - 9-ol – xanthen - 9 - one, benzhydrol – benzophenone, 1,1,4,4 - tetraphenyl - 2 - butene – 1,1,4,4 - tetraphenyl - 2,3 - butadiene and acridan – azobenzene. Electron transfer was not observed in these systems, even in pure dimethyl sulfoxide: 1,3-cyclohexadiene–benzene, 1,4 - dihydronaphthalene – naphthalene, 1,1,2,2 - tetraphenylethane – tetraphenylethylene, hydrazo - bis - isobutyronitrile – azo - bis - isobutyronitrile, 1,2-bis-(4-pyridyl)-ethane–1,2-bis-(4-pyridyl)-ethylene, N,1,1-triphenylmethylamine–N-diphenylmethyleneaniline, and N-phenylbenzylamine–N-benzylideneaniline.

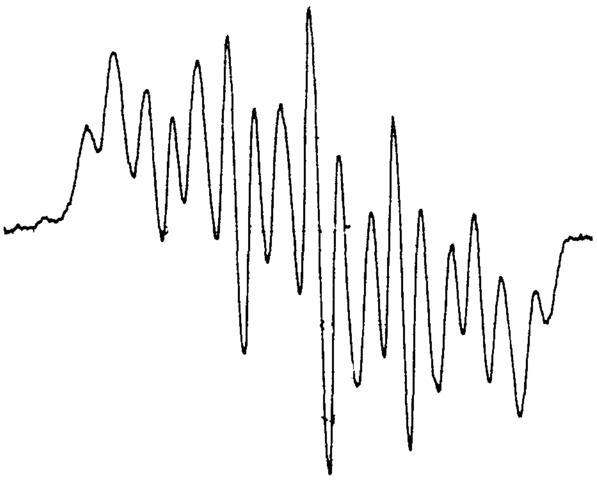

Fig. 2.—Radical-anion produced by electron transfer between 2,3-diphenylquinoxaline (0.01 *M*) and 1,2-dihydro-2,3-diphenylquinoxaline (0.01 *M*) in dimethyl sulfoxide (80)–*t*-butyl alcohol (20) containing 0.02 *M* potassium *t*-butoxide.

Many of the radical-ions produced have not been reported by more conventional syntheses.[6a,11] Figures 1 and 2 give the spectra of the radical-ions produced by electron transfer between hydrazobenzene and azobenzene and between 1,2-dihydro-2,3-diphenylquinoxaline and 2,3-diphenylquinoxaline. The e.s.r. spectra of some of the new radical-anions are summarized in Table I.

We have estimated the concentrations of radical-anions by comparison with diphenylpicrylhydrazyl in three of the cases and found over 50% of the starting compounds in the form of the radical-anions in the fluoren-9-ol–fluoren-9-one, xanthen-9-ol–xanthen-9-one, and hydrazobenzene–azobenzene systems.

Many of the radical-anions have been detected in the base-catalyzed autoxidation of the dihydro-compounds. Significant concentrations of the radical-anions were found in the reaction of traces of oxygen with hydrazobenzene, dihydrocinnamoin, fluoren-9-ol, xanthen-9-ol, 9,10-dihydroanthracene, acridan, 1,1,2,2-tetraphenylethane, 1,2-dihydro-2,3-diphenylquinoxaline, 9,9′-bifluorene, N-phenylbenzylamine, 1,4-dihydronaphthalene and 1,1,4,4-tetraphenyl-2-butene in dimethyl sulfoxide (80)–*t*-butyl alcohol (20) solution containing excess potassium *t*-butoxide. In these cases a radical-anion may be the primary reaction product

$$\pi H^- + O_2 \longrightarrow \pi\cdot^- + H^+ + \cdot O_2^-;\quad \pi^- + O_2 \longrightarrow \pi\cdot^- + \cdot O_2^- \qquad (a)$$

or a result of dehydrogenation followed by electron transfer

$$\pi H_2 + O_2 \xrightarrow{\text{base}} \pi;\quad \pi + \pi H_2 \xrightarrow{\text{base}} 2\pi\cdot^- \qquad (b)$$

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[8] W. Schlenk and R. Ochs, *Ber.*, **49**, 608 (1916); G. Wittig and D. Wittenberg, *Ann.*, **606**, 1 (1957).

[9] (a) D. H. Geske, J. L. Ragel, M. Bambenck and A. L. Balch, Abstracts of Papers, 142nd Meeting of the Am. Chem. Soc., Atlantic City, 1962, p. 10-T. (b) J. J. Eisch and R. M. Thompson, Abstracts of Papers, 140th Meeting of the Am. Chem. Soc., Chicago, 1961, p. 33-Q.

[10] NOTE ADDED IN PROOF.—The dipotassium salt of α,α,α′,α′-tetrakis-(ethylsulfonyl)-*p*-xylene (which can be made from the parent compound by potassium *t*-butoxide in *t*-butyl alcohol solution) undergoes electron transfer with 7,7,8,8-tetrakis-(ethylsulfonyl)-*p*-quinodimethan in acetonitrile solution (W. R. Hertler and R. E. Benson, *J. Am. Chem. Soc.*, **84**, 3474 (1962)).

[11] D. H. Geske and A. H. Maki, *J. Am. Chem. Soc.*, **82**, 2671 (1960); R. L. Ward, *ibid.*, **83**, 1296, 3523 (1961).

TABLE I

DESCRIPTION OF E.S.R. SPECTRA OF SOME RADICAL-ANIONS IN DIMETHYL SULFOXIDE(80)-*t*-BUTYL ALCOHOL(20)

System	No. of observed lines	Observed line width (gauss)[a]	Hyperfine structure
	17	29.3	A_N = 5.2, A_H = 1.5 gauss[b]
9,9′-Bifluorene-Δ-9,9′-bifluorene	19	13.4	Main quintet
Hydroazobenzene-azobenzene	41	38.2	Complex
Furoin-furil[c]	27	9.3	Main quintet
Fluorene-9-ol-fluoren-9-one	25	12.6	Main quintet
Xanthen-9-ol-xanthen-9-one	15	17.8	5 sets of 3
$Ph_2CHCH{=}CHCHPh_2 + Ph_2C{=}CHCH{=}CPh_2$	28	10.9	Complex

[a] Distance from first resolved maximum to last resolved minimum measured by comparison with *p*-benzosemiquinone (E. W. Stone and A. H. Maki, *J. Chem. Phys.*, **36**, 1944 (1962)). [b] Two equivalent nitrogen atoms and four equivalent hydrogen atoms. [c] In the presence of potassium hydroxide in ethanol.

However, for 1,1,2,2-tetraphenylethane and 1,4-dihydronaphthalene (a) rather than (b) must be occurring since under the reaction conditions electron transfer between the dihydro and unsaturated molecules cannot be observed.

Electron transfer may often involve the formation of an intermediate dimeric species.[9b]

$$\pi^{-} + \pi \rightleftarrows {}^{-}\pi - \pi^{-} \rightleftarrows 2\pi\cdot^{-}$$

Subjecting compounds of the type $H{-}\pi{-}\pi{-}H$ to highly basic conditions often leads to the radical anions. In the case of the pinacol of fluoren-9-one in pyridine(80%)-*t*-butyl alcohol (20%) in the presence of excess potassium *t*-butoxide, the fluorenyl ketyl is produced in high yield.[12]

Our results suggest a widespread occurrence of radical-anions as intermediates in reactions occurring in basic solution. In the future we will report on our studies utilizing unsaturated compounds in the presence of good monoanion donors in the carbanion, nitranion, and mercaptide ion categories.

[12] The cleavage by base of pinacols to ketyls is well known. See W. E. Bachmann, *ibid.*, **55**, 355 (1933); W. Schlenk and A. Thal, *Ber.*, **46**, 2840 (1913).

[13] Alfred P. Sloan Foundation Fellow.

[14] National Institutes of Health Predoctoral Fellow, 1962-1963.

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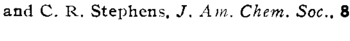
6-METHYLENETETRACYCLINES. II. MERCAPTAN ADDUCTS

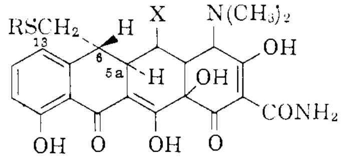
Sir:

6-Methylenetetracyclines[1] (1) have been found to react with mercaptans to produce adducts of structure 2. The reaction is general, and the sulfides themselves are reactive intermediates. Thus a new route is provided for broad structural variation at a position amply demonstrated[1,5,6] to be outside the area of the tetracycline molecule intimately associated with antimicrobial activity.[2]



1

1a, X = H
1b, X = OH



2

2a, R = C_6H_5, X = H
2b, R = C_6H_5, X = OH
2c, R = $C_6H_5CH_2$, X = H
2d, R = $C_6H_5CH_2$, X = OH
2e, R = $HOCH_2CH_2$, X = OH
2f, R = CH_3CO, X = H
2g, R = CH_3CO, X = OH

Exemplary of the 13-alkyl, aryl, aralkyl and acyl-α-6-deoxytetracyclines prepared are compounds **2a-2g**.[3] (Table I). The reaction is a typical free radical addition of mercaptan to olefinic double bond,[4] being catalyzed by oxygen, peroxides, or, as preferred in practice, 2,2′-azo-bis-(2-methylpropionitrile). Solvent is not critical, the mercaptan itself being used where suitable. That the products arise from addition across the double bond is evident from analyses, ultraviolet spectra (there is no longer the extended BCD-ring chromophore of the methylenetetracyclines[1]) and acid stability which is typical of the 6-deoxytetracyclines.[5,6] That the direction of addition is anti-Markownikow is shown by C-methyl analyses and n.m.r. spectra, which indicate lack of C-methyl groups. Stereochemistry at C.6 is assigned on the basis of Raney nickel desulfurization to the α-6-deoxytetracyclines (**3**),[6] for which independent stereochemical arguments have been presented.[6,7]

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[1] R. K. Blackwood, J. J. Beereboom, H. H. Rennhard, M. Schach von Wittenau and C. R. Stephens, *J. Am. Chem. Soc.*, **83**, 2773 (1961).

[2] Biological aspects of the sulfur derivatives will be reported.

[3] Other mercaptans successfully employed include R = CH_3, *n*-C_4H_9, $HOOCCH_2$, $C_2H_5OOCCH_2$, $H_2NCH_2CH_2$ and $HOOCCH(NH_2)CH_2$.

[4] See C. Walling, "Free Radicals in Solution," John Wiley and Sons, Inc., New York, N. Y., 1957, pp. 313-326, for a discussion of this reaction.

[5] (a) C. R. Stephens, K. Murai, H. H. Rennhard, L. H. Conover and K. J. Brunings, *J. Am. Chem. Soc.*, **80**, 5324 (1958); (b) J. R. D. McCormick, E. R. Jensen, P. A. Miller and A. P. Doerschuk, *ibid.*, **82**, 3381 (1960).

[6] M. Schach von Wittenau, J. J. Beereboom, R. K. Blackwood and C. R. Stephens, *ibid.*, **84**, 2645 (1962).

[7] H. Muxfeldt, *Angew. Chem. Internat. Edit.*, **1**, 372 (1962).