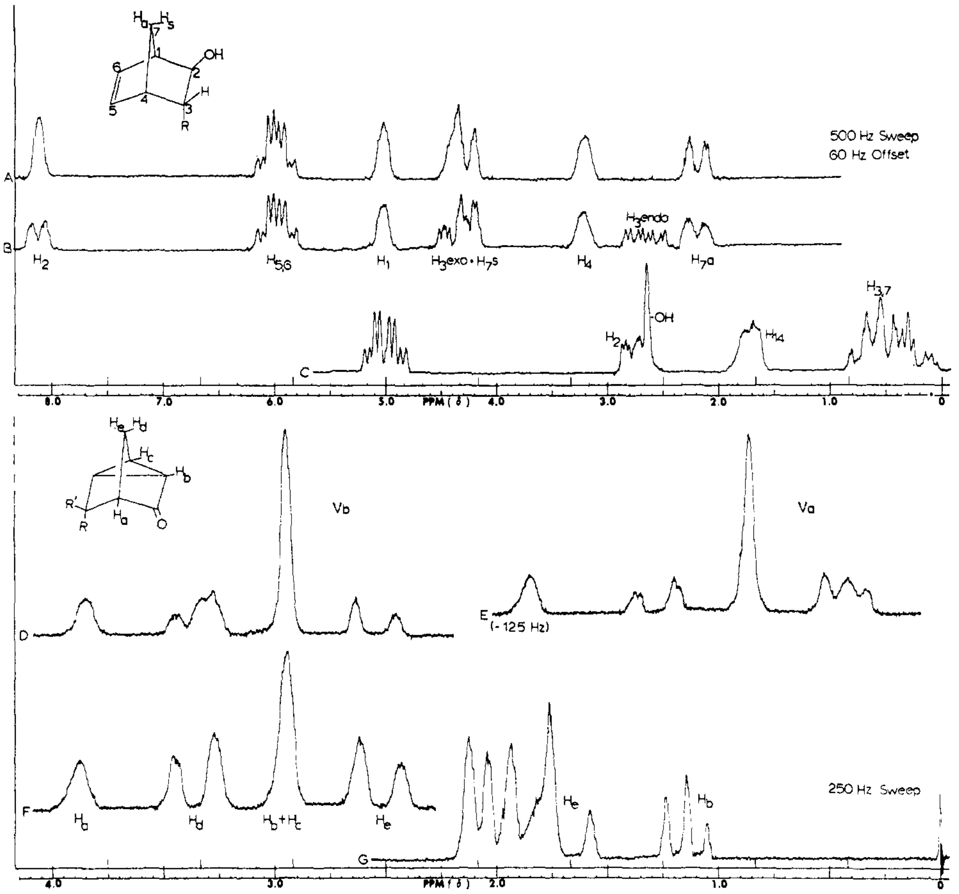
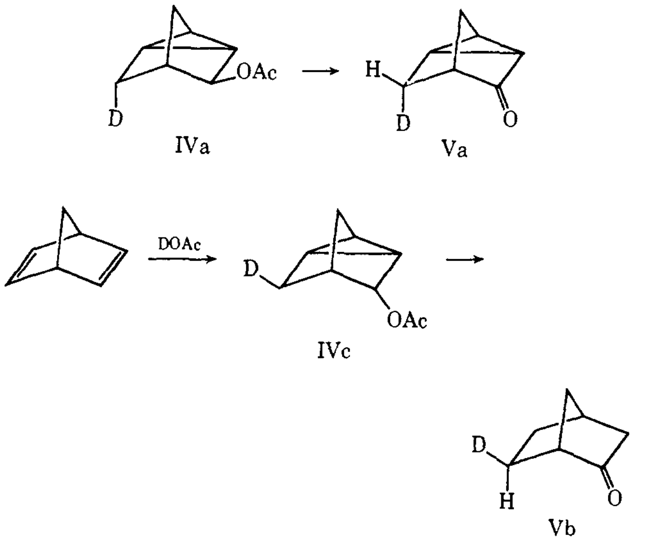


Figure 1. *exo*-Norbornenol: trace A, R = D; 22 mol % Eu(DPM)$_3$-CCl$_4$; B, R = H; 22 mol % Eu(DPM)$_3$-CCl$_4$; C, R = H; CCl$_4$. Nortricyclenone: trace D (Vb), R^1 = D; R = H; 22 mol % Eu(DPM)$_3$-CCl$_4$; E (Va), R^1 = H; R = D; 22 mol % Eu(DPM)$_3$-CCl$_4$; F, R^1 = R = H; 22 mol % Eu (DPM)$_3$-CCl$_4$; G, R^1 = R = H; CCl$_4$.

of the resulting spectrum (Figure 1, trace E) shows that deuterium in Va is located exclusively at the 5-endo position. The isomeric 5-exo deuterated ketone Vb was prepared from the known acetate IVc,[10] and comparison of the spectra of Va and Vb confirms our spectral and stereochemical assignments.[11]



IVa

Va

IVc

Vb

Both Ia and IIa are reduced by sodium borodeuteride with >97% retention of stereochemistry[12] and structure. The high specificity of reduction is inconsistent with a mechanism involving long-lived radical intermediates, as proposed for reduction of the mercury analogs of I and II.[1] Our results are consistent with an alternate interpretation involving initial formation of RPdH followed by concerted collapse to RH and palladium metal.[13]

Acknowledgment. We thank the donors of the Petroleum Research Fund, administered by the American Chemical Society, for support of this research.

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[10] S. J. Cristol, T. C. Morill, and R. A. Sanchez, *J. Org. Chem.*, 31, 2719 (1966), and references therein.

[11] Mass spectral analysis indicates the following distribution of deuterium, confirmed by nmr integration: IIIa, 7% d_0, 92% d_1, 1% d_2; Va, 9.5% d_0, 90% d_1, 0.5% d_2; Vb, 6.5% d_0, 92% d_1, 1.5% d_2. The per cent d_0 species corresponds to the isotopic distribution of the commercial deuterated reagents NaBD$_4$ and DOAc used in our work.

[12] Predominant retention of stereochemistry (per cent unspecified) has also been observed in the reduction of methoxydicyclopentadienylpalladium chloride dimer by Stille and Morgan.[3a]

[13] A nonradical bimolecular mechanism is also conceivable, and has some analogy: G. M. Whitesides, J. San Filippo, Jr., E. R. Stredronsky, and C. P. Casey, *J. Amer. Chem. Soc.*, 91, 6542 (1969).

* Address correspondence to this author.

Edwin Vedejs,* Mary F. Salomon
Department of Chemistry, University of Wisconsin
Madison, Wisconsin 53706
Received August 24, 1970

Exchange of Olefins with Oxymercurials

Sir:

We have found that oxymercurial ions (abbreviated Hg(Ol)OH$^+$), formed by reactions of olefins with mer-

Table I. Summary of Kinetic Data at 25°

$\mathrm{Ol_A}$	$\mathrm{Ol_B}$	k_4, M^{-1} sec^{-1}	k_5', M^{-1} sec^{-1}	k_1^{A}, M^{-1} sec$^{-1\,b}$	k_1^{B}, M^{-1} sec$^{-1\,b}$	$K_{\mathrm{eq}}^{\mathrm{A}\,c}$	k_1^{B}/k_5'
Ethylene	1-Hexen-6-ol[a]	$<5 \times 10^{-3}$	2.4	5.1×10^{3}	$\sim 1 \times 10^{5}$	$>10^{6}$	$\sim 4 \times 10^{4}$
Ethylene	2-Methyl-1-propen-3-ol	$\sim 5 \times 10^{-4}$	2.9×10^{-2}	5.1×10^{3}	3×10^{4}	$\sim 10^{7}$	1×10^{7}
Propylene	1-Penten-5-ol[a]	8.5×10^{-3}	2.1	1×10^{5}	$>10^{6}$	1.1×10^{7}	$>5 \times 10^{5}$
Propylene	2-Methyl-1-propen-3-ol	7.8×10^{-3}	8.5×10^{-2}	1×10^{5}	3×10^{4}	1.3×10^{7}	4×10^{5}
1-Butene	1-Penten-5-ol[a]	1.4×10^{-2}	1.6	8×10^{4}	$>10^{6}$	5×10^{6}	$>6 \times 10^{5}$
Isobutylene	1-Penten-5-ol[a]	6.1×10^{-1}	16	$>10^{6}$	$>10^{6}$	$>1.6 \times 10^{6}$	$>6 \times 10^{4}$
cis-2-Butene	1-Penten-5-ol[a]	8.8×10^{-2}	2.1	5.8×10^{3}	$>10^{6}$	6.6×10^{4}	$>5 \times 10^{5}$
cis-2-Butene	1-Hexen-6-ol[a]	9.3×10^{-2}	1.5	5.8×10^{3}	$\sim 1 \times 10^{5}$	6.2×10^{4}	6×10^{4}
cis-2-Butene	2-Methyl-1-propen-3-ol	9.0×10^{-2}	4.3×10^{-2}	5.8×10^{3}	3×10^{4}	6.5×10^{4}	7×10^{5}
cis-2-Butene	1-Buten-4-ol	9.3×10^{-2}	9.8×10^{-3}	5.8×10^{3}	8.4×10^{3}	6.2×10^{4}	9×10^{5}
trans-2-Butene	1-Penten-5-ol[a]	6.6×10^{-2}	2.7	1.7×10^{3}	$>10^{5}$	2.6×10^{5}	$>4 \times 10^{5}$
trans-2-Butene	1-Hexen-6-ol[a]	6.4×10^{-2}	1.6	1.7×10^{3}	$\sim 1 \times 10^{5}$	2.7×10^{5}	$\sim 6 \times 10^{4}$
trans-2-Butene	1-Buten-4-ol	6.6×10^{-2}	8.9×10^{-3}	1.7×10^{3}	8.4×10^{3}	2.6×10^{5}	9×10^{5}
Cyclohexene	1-Hexene-6-ol[a]	1.1×10^{-1}	1.4	5×10^{3}	1×10^{5}	5×10^{4}	$\sim 7 \times 10^{4}$
Cyclohexene	2-Methyl-1-propen-3-ol	1.0×10^{-1}	3.0×10^{-2}	5×10^{3}	3×10^{4}	5×10^{4}	1×10^{6}
Cyclohexene	1-Butene-4-ol	1.1×10^{-1}	1.1×10^{-2}	5×10^{3}	8.4×10^{3}	5×10^{4}	8×10^{5}
2-Methyl-1-propen-3-ol	1-Pentene-5-ol[a]	2.4×10^{-2}	1.8	3×10^{4}	$>10^{6}$	1×10^{6}	$>5 \times 10^{5}$
2-Methyl-1-propen-3-ol	1-Hexen-6-ol[a]	2.4×10^{-2}	5.7	3×10^{4}	$\sim 1 \times 10^{5}$	1×10^{6}	$\sim 2 \times 10^{4}$

[a] As previously shown the oxymercuration products of 1-penten-5-ol and 1-hexen-6-ol are cyclic ethers, namely 2-mercurimethyltetrahydrofuran and 2-mercurimethyltetrahydropyran, respectively.[1] [b] From ref 1. [c] Computed from $K_{\mathrm{eq}}^{\mathrm{A}} = k_1^{\mathrm{A}}/k_4$.

cury(II) according to eq 1, undergo facile exchange reactions with other olefins in aqueous solution (eq 2). This communication describes some kinetic and mechanistic features of these exchange reactions, the study of which has also yielded values, not otherwise readily measurable, of the equilibrium quotients of oxymercuration reactions.

$$\mathrm{Hg^{2+} + CHR{=}CHR' + H_2O \xrightarrow{k_1} HgCHRCHR'OH^+ \,[\equiv Hg(Ol)OH^+] + H^+} \qquad (1)$$

$$\mathrm{Hg(Ol_A)OH^+ + Ol_B \longrightarrow Hg(Ol_B)OH^+ + Ol_A} \qquad (2)$$

The reactions examined include the exchanges of the oxymercurials of ethylene, propylene, cyclohexane, *cis*- and *trans*-2-butene, and various unsaturated alcohols, with other unsaturated alcohols whose oxymercuration reactions have previously been examined.[1,2] All the reactant and product oxymercurial ions have previously been prepared and characterized.[1]

The kinetic measurements were performed at 25° in aqueous $\mathrm{HClO_4}$ solutions in which the ionic strength was maintained at 0.10 M with $\mathrm{NaClO_4}$. The reaction stoichiometries were confirmed for several representative systems, spectrophotometrically, by gas chromatographic determination of the displaced olefins, and by isolation of the oxymercurial products as halide salts. Kinetic measurements on each reaction typically encompassed the following initial composition ranges: 1×10^{-4}–2×10^{-4} M $\mathrm{Hg(Ol_A)OH^+}$, 2×10^{-3}–2×10^{-2} (in some cases to 10^{-1}) M $\mathrm{Ol_B}$, and 0.01–0.1 M $\mathrm{H^+}$. The reactions which (by virtue of the substantially constant $\mathrm{H^+}$ and $\mathrm{Ol_B}$ concentrations throughout each experiment) exhibited pseudo-first-order kinetic behavior were followed spectrophotometrically in the 220–240-nm range.

Over the extensive concentration ranges examined, all the reactions listed in Table I accurately obeyed the rate law described by eq 3. Values of the two rate constants, k_4 and k_5', were determined for each reaction and are listed in Table I.

$$-\mathrm{d[Hg(Ol_A)OH^+]}/\mathrm{d}t = k_4\mathrm{[Hg(Ol_A)OH^+][H^+]} + k_5'\mathrm{[Hg(Ol_A)OH^+][Ol_B]} \qquad (3)$$

We ascribe the two terms in the rate law to the paths depicted by eq 4 and 5, respectively. The rate-determining step in the first of these paths corresponds to the deoxymercuration reaction (*i.e.*, the reverse of eq 1) while the second path corresponds to the formation of a transient bisoxymercurial.[3] According to this interpretation, $k_5' = k_5k_6/(k_{-5} + k_6)$. Combination of the k_4 values with our previously determined oxymercuration rate constants, k_1,[1] yields the equilibrium quotients, K_{eq} $(= k_1/k_4)$, of the oxymercuration reactions. Values of both k_1 and K_{eq} are listed in Table I.

$$\mathrm{Hg(Ol_A)OH^+ + H^+ \xrightarrow{k_4} Hg^{2+} + Ol_A + H_2O \xrightarrow[\text{fast}]{Ol_B} Hg(Ol_B)OH^+ + Ol_A + H^+} \qquad (4)$$

$$\mathrm{Hg(Ol_A)OH^+ + Ol_B + H_2O \underset{k_{-5}}{\overset{k_5}{\rightleftharpoons}} HO(Ol_B)Hg(Ol_A)OH + H^+ \xrightarrow{k_6} Hg(Ol_B)OH^+ + Ol_A + H_2O} \qquad (5)$$

Examination of the data in Table I reveals the following features. 1. As required by the proposed interpretation the k_4 values for a given $\mathrm{Hg(Ol_A)OH^+}$ species are substantially independent of $\mathrm{Ol_B}$. 2. The trend of deoxymercuration rate constants (k_4^{A}) for the oxymercurial ions of the simple terminal olefins (*i.e.*, ethylene < propylene $\lesssim$ 1-butylene < isobutylene) parallels that of the corresponding oxymercuration rate constants (k_1^{A}), as well as the previously determined trends among the rate constants of (the somewhat faster) halide-assisted deoxymercuration reactions.[6,7] The k_4 values for

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[1] J. Halpern and H. B. Tinker, *J. Amer. Chem. Soc.*, **89**, 6427 (1967).

[2] The exchange reactions described in this communication appear to be quite general. The choice of unsaturated alcohols as the exchanging species ($\mathrm{Ol_B}$) for the purpose of our kinetic measurements was governed (as in the case of our earlier studies on the kinetics of oxymercuration)[1] by solubility considerations.

[3] The formation of bis(mercurials) has also been noted in the reaction of ethylene with phenylmercury(II) in methanol,[4] and in the mercury(II)-catalyzed hydrolysis of isopropenyl acetate.[5]

[4] L. R. Barlow and J. M. Davidson, *J. Chem. Soc. A*, 1609 (1968).

[5] J. Halpern and J. E. Byrd, *Chem. Commun.*, in press.

other olefins (*e.g.*, 2-butene, cyclohexene) lie outside this simple correlation. The values of K_{eq}, which reflect the superposition of the separate trends of k_1 and k_4, do not exhibit any obviously simple correlation (such as k_1 does) with olefin structure. 3. The oxymercuration equilibrium quotients (K_{eq}) span the range of values 5×10^4–1.2×10^7. The oxymercuration equilibria (eq 1) are thus displaced far to the right even in strongly acid solutions and are correspondingly difficult to measure directly.[8] In the two cases for which K_{eq} has previously been estimated, our values are in satisfactory accord with the earlier ones, namely 5.1×10^4 for Hg(cyclohexene)OH$^+$,[9] and 3.6×10^6 for Hg(ethylene)OH$^+$[10] (both at unit ionic strength). 4. Although our measurements do not yield separate values of k_5, k_{-5}, and k_6, it seems likely that for most of the reactions $k_6 \gtrsim k_{-5}$ and hence that $k_5' \sim k_5$.[11] In line with this, the trend of k_5' values for different unsaturated compounds (Ol_B) are found to be similar to the corresponding trends for the oxymercuration rate constants (k_1^B).[1] The expectation of such a correlation is reasonable since both k_1^B and k_5^B refer to oxymercuration processes for the same olefin. The rather high observed values of the ratio k_1^B/k_5' (10^4–10^7) reflect the much lower reactivities of the oxymercurial ions (compared to the free Hg^{2+} ion) toward further oxymercuration.

Finally, in view of the recent controversies surrounding this subject, it should perhaps be noted that our observation of these olefin exchange reactions and our interpretation of their mechanisms neither provide support for, nor rule out, the occurrence (in concentrations too low to be kinetically detectable from either the acid or olefin dependence) of the mercurinium ions that have been postulated as coexisting in equilibrium with oxymercurials and/or as intermediates in oxymercuration–deoxymercuration reactions.[12]

Acknowledgments. Support of this work by the National Science Foundation and by the Petroleum Research Fund, administered by the American Chemical Society, is gratefully acknowledged. J. E. B. also thanks the Shell Companies Foundation, Inc. for a Fellowship award.

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(6) L. L. Schaleger, M. A. Turner, T. C. Chamberlin, and M. M. Kreevoy, *J. Org. Chem.*, **27**, 3421 (1962).

(7) K. Ichikawa, K. Nishimira, and S. Takayama, *ibid.*, **30**, 1593 (1965).

(8) Deoxymercuration is favored by complexing of Hg^{2+}, notably by halide ions. In the presence of halide ions deoxymercuration can be effected at moderate acid concentrations and several quantitative kinetic studies of such halide-assisted deoxymercuration reactions have been reported.[6,7] While we have noted certain parallels between the rate constants of such reactions and our values of k_4, halide-assisted deoxymercurations do not correspond strictly to the reverse of the oxymercuration reactions depicted in eq 4.

(9) H. Lucas, F. Hepner, and S. Winstein, *J. Amer. Chem. Soc.*, **61**, 3102 (1939).

(10) P. Brandt and O. Plum, *Acta Chem. Scand.*, **7**, 97 (1953).

(11) It should be possible to derive actual values of k_5 from kinetic measurements on self-exchange reactions (*i.e.*, $Ol_A \equiv Ol_B$) using isotopically labeled olefins since for such reactions (apart from small kinetic isotope effects) $k_{-5} = k_6$. Attempted measurements of this type are now in progress.

(12) R. G. Parker and J. D. Roberts, *J. Amer. Chem. Soc.*, **92**, 743 (1970), and references therein.

* Address correspondence to this author.

James E. Byrd, Jack Halpern*
Department of Chemistry, University of Chicago
Chicago, Illinois 60637

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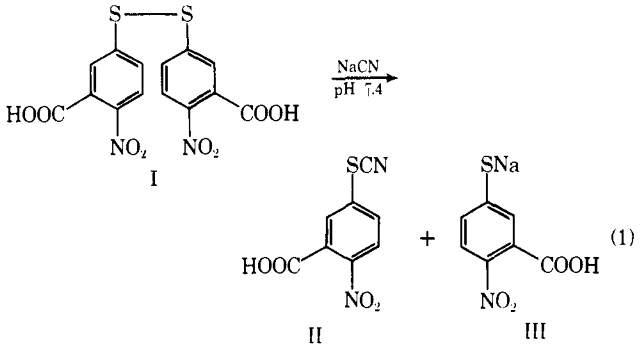
Selective Cyanylation of Sulfhydryl Groups

Sir:

Cysteine peptide bonds can be cleaved *via* a β-elimination reaction of *S*-dinitrophenylcysteine derivatives to dehydroalanine residues.[1,2] In peptide chains containing both cysteine and cystine residues, this method cannot be used since, under the alkaline conditions required for the elimination, cystine residues may also be converted to dehydroalanine residues by elimination of disulfide groups.[3,4] The elimination of the stronger electron-attracting *S*-picryl group is rather more selective, but the yields are lower due to partial alkaline hydrolysis.[4] Cyanide ions are known to slowly split the disulfide group of the cystine residue at pH 7–8 to form a thiol and a β-thiocyanoalanine residue which subsequently undergoes cyclization to an *N*-acyl-2-iminothiazolidine derivative, followed by hydrolysis of the *N*-acyl bond.[5,6] It was realized that if cysteine residues could be cyanylated directly and selectively to β-thiocyanoalanine residues, the cyclization reaction could be used for the cleavage of cysteine peptide bonds in the presence of cystine residues.

We wish to report in the present communication a method for the direct conversion of thiol groups into thiocyanates using 2-nitro-5-thiocyanobenzoic acid (II, NTCB) under very mild conditions. The reagent was synthesized by treatment of 5,5′-dithiobis(2-nitrobenzoic acid) (I, Ellman's reagent,[7] DTNB) with NaCN in equimolar concentrations in 0.1 *M* phosphate buffer, pH 7.4.



The thionitrobenzoate (III, TNB) formed together with NTCB (II) was removed from the product mixture by treatment with bromoacetylcellulose,[8] thus shifting the equilibrium toward quantitative completion of the reaction. The reagent II was purified by crystallization from ethyl acetate–petroleum ether; mp 162–163°. *Anal.* Calcd for $C_8H_4N_2O_4S$: C, 42.87; H, 1.80; N, 12.50; S, 14.28. Found: C, 42.95; H, 1.75; N, 12.45; S, 14.06. The mass spectrum showed the parent molecular peak at *m/e* 224. The uv spectrum of the reagent is shown in Figure 1. ^{14}C-Labeled NTCB was analogously prepared by using Na^{14}CN.

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(1) A. Patchornik and M. Sokolovsky, *J. Amer. Chem. Soc.*, **86**, 1206 (1964).

(2) M. Sokolovsky, T. Sadeh, and A. Patchornik, *ibid.*, **86**, 1212 (1964).

(3) Z. Bohak, *J. Biol. Chem.*, **239**, 2878 (1964).

(4) T. F. Spande, B. Witkop, Y. Degani, and A. Patchornik, *Advan. Protein Chem.*, **24**, 98 (1970).

(5) J. L. Wood and N. Catsimpoolas, *J. Biol. Chem.*, **238**, 2887 (1963).

(6) N. Catsimpoolas and J. L. Wood, *ibid.*, **241**, 1790 (1966).

(7) G. L. Ellman, *Arch. Biochem. Biophys.*, **82**, 70 (1959).

(8) A. Patchornik, Israel Patent Application No. 18207 (1962).