	k_R (M^{-1} sec.$^{-1}$)	k_D (sec.$^{-1}$)
H_2S	7.5×10^{10}	4.3×10^{8} (±15%)
HF	$\sim 1.0 \times 10^{11}$	$\sim 6.7 \times 10^{7}$

For HF no essential dispersion was found. As a result, the value given above represents a lower limit, which is, however, almost identical with the upper limit required by equation (1).

To examine these rate constants in the light of steric effects we make a comparison with the rate constant of the neutralization reaction

$$H^+ + OH^- \underset{k_D}{\overset{k_R}{\rightleftarrows}} H_2O \qquad \text{(III)}$$

for which $k_R = 1.3 \times 10^{11}\ M^{-1}$ sec.$^{-1}$.[10] This value of k_R may be calculated from equation (1) with the macroscopic dielectric constant of 78.5 and an effective reaction distance a of 7.5 Å.[2]

Because of the uniquely high mobility of hydrogen and hydroxyl ions, $[k_R]_{H_2O}$ may be considered an upper limit for diffusion controlled bimolecular rate constants of this charge type. The steric factor is unity, since the hydrogen and hydroxyl ions are always correctly oriented when diffusing toward each other. For the spherical fluoride ion the ratio of rate constants for reactions (II) and (III) is given by the ratio of the ionic mobilities provided the effective reaction distance remains the same. A value of $[k_R]_{HF} = 9.6 \times 10^{10}\ M^{-1}$ sec.$^{-1}$ results. Since the dissociation field effect showed essentially no dispersion, we find that a value of about 1.0×10^{11} M^{-1} sec.$^{-1}$, with an effective reaction distance of 2–3 hydrogen bonds, represents a reasonable rate constant for this system.

The bisulfide ion, in contrast to the fluoride ion, should show a steric effect. When the hydrated proton and bisulfide ion approach with the hydrogen end of the bisulfide ion directed toward the $(H_9O_4)^+$ complex an unfavorable orientation occurs. From a consideration of the molecular structure of the bisulfide ion it is estimated that the solid angle corresponding to unreactive collision paths decreases the number of successful encounters by about 25%. Thus, we may estimate $[k_R]_{H_2S} = 7.5 \times 10^{10}\ k^{-1}$ sec.$^{-1}$, which is in excellent agreement with the measured value.

Steric restrictions are still more pronounced when the reacting group represents only a small residue of a larger molecule as is often the case for organic anions. Two examples will be discussed in the following, namely, *p*- and *m*-nitrophenol, which in addition seem to show another small restrictive influence resulting from charge delocalization in a structure exhibiting resonance.

The measurements were carried out using Riedel De Haen *p*-nitrophenol (m.p. 114°) and E. Merck *m*-nitrophenol. The latter was washed repeatedly and recrystallized from water until the m.p. was 96°. All measurements were made at 25° and essentially zero ionic strength. The reactions studied are:

$$H^+ + O_2NC_6H_4O^- \underset{k_D}{\overset{k_R}{\rightleftarrows}} O_2NC_6H_4OH \qquad \text{(IV)}$$

for the *meta* and *para* isomers. Since the equilibrium constants are known[11] both rate constants may be determined. The results are:

	k_R (M^{-1} sec.$^{-1}$)	k_D (sec.$^{-1}$)
m-Nitrophenol	4.2×10^{10}	1.9×10^{2} (±15%)
p-Nitrophenol	3.6×10^{10}	2.6×10^{3} (±15%)

A comparison of k_R with equation (1) yields a steric factor of about 0.5 for both phenols. Weller[12] found a similar value for the corresponding reaction of β-naphthol (in the excited state) from fluorescence transformation measurements (k_R = $4.8 \times 10^{10}\ M^{-1}$ sec.$^{-1}$). The greater localization of charge on the *m*-phenolate oxygen may enhance somewhat the diffusion controlled rate of recombination with respect to the *para*-isomer. The same effect also is expressed in the entropy of ionization,[13] where it indicates that water molecules are more effectively oriented by the *m*-phenolate oxygen. However, the present accuracy of the measurements is not yet great enough to permit one to draw such detailed conclusions with safety.

We are indebted to the National Cancer Institute, United States Public Health Service, for granting a Postdoctoral Fellowship to K. K. during the tenure of which this work was done.

---

[10] M. Eigen and L. De Maeyer, *Z. Elektrochem.*, **59**, 986 (1955).

[11] C. M. Judson and M. K. Kilpatrick, *J. Am. Chem. Soc.*, **71**, 3110 (1949).

[12] A. Weller, *Z. physik. Chem.*, NF., **17**, 224 (1958).

[13] L. P. Fernandez and L. G. Hepler, *J. Am. Chem. Soc.*, **81**, 1783 (1959). We are indebted to Prof. H. Morawetz for calling our attention to this article.

MAX PLANCK INSTITUT FUER
PHYSIKALISCHE CHEMIE
GOETTINGEN, GERMANY

MANFRED EIGEN
KENNETH KUSTIN

RECEIVED SEPTEMBER 26, 1960

OPTICAL ROTATORY DISPERSION STUDIES. XLIV.[1] ANOMALOUS ROTATORY DISPERSION CURVES OF OLEFIN DERIVATIVES. OSMATE ESTERS[2]

Sir:

We have pointed out already[1,3] that the most effective way of extending the scope of anomalous rotatory dispersion applications—which have proved so useful[3] with optically active chromophores such as the carbonyl group—is to convert a "non-chromophoric" functional group into a "chromophoric" derivative. Some successful approaches in converting amino, hydroxyl, and carboxylic acid functions into such derivatives have already been recorded,[1,3,4] but one of the most severe challenges, namely, how to secure Cotton effect curves among mono-unsaturated olefins, has not yet been met. Indeed, the spectroscopic properties of such olefins preclude with the presently available instruments direct measurement of any Cotton effect that may be associated with their absorption maximum below 200 mμ. Nevertheless,

---

[1] Paper XLIII, C. Djerassi and K. Undheim, THIS JOURNAL, **82**, 5755 (1960).

[2] Supported by grant No. CRTY-5061 from the National Cancer Institute, National Institutes of Health, U. S. Public Health Service, and by the National Science Foundation.

[3] C. Djerassi, *Rec. Chem. Progress*, **20**, 140 (1959); C. Djerassi, "Optical Rotatory Dispersion: Applications to Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1960, Chapter 15.

[4] B. Sjöberg, A. Fredga and C. Djerassi, THIS JOURNAL, **81**, 5002 (1959).

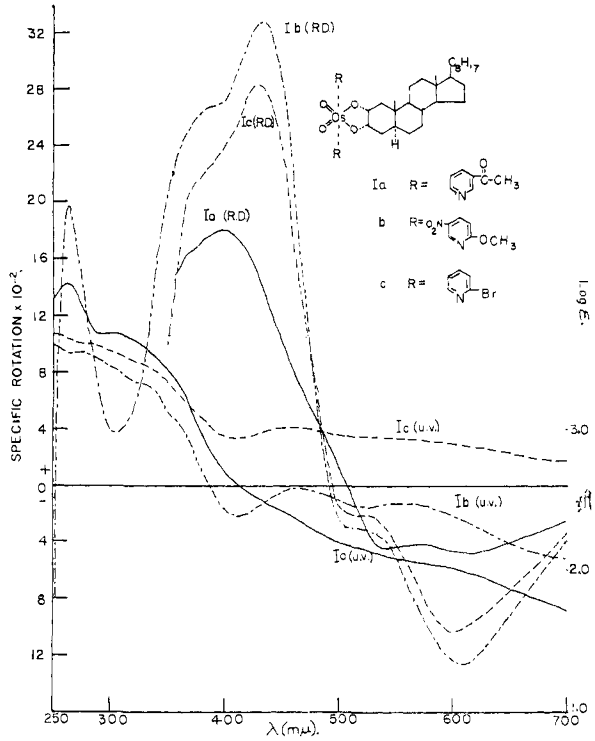

Fig. 1.—Optical rotatory dispersion curves and ultraviolet spectra in methylene dichloride of Δ^2-cholestene osmate adduct with 3-acetylpyridine (Ia), 2-methoxy-5-nitropyridine (Ib), and 2-bromopyridine (Ic).

it would be desirable to have available an anomalous dispersion approach to certain stereochemical and structural problems among optically active olefins.[5]

Milas and collaborators[6] have demonstrated recently that treatment of olefins with osmium tetroxide–hydrogen peroxide in *tert*-butyl alcohol leads to complexes with low intensity ultraviolet absorption at 288 mμ. The particular reagents and conditions employed by them are not too suitable for rotatory dispersion work, but their spectroscopic findings prompted us to undertake a detailed examination of the optical rotatory dispersion behavior and spectroscopic properties of various reaction products of steroidal olefins with osmium tetroxide. Our results have been sufficiently promising to suggest that this rotatory dispersion approach may have rather wide applications.

Spectroscopic studies in our hands have shown that osmate esters,[7] especially the pyridine complexes, exhibit several maxima or inflections in the visible and ultraviolet spectral regions. *These can be optically active and give rise to rotatory dispersion Cotton effects.* Figure 1 contains the spectra and rotatory dispersion curves of the osmate ester I of Δ^2-cholestene as the adduct of three substituted pyridines, while in Fig. 2 are reproduced the plain rotatory dispersion curves of four steroidal olefins and the Cotton effect curves of their corresponding osmate esters (as the di-pyridine adduct). The following conclusions can be reached:

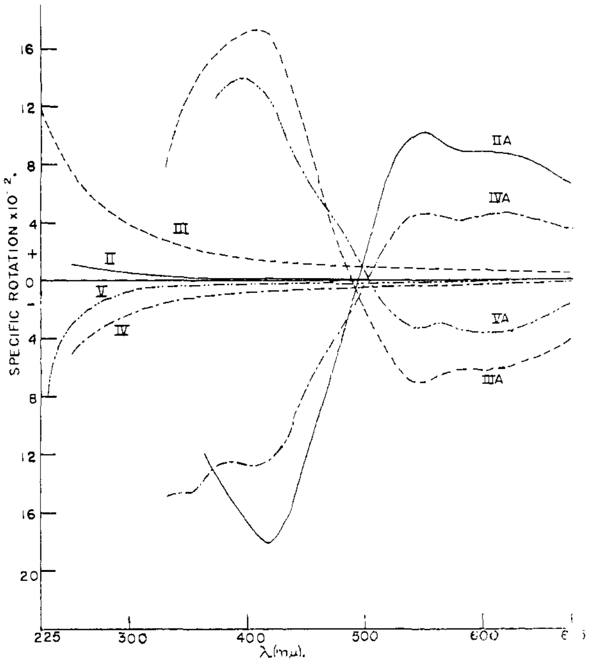

Fig. 2.—Optical rotatory dispersion curves of Δ^1-cholestene (II), Δ^2-cholestene (III), cholesterol acetate (IV), and Δ^6-coprostene (V), and of the di-pyridine adducts of their osmate esters (IIA, IIIA, IVA, VA). The olefins were measured in isoöctane solution and the osmate esters in methylene dichloride.

(1) The different ligands (over eighteen substituted pyridines and quinolines were examined) do not affect the sign of the Cotton effect, but may produce significant differences in the rotatory dispersion amplitude, fine structure, and, in the positions of the extrema, variations which are also noted in their absorption spectra. The three examples of different ligands collected in Fig. 1 were measured on the isolated osmate ester, but it is feasible to conduct measurements directly on the reaction mixture.[8] The velocity of formation of the osmate ester is dependent upon the nature of the base (*e.g.*, β-picoline > pyridine > 2-nitropyridine).

(2) The polarity of the solvent plays no important role in the rotatory dispersion curve as was noted in a comparison of methylene dichloride, dimethyl sulfoxide, dioxane or isoöctane.

(3) Olefins show only plain dispersion curves, while their osmate esters show Cotton effects (see Fig. 2). By considering the sign of the plain curve in conjunction with the sign of the principal Cotton effect of the corresponding osmate (*e.g.*, Δ^1-cholestene (II), plain positive; osmate IIA,

---

[5] Far-ultraviolet absorption spectra sometimes are useful in this connection. For leading references, see K. Stich, G. Rotzler and T. Reichstein, *Helv. Chim. Acta*, **42**, 1480 (1959).

[6] N. A. Milas, J. H. Trepagnier, J. T. Nolan and M. I. Ilipoulos, THIS JOURNAL, **81**, 4730 (1959).

[7] R. Criegee, *Ann.*, **522**, 75 (1936); R. Criegee, B. Marchand and H. Wannowius, *ibid.*, **550**, 99 (1942).

[8] As a typical preparation, 5–10 mg. of the olefin and two molar equivalents of the base dissolved in 5–10 cc. of isoöctane is treated with one equivalent of osmium tetroxide. After standing for a suitable period (generally 24–48 hours), the osmate ester adduct is filtered and washed well with isoöctane. When the rotatory dispersion curve of the reaction mixture (without isolation of the osmate) is to be measured, isoöctane should be replaced by methylene dichloride (suggested concentration: 0.5 mg./cc.).

Cotton effect, positive; Δ^2-cholestene (III), plain positive; osmate IIIA, Cotton effect negative), considerable information on the location of the double bond can be secured.

(4) The reaction can be conducted on a micro scale,[8] the osmate ester can be isolated and in fact can be chromatographed on silicic acid.

The rotatory dispersion curves of osmate esters of a variety of steroid olefins will be recorded in our detailed paper, together with structural and stereochemical correlations. Experiments are currently underway to expand this approach to *vic*-glycols, since these react[7] with osmium trioxide (in the form of the di-pyridine adduct) to give osmate esters.

[9] National Institutes of Health Postdoctorate Research Fellow, 1959–1960.

DEPARTMENT OF CHEMISTRY
STANFORD UNIVERSITY
STANFORD, CALIFORNIA
E. BUNNENBERG[9]
CARL DJERASSI

RECEIVED OCTOBER 10, 1960

THE IDENTIFICATION OF RADICAL PRODUCTS FROM THE OXIDATION OF DIPHENYLAMINE

Sir:

The mechanism of oxidation inhibition by aromatic amines has been the subject of extensive investigation. Harle and Thomas[1] reported the detection of a relatively stable radical derived from phenyl-α-naphthylamine when this compound was used to inhibit the autoxidation of 1-octadecene at 170°. *Via* kinetic arguments, the concentration *versus* time relationship of this intermediate radical was interpreted in terms of the reversible complex mechanism proposed by Hammond, Boozer, *et al.*,[2] in preference to alternatively proposed schemes of inhibition.

This note reports the identification of the stable radical, diphenyl nitric oxide, as an intermediate product when diphenylamine is used as an oxidation inhibitor. The radical, whose electron paramagnetic resonance spectra is shown in Fig. 1, is detected readily when diphenylamine is present in a hydrocarbon solution undergoing azo-bis-isobutyronitrile (ABN) catalyzed oxidation at 68.5°. The electron paramagnetic resonance spectrum, shown in Fig. 1, is identical with that of diphenyl nitric oxide prepared by the method of Wieland and Offenbäcker,[3] Hoskins[4] observed a similar spectrum when an alkaline solution of diphenylamine was oxidized with air and suggested that the radical responsible was diphenyl nitric oxide.

Azo-bis-isobutyronitrile catalyzed oxidation of solutions containing phenyl-α-naphthylamine, aniline, N-methylaniline, and phenothiazine has also been observed to yield relatively high concentrations of moderately stable radicals. By analogy, it is believed that these radicals are also nitric oxide derivatives. Their electron paramagnetic resonance spectra, which will be published and discussed elsewhere, are consistent with this interpretation. No stable radical products have been observed from very weakly inhibiting tertiary amines, such as N-dimethylaniline.

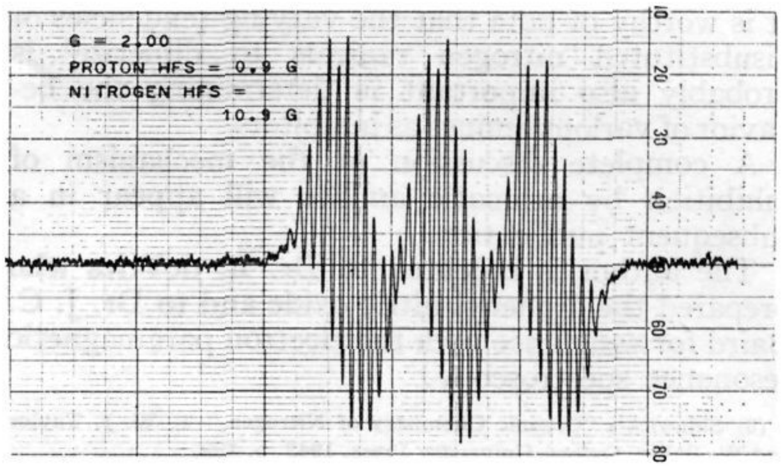

Fig. 1.

Diphenyl nitric oxide is produced when dilute solutions of tetraphenylhydrazine are subjected to ABN catalyzed oxidation. Table I shows the steady state radical concentration to be first order with respect to tetraphenylhydrazine concentration.

TABLE I

STEADY STATE CONCENTRATION OF DIPHENYL NITRIC OXIDE FROM TETRAPHENYLHYDRAZINE AT 68.5°

0.93 *M* cumene in chlorobenzene; 10^{-3} *M* ABN, 1 atmosphere of O_2

$(C_6H_5)_2N\cdot \times 10^4\ M$	2.5	5	10
$(C_6H_5)_2NO\cdot \times 10^5\ M$	3.2	7	13.5

Tetraphenylhydrazine is a weak oxidation inhibitor as shown by the data in Table II, while diphenyl nitric oxide and diphenylamine are strong oxidation inhibitors. From induction period measurements by the method of Boozer and Hammond,[5] we find that diphenyl nitric oxide terminates one half as many oxidation chains as diphenylamine. The rate of oxidation during the inhibition period due to tetraphenylhydrazine is about that to be expected from the observed steady state concentration of diphenyl nitric oxide.

TABLE II

INITIAL OXIDATION RATES AT 68.5°

0.93 *M* cumene in chlorobenzene, 10^{-3} *M* ABN, 1 atmosphere of O_2

Inhibitor	Rate, cc. O_2 l.$^{-1}$ min.$^{-1}$
None	0.62
$10^{-4}\ M\ (C_6H_5)_2NH$	.10
$10^{-4}\ M\ (C_6H_5)_2NO\cdot$	.10
$5 \times 10^{-4}\ M\ (C_6H_5)_2N\cdot$	.20

In the absence of oxygen, diphenyl nitric oxide reacts rapidly with the radicals produced from ABN decomposition; it appears to react considerably more slowly with RO_2 radicals.

These observations suggest that diphenyl nitric oxide is produced by reactions (1) and (2). They also suggest that disubstituted nitrogen radicals

$$(C_6H_5)_2NH + RO_2\cdot \longrightarrow (C_6H_5)_2N\cdot + RO_2H \quad (1)$$

$$(C_6H_5)_2N\cdot + RO_2\cdot \longrightarrow (C_6H_5)_2NO\cdot + RO\cdot \quad (2)$$

and the corresponding nitrogen oxide radicals derivable from amines play an important role in the action of aromatic amines as oxidation inhibitors.

---

[1] O. L. Harle and J. R. Thomas, *J. Am. Chem. Soc.*, **79**, 2973 (1957).

[2] G. S. Hammond, C. E. Boozer, C. E. Hamilton and J. N. Sen, *ibid.*, **77**, 3238 (1955).

[3] H. Wieland and M. Offenbäcker, *Ber.*, **47**, 2111 (1914).

[4] R. H. Hoskins, *J. Chem. Phys.*, **25**, 788 (1956).

[5] C. E. Boozer, G. S. Hammond, C. E. Hamilton and J. N. Sen, *J. Am. Chem. Soc.*, **77**, 3233 (1955).