Notes

Ion Radicals. X. The Formation of the Phenothiazinyl Radical by the Ultraviolet Irradiation of Phenothiazine Solutions[1,2]

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The irradiation of solutions of phenothiazine in ethanol and aqueous methanol with ultraviolet light gave the phenothiazinyl radical (II). The esr spectrum consisted of a triplet of 9.7-gauss spacing, and two somewhat overlapping quintets with hyperfine spacing of 2.3 and 0.57 gauss. Acidification of the solutions of II converted II to the phenothiazine cation radical (III).

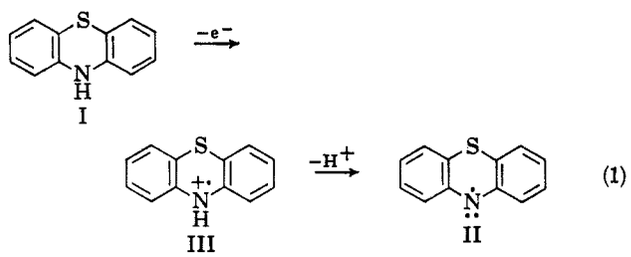
We noted briefly in a previous discussion[4] of the reactions of phenothiazine (I), that a radical was formed by the ultraviolet irradiation of I in ethanol solution, which appeared from its esr spectrum to be the neutral phenothiazinyl radical (II). Further work supports this view.

The esr spectrum of an ultraviolet-irradiated solution of I is shown in Figure 1. A major triplet of spacing 9.7 gauss is seen. Further hyperfine splitting by two sets of four equivalent protons is also seen. The coupling constants for these protons, measured from the spectrum in Figure 1, are 2.3 and 0.57 gauss. On this basis, a total of 75 lines should be observed. The spectrum has 55 lines, 27 on each side of the center of the triplet. The loss of ten hyperfine lines on each side of the triplet center arises from the overlapping of ten pairs of lines. A line diagram spectrum for the complete hyperfine splitting was drawn, using the spacings quoted above. This is also given in Figure 1, where those lines which overlapped or were less than 0.2 gauss apart are drawn as single lines with summed intensities. It can be seen that the line diagram fits the experimental spectrum very well. The g value of the radical II in solution is close to that of the calibrating standard (2.0057).

The irradiation of acetic acid solutions of I give the phenothiazine cation radical.[4] Evidently, II is very easily protonated. Figure 2 shows the esr spectrum (A) of a solution of I in ethanol which was irradiated with ultraviolet light, and the esr spectrum (B) of the same solution recorded without further irradiation, but after adding dilute sulfuric acid. The poorly resolved triplet of the neutral solution (A) was replaced by a poorly resolved quartet (B) of the acidic solution. The spacing of the quartet is 7.4 gauss, which is near to that (7.0 gauss) found by others for the quartet of the phenothiazine cation radical.[5] We propose that the change in spectrum (from A to B) is due to the protonation of the radical II. The addition of dilute sulfuric acid to a solution of I in ethanol without prior irradiation did not cause radical formation. On the other hand, the irradiation of a solution of I in ethanol containing dilute sulfuric acid gave a radical whose esr spectrum was identical with B in Figure 2. Similar results to those described were obtained by adding acetic acid to irradiated solutions of I in ethanol.

The spacing of 9.7 gauss for the triplet of the spectrum of II, due to spin coupling with the nitrogen atom, is consistent with the value of 9.4 gauss for the N-hyperfine coupling constant of the somewhat similar diphenylimino radical.[6] Lagercrantz and Yhland[7] illuminated a solution of I containing eosine with visible light, and obtained an esr spectrum with three main lines separated by about 9.5 gauss. The spectrum was thought to be due to II. The radical responsible for the spectrum was said to be unstable, and it was not possible to obtain a complete spectrum under high-resolution conditions. We must note that we, also, were not always able to obtain a well-resolved spectrum of II. The resolution varied from experiment to experiment, with no apparent reason. The difference in resolution obtained at two different times is illustrated by the spectra in Figures 1 and 2.

Lewis and Bigeleisen[8] irradiated a solution of I in a mixture of ether, isopentane, and ethanol at −193°. The visible spectrum of the solution was due to the presence of phenothiazine cation radical (III), the main band being at 515 mμ (as estimated from Figure 2 of the publication[8]). When the solution stood at −183° the spectrum changed to one with a single band at 532 mμ (estimated from the figure). It was proposed[8] that the change was due to the loss of a proton by III resulting in the formation of II (eq 1).[8a]



(1)

The visible spectrum of our solutions of I in ethanol and 80% methanol after irradiation with ultraviolet light had a broad band in the region of 520 mμ. After acidification of the solutions the 400–500-mμ region of the spectrum changed to that of III.[4] The change in the visible spectrum is attributable to the protona-

(1) Part IX: H. J. Shine, L. Hughes, and D. R. Thompson, *Tetrahedron Letters*, **No. 21**, 2301 (1966).

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(3) Postdoctoral fellow, 1964–1965.

(4) H. J. Shine and E. E. Mach, *J. Org. Chem.*, **30**, 2130 (1965).

(5) J.-P. Billon, G. Cauquis, and J. Combrisson, *J. Chim. Phys.*, **61**, 374 (1964).

(6) J. Pannell, *Mol. Phys.*, **5**, 291 (1962).

(7) C. Lagercrantz and M. Yhland, *Acta Chem. Scand.*, **16**, 508 (1962).

(8) G. N. Lewis and J. Bigeleisen, *J. Am. Chem. Soc.*, **65**, 2419 (1943).

(8a) Note Added in Proof.—We have not long learned of another, recent report [B. C. Gilbert, P. Hanson, R. O. C. Norman, and B. T. Sutcliffe, *Chem. Commun.*, 161 (1966)] of the spectrum of II which is substantially different from ours. The reason for the difference in spectra is being sought.

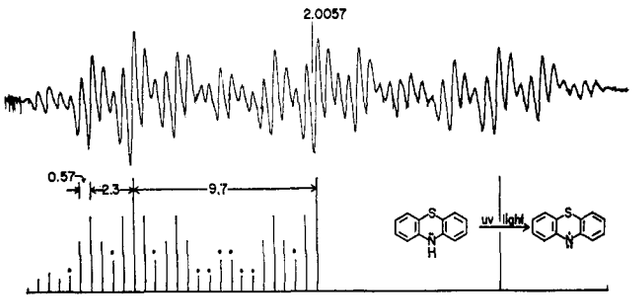

Figure 1.—The esr spectrum of a solution of phenothiazine in 95% ethanol after irradiation with ultraviolet light. The vertical line (g = 2.0057) represents the center of the spectrum of the nitrosodisulfonate ion. The line diagram in the lower half of the spectrum was constructed with the hyperfine spacings of the experimental spectrum and the intensities of a 1:1:1 nitrogen triplet split successively into two quintets. The small circles above some lines indicate the overlap and summation of two lines.

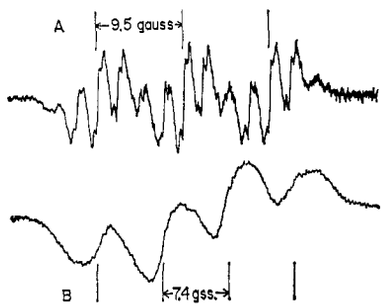

Figure 2.—The esr spectrum of a solution of phenothiazine in absolute ethanol after irradiation with ultraviolet light (A). The esr spectrum of a similar, irradiated solution after dilution with an equal volume of alcoholic sulfuric acid (10 volumes of sulfuric acid to 90 volumes of absolute ethanol) (B).

tion of the II which had been formed by the irradiation of I. This is the reverse of the observation of Lewis and Bigeleisen, and is expected from the higher acidity of our final solutions.

Experimental Section

Phenothiazine, practical grade, Distillation Products Industries, was recrystallized from butanol and had mp 182–184°. No impurity was detected with the use of thin layer chromatography.

Irradiations were carried out on solutions in quartz esr cells or silica cuvettes. In some irradiations a G.E. H250-A5 lamp was used. In others a Dallons Laboratory low-intensity lamp was used, similar to a mineralight lamp, with the major emission at 2537 A.

Esr spectra were obtained with a Varian Associate's instrument using a dual-sample cavity.[9]

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The Oxidation of Selenocystamine to 2-Aminoethaneselenenic Acid

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The rapid conversion of diselenides to seleninic acids by oxidizing agents without the isolation or even

$$\mathrm{RSeSeR} \xrightarrow[\mathrm{H_2O}]{[\mathrm{O}]} 2\ \mathrm{RSeO_2H}$$

detection of intermediate compounds leaves uncertainty as to the steps by which the above-mentioned oxidation takes place. Fromm and Martin[2] attempted to oxidize dibenzyl diselenide to dibenzyl diselenoxide but did not obtain the desired product. Twiss[3] likewise was unsuccessful in obtaining a compound of an intermediate oxidation state by the action of hydrogen peroxide on dibenzyl diselenide. In the ozonolysis of dialkyl and diaryl diselenides to seleninic anhydrides, Ayrey, Barnard, and Woodbridge[4] were unable to isolate intermediate products. They suggested, however, that the following may be the sequence by which a diselenide is converted into a seleninic acid by either ozone or *t*-butyl hydroperoxide.

$$\mathrm{RSeSeR} \longrightarrow \mathrm{RSeSeR} \overset{\|}{\mathrm{O}} \longrightarrow \mathrm{RSeOSeR} \longrightarrow \mathrm{RSeOSeR} \overset{\|}{\mathrm{O}} \longrightarrow$$

$$\mathrm{RSeOSeR} \quad \overset{\|}{\mathrm{O}}\ \overset{\|}{\mathrm{O}}$$

$$\downarrow \mathrm{H_2O}$$

$$2\mathrm{RSeO_2H}$$

Caldwell and Tappel[5] attribute the failure to observe a diselenoxide in the oxidation of selenocystine to the probable instability and high reactivity of the former type of compound.

Cystamine [bis(2-aminoethyl) disulfide] can be oxidized stepwise to the monoxide, 2-aminoethyl 2-aminoethanethiolsulfinate,[6] the dioxide, 2-aminoethyl 2-aminoethanethiolsulfonate,[7] before 2-aminoethanesulfinic acid[8] is obtained.

In a recent communication[9] we reported that selenocystamine [I, bis(2-aminoethyl) diselenide] and its dihydrochloride salt are oxidized by excess hydrogen peroxide to 2-aminoethaneseleninic acid (H_2NCH_2-CH_2SeO_2H). In an effort to isolate selenium compounds related to the above series of aminoethyl-substituted sulfur intermediates, compound I dihydrochloride was subjected to oxidation with 1 equiv of *m*-chloroperbenzoic acid in a method analogous to the preparation of 2-aminoethyl 2-aminoethanethiolsulfinate dihydrochloride.[6b] Instead of the desired monoxide there was obtained 47% of the starting material and 43% of a new compound, $C_2H_8ClNOSe$ (II hydrochloride). Use of 2.2 equiv of *m*-chloroperbenzoic acid raised the yield of II hydrochloride to 96.9%. This material could be prepared in a simpler manner and in 98% yield by the action of 2.2 equiv of hydrogen peroxide on an aqueous solution of I dihydrochloride.

Oxidation of I (free base) with 2.2 equiv of hydrogen peroxide resulted in the formation of a crystalline material which gave microanalytical data for C_2H_7NOSe.

(1) To whom communications should be sent.
(2) E. Fromm and K. Martin, *Ann.*, **401**, 177 (1913).
(3) D. F. Twiss, *J. Chem. Soc.*, **105**, 36 (1914).
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(5) K. A. Caldwell and A. L. Tappel, *Biochemistry*, **3**, 1643 (1964).
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