

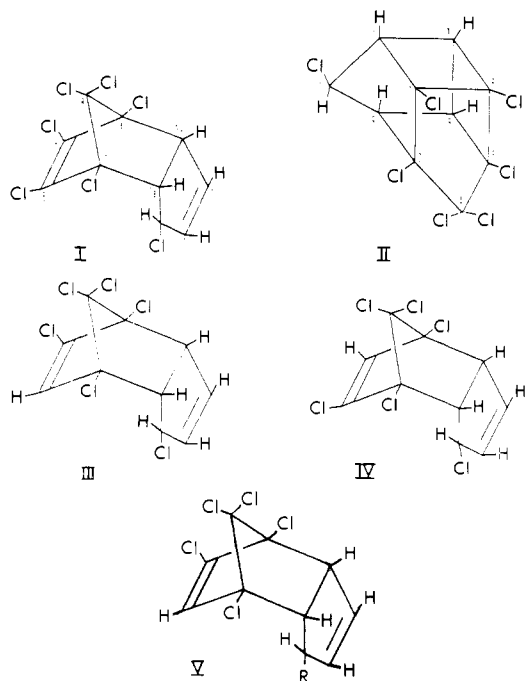
Photochemistry of Bioactive Compounds

Photolysis of 1,4,5,6,7,8,8-Heptachloro-3a-4,7,7a-Tetrahydro-4,7-methanoindene (Cage Formation vs. Photodechlorination)

The photolysis of heptachlor has been studied in several solvents. The products of the reaction have been identified as a pair of monodechlorination

isomers or a cage compound and a solvent adduct, depending on the reaction conditions. A mechanism of reaction is proposed.

The photodecomposition of substituted polychlorinated norbornyl systems has been shown to proceed by two reaction pathways: photodechlorination of one of the olefinic chlorines (Anderson *et al.*, 1968; Henderson and Crosby, 1967; and Rosen, 1967); and cage formation (Anderson *et al.*, 1968; and Rosen *et al.*, 1969). Moreover, Anderson *et al.*, (1968) have investigated the multiplicity of the excited states and have shown that photodechlorination takes place *via* a singlet state, while the cage formation occurs *via* a triplet. Our present investigations of the photolysis of heptachlor, 1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene (I), are in agreement with these findings and have shown the presence of a third major product (V) which yields further insight into the mechanism of this reaction.



EXPERIMENTAL MATERIALS AND METHODS

Chemicals. HEPTACHLOR. A commercial sample of heptachlor (25% by weight) was purified by filtration of an acetone solution of the raw material followed by evaporation of the solvent. The resulting solid was redissolved in *n*-hexane and passed through a column of activated alumina. Fifty-milliliter fractions were collected and analyzed by vapor-phase chromatography (VPC). Fractions three and four

were combined, the solvent was evaporated, and this was used as the stock heptachlor. Heptachlor purified in this manner was identical as verified by gas chromatography to a sample purchased from City Chemical Corporation of 99% purity (ESA Pesticide Reference Standard).

SOLVENTS. All solvents were "distilled in glass" from Burdick and Jackson Laboratories Inc., and were used without further purification.

Photolyses of (I) to Yield (III) and (IV). The monodechlorinated compounds 1,4,5,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene (III) and 1,4,6,7,8,8-hexachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene (IV) were obtained by photolyzing $10^{-4}M$ solutions of heptachlor in hexane or cyclohexane at 253.7 nm using a filtered NFU-300 (Nester-Faust Corp.) ultraviolet source. This system gave 96% of the total energy as a single line at 253.7 nm. Under these conditions, compounds (III) and (IV) were the only products of the photolysis after three hours.

Separation and purification of these two isomers was carried out by VPC on a 6-ft by $1/8$ -in. DC-11 column (5% liquid phase on 60/80 mesh Gas-Chrom Q) at a column temperature of 160° C and carrier gas flow of 40 ml/minute of pre-purified helium. The two isomers are referred to in the order of their elution from the DC-11 column (Peak 1 and Peak 2).

Dechlorination of (III) and (IV). A solution of 2.7 grams of the photoproduct in 10 grams of *t*-butyl alcohol was slowly added to 3.0 grams of lithium chips in 25 ml of tetrahydrofuran. The mixture was gently refluxed for three hours, poured over ice, extracted with ether, and dried over anhydrous $MgSO_4$.

Photolysis of (I) to Yield (II). The cage compound 2,3,4,4,5,6,10-heptachloro-pentacyclo(5.3.0.0^{2,3}.0^{3,4}.0^{3,7})decane (II) was prepared by photolyzing an acetone solution of heptachlor in a Rayonet Photochemical Reactor (The Southern N. E. Ultraviolet Co.) fitted with lamps having a peak output at 300 nm (bandwidth unknown). Final purification was accomplished on the gas chromatographic column described above.

Photolysis of (I) to Yield (V). The solvent adduct (V) was obtained as the major product when the photolysis of heptachlor was carried out in mixtures of cyclohexane and acetone ranging from 10–50% acetone. Compound (V) was separated and purified by gas chromatography on a 5-ft. by $1/4$ -in. column packed with 5% DC-11 on 60/80 mesh Gas-Chrom Q. Similar products were obtained when the reactions were carried out in mixtures of acetone with cyclopentane, *n*-hexane, or ethyl acetate.

Table I. Nuclear Magnetic Resonance (NMR) Data of Heptachlor and Heptachlor Photolysis Products

| Proton | Heptachlor | Monodechlorination ^a | | Cage | Adduct |
|------------------|--------------|---------------------------------|---------------|---------------|---------------|
| | | Peak 1 | Peak 2 | | |
| H ₃ | 4.1 (2H) (s) | 4.25 (2H) (s) | 4.30 (2H) (s) | 6.6 (2H) (m) | 4.73 (1H) (s) |
| H ₂ | | | | | 4.28 (1H) (m) |
| H ₁ | 5.2 (1H) (m) | 5.42 (1H) (m) | 5.5 (1H) (m) | 5.45 (1H) (m) | 7.55 (1H) (m) |
| H _{7a} | 6.5 (1H) (m) | 6.5 (1H) (m) | 6.5 (1H) (m) | | 6.9 (1H) (m) |
| H _{3a} | 5.9 (1H) (m) | 6.07 (1H) (m) | 6.09 (1H) (m) | 6.6 (2H) (m) | 6.2 (1H) (m) |
| H _{5/6} | | 4.2 (1H) (s) | 4.2 (1H) (s) | | |

^a Refer to elution peaks on VPC (see experimental). NMR chemical shifts expressed in τ values. (m) = multiplet. (s) = singlet. Location of protons (H_x) based on I.

RESULTS AND DISCUSSION

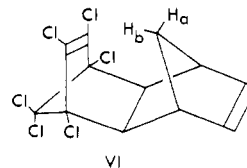
Heptachlor (I) undergoes photolysis upon irradiation in either hexane or cyclohexane solution at 253.7 nm to yield two isomeric monodechlorination products, (III) and (IV), as the major photoproducts. (These are the only products formed under these conditions at short irradiation times and low concentration, *e.g.*, less than three hours at $10^{-4}M$). The elemental analyses, mass and infrared spectra of the two isomers are essentially identical—and consistent with monodechlorination.

Both mass spectra show strong peaks at m/e 335 ($C_{10}H_5Cl_6$)⁺, m/e 300 ($C_{10}H_5Cl_5$)⁺, and m/e 264 ($C_{10}H_4Cl_4$)⁺. The infrared spectra show the presence of double bonds having absorptions at 1580 cm^{-1} (C=C stretch) and at 3090 and 750 cm^{-1} (=C—H). In addition, both isomers decolorize dilute solutions of $KMnO_4$ and Br_2 in CCl_4 .

The nuclear magnetic resonance (NMR) spectrum of I (Table I) is not entirely consistent with what would be expected from analysis of models of the compound. The multiplet at 6.5 τ (quartet) is assigned to H_{7a}, a proton which is neither allylic or vinyl. The multiplet at 5.9 τ (octet) is assigned to H_{3a}—which is an allylic proton split by H₃, H_{7a}, and the long-range splitting of H₂. The multiplet at 5.2 τ arises from H₁—an allylic proton shifted further downfield (lower τ values) than H_{3a} by the geminal chlorine. The two proton singlet at 4.1 τ arises from H₃ and H₂. This is consistent with the olefinic protons on norbornene which fall at 4.06 τ . It is only by chance that H₃ and H₂ give a singlet. There is no plan of symmetry in the molecule. The angles between H₃ and H_{3a} or H₂ and H₁ are both 75°, in which case splitting is expected.

Close inspection of the NMR spectra (Table I) allows the assignment of a definitive structure to each of the monodechlorination isomers. Examination of the molecular model of I shows that the allyl hydrogen (H₁) should be shielded by the electronic clouds of both the chlorinated double bond and the chlorine attached to carbon 6. Replacement of the electronegative chlorine atom for either carbon 5 or carbon 6 by a hydrogen (H_{5/6}) should cause an increase in the size of the electronic cloud associated with the 5,6 double bond, and, consequently, increase the shielding of H₁—causing an upfield shift of its NMR absorption (an increase in the τ value of the chemical shift). Table I shows that this upfield shift of H₁ does, indeed, occur in the NMR spectra of both Peak 1 and Peak 2. However, the replacement of the chlorine on carbon 6, while it increases the shielding due to the double bond, eliminates the shielding due to the replaced chlorine. Consequently, the replacement of the chlorine on carbon 6 would have less of an overall shielding effect on H₁ than the replacement of the chlorine on carbon 5. On this basis, structure III is assigned to Peak 1 and structure IV to Peak 2. Rosen (1967) has recently noted the same phenomenon (change in

the chemical shift of a nearby proton upon photodechlorination) in his study of the photolysis of Aldrin (VI). Replacement of one of the vinyl chlorines (equivalent due to the symmetry of VI) caused a shift in the τ value for H_b. The shift was, however, in the opposite direction from that found on dechlorination of I (H_b = 8.40 τ in VI, H_b = 7.34 τ in the photoproduct). Examination of the molecular model of VI shows that H_b lies in the deshielded field of the double bond rather than being shielded by it. Further deshielding by replacement of one of the vinyl chlorines by hydrogen is, therefore, to be expected.



Total dechlorination of each isomer by metal reduction yielded only dicyclopentadiene. This established that the original carbon skeleton was retained in the photoproducts.

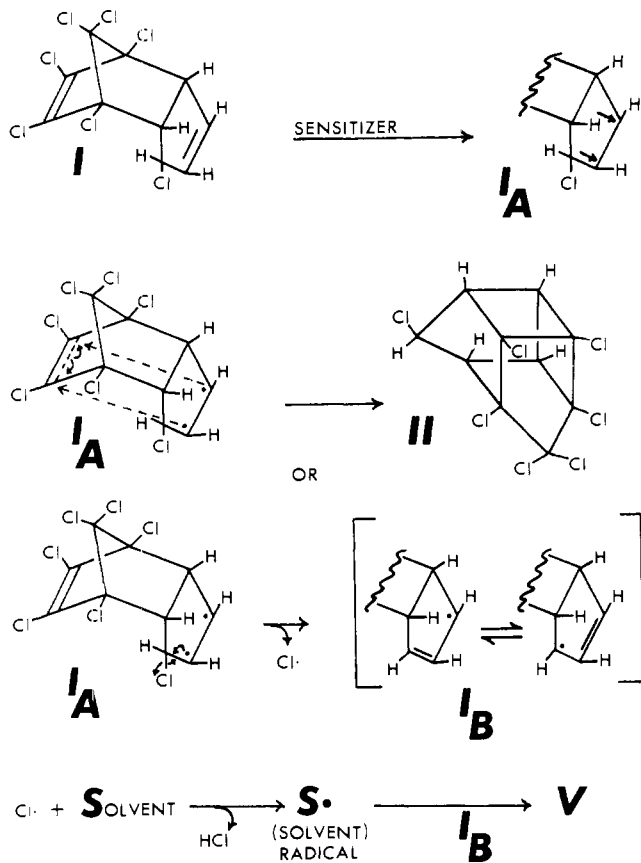
The photolysis of (I) at 300 nm in acetone (a triplet sensitizer) yielded exclusively the cage compound (II). Infrared, NMR, and mass spectral data agree with that reported by Rosen *et al.* (1969). However, Rosen reports the cage formation to be sensitized by benzophenone. Our investigation has failed to verify this, since solutions of heptachlor and benzophenone in cyclohexane remain unchanged after irradiation at wavelengths ranging from 300 to 366 nm. It is suggested that, since Rosen's experiments were carried out in benzene, an inefficient triplet sensitizer, this solvent might be the sensitizing agent for the cage formation from heptachlor [benzophenone E_T = 69 Kcal/mole, acetone E_T = 76 Kcal/mole, benzene E_T = 85 Kcal/mole (see Turro, 1965)].

The photolysis of (I) at 300 nm in mixtures of cyclohexane and acetone ranging from 10% to 50% acetone gave, as the major product, a compound (V) having a much longer retention time on VPC. Formation of cage compound (II) was much less (10%). The mass spectrum of (V) shows a parent peak at m/e 418 ($C_{16}H_{16}Cl_6$)⁺ with large peaks at m/e 383 ($C_{16}H_{16}Cl_5$)⁺, m/e 347 ($C_{16}H_{15}Cl_4$)⁺, m/e 335 ($C_{16}H_{15}Cl_3$)⁺, and m/e 83 (C_8H_{11})⁺. The infrared spectrum of (V) at greater than 1300 cm^{-1} is essentially at superimposition of the spectrum of cyclohexane on that of heptachlor—having strong absorptions at 2925 cm^{-1} (ν_{as} —CH₂—), 2850 cm^{-1} (ν_s —CH₂—), 1610 cm^{-1} (ν C=C), 1450 cm^{-1} (—CH₂— scissor), with a weak absorption at 3060 cm^{-1} (ν =CH—). The infrared and mass spectral data, taken together, indicate that a cyclohexyl group replaces a chlorine on heptachlor (I) to form (V).

In addition to the NMR data given in Table I, a broad multiplet consisting of 11 hydrogens appears at τ 8.55 in the

spectrum of (V). The nonequivalence of H₂ and H₃, the upfield shift of the entire spectrum, and the drastic upfield shift of H₁ indicate that it is the allyl chlorine which is replaced to yield (V). Similar products are found when the photolysis is carried out in mixtures of acetone and *n*-hexane, cyclopentane, and ethyl acetate.

Based upon the above evidence, it is proposed that the photodechlorination takes place *via* an excited singlet state which involves only the chlorinated double bond of heptachlor. The cage formation, a sensitized triplet reaction, would then take place by the following scheme:



Heptachlor (I) reacts with a triplet sensitizer to form I_A which then either loses a chlorine radical (Cl·) to yield the stable allyl free-radical (I_B) or reacts with the chlorinated double bond to form the cage compound (II). Intermediate (I_B) will then react with a solvent radical, formed by proton abstraction by Cl·, to form (V).

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R. R. McGuire
 M. J. Zabik
 R. D. Schuetz
 R. D. Flotard

Department of Entomology,
 Department of Chemistry, and
 Institute of Biology and Medicine
 Michigan State University
 East Lansing, Mich. 48823

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