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74. **Hiroshi Watanabe**: Studies on Azulenes. VII.[1] Oxidation of Hydroazulenes with Selenium Dioxide.

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It is well known that on dehydrogenation, several derivatives of cyclopentacycloheptane yield azulenes, especially the derivatives having a carbonyl group (hydroazulenones), after alkylation by Grignard reaction and dehydrogenation, give the corresponding alkyl-substituted azulenes.

As for the synthesis of such hydroazulenones the following four methods have been reported :

1) Cyclopentanone-2-carboxylates obtained by Dieckmann's cyclization reaction for ethyl adipate are converted into 3,4-cyclopenta- or 4,5-cyclopentasuberic acids and the dicarboxylic acids thus obtained are cyclized to 5- or 6-oxo derivative of decahydroazulene.[2,3]

2) 3,4-Cycloheptaadipic acid derived from cycloheptanone is cyclized to obtain 2-oxo-decahydroazulene.[4]

3) 1-Cycloheptenyllithium is condensed with α,β-unsaturated aldehyde to give cycloheptenyl vinyl ketone derivative and the latter is condensed intramolecularly to give 1-oxo-3-alkyl-Δ^9-octahydroazulene.[5]

4) 1,6-Cyclodecanedione, an ozonolysis product of Δ^9-octalin (1,2,3,4,5,6,7,8-octahydronaphthalene), is condensed intramolecularly to 4-oxo-Δ^9-octahydroazulene.[6]

However, no investigations have been made to obtain hydroazulenones by direct oxidation of partially hydrogenated azulenes with selenium dioxide.

This paper deals with the results of oxidation of Δ^9-octahydroazulene (I) and $\Delta^{4,9}$-hexahydroazulene (VI) with selenium dioxide.

The starting compounds, (I) and (VI), were prepared from 4-oxo-Δ^9-octahydroazulene according to the methods reported respectively by Ukita, *et al.*[7] and by Anderson.[8]

In the structure of Δ^9-octahydroazulene (I), there are two active methylene groups at the positions 1 and 4 (or 3 and 8), which are comparable with those at 1- and 5-positions of Δ^9-octalin and are supposed to be easily oxidized by selenium dioxide. However, according to the asymmetric structure of the compound (I), there should be some difference between the two methylene groups in their susceptibility to oxidation.

As the starting material, Δ^9-octahydroazulene (I) purified through its Girard condensation product was used. (I) was oxidized with selenium dioxide and after removal of selenium by filtration and subsequent shaking of the ethereal solution of the product with potassium cyanide solution, an oily product, a keto-ene (II), $C_{10}H_{14}O$, was separated in 23% yield. This ketone gave a semicarbazone, m.p. 238°(decomp.), which was identified with the semicarbazone of 1-oxo-Δ^9-octahydroazulene reported by Plattner, *et al.*[3]

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[1] This paper constitutes a part of a series entitled "Studies on Azulenes" by T. Ukita. Part VI : This Bulletin, 5, 422(1957).

[2] F. Šorm, J. Fajkoš : Collection Czechoslov. Chem. Communs., **12**, 81(1947).

[3] Pl. A. Plattner, A. Studer : Helv. Chim. Acta, **29**, 1432(1946).

[4] Pl. A. Plattner, G. Büchi : *Ibid.*, **29**, 1608(1946).

[5] E.A. Braude, W.F. Forbes : Nature, **168**, 874(1951).

[6] Pl. A. Plattner, A. Fuerst, K. Jirasek : Helv. Chim. Acta, **29**, 730, 740(1946); A.G. Anderson, J.A. Nelson : J. Am. Chem. Soc., **73**, 232(1951).

[7] T. Ukita, H. Watanabe, M. Miyazaki : J. Am. Chem. Soc., **76**, 4584(1954).

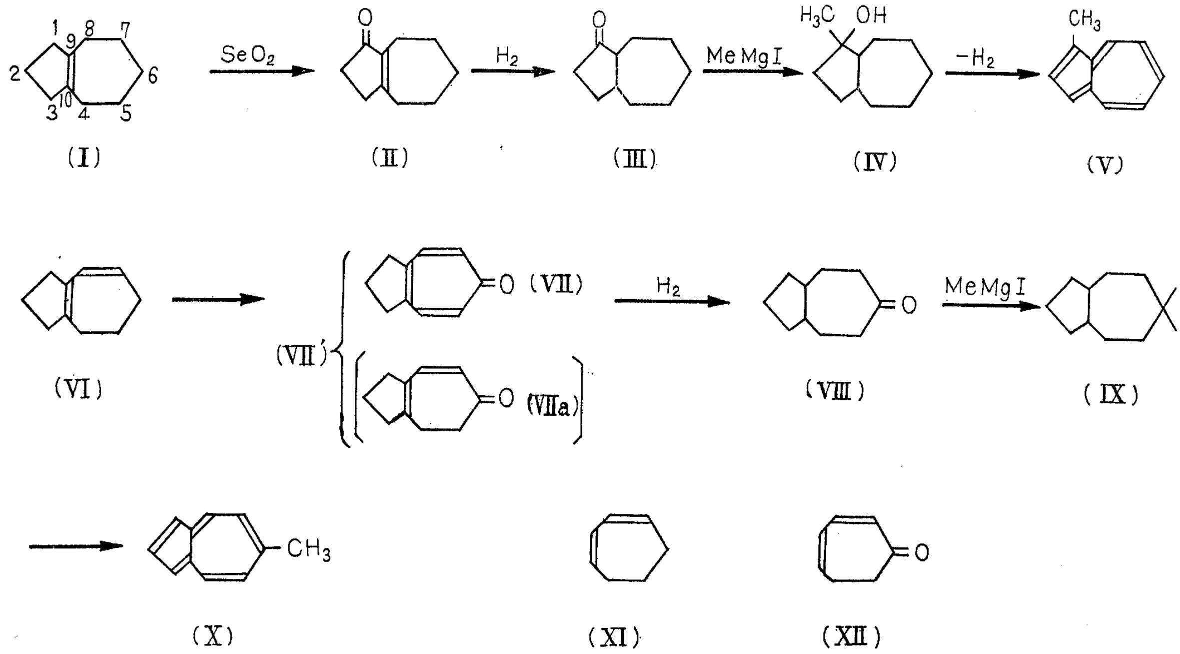
[8] A.G. Anderson, J.J. Tazuma : *Ibid.*, **75**, 4979(1953).

(II) was catalytically hydrogenated with palladium-charcoal as a catalyst to give a saturated ketone (III). The properties of its semicarbazone, m.p. 229° (decomp.), showed identity with that of 1-oxo-decahydroazulene reported by Cook, *et al.*[9] On Grignard reaction with methylmagnesium iodide, (III) yielded a carbinol compound (IV) which gave a methylazulene (V) on dehydrogenation with palldium-charcoal. The trinitrobenzene (T.N.B.) complex of (V) showed m.p. 161°, which was also in good agreement with that of T.N.B complex of 1-methylazulene.[10] The pure methylazulene (V) regenerated from its T.N.B complex by chromatography through alumina showed an identical absorption curve in visible range with that of 1-methylazulene reported by Plattner, *et al.*[11]

From the results described above, the oxidation of (I) with selenium dioxide occurred at the active methylene group at 1-position. Of the two active methylene groups at 1- and 4-positions in the structure of (I), the former was found to have predominant susceptibility to oxidation.

The oxidation of (VI) was performed similar to the case of (I) and after treatment of the product with Girard reagent, an unsaturated ketone (VII') was obtained. On further purification of (VII') by chromatography with alumina and repeated distillation, it gave an oil with constant boiling point 95~96°/0.4 mm. Hg and molecular formula $C_{10}H_{10}O$ (VII) in 19% yield. The pure ketone gave a salt with hydrogen bromide and absorption in ultraviolet range specific for tropone derivatives (λ_{max} 252 mμ (log ε : 4.12)).

This compound consumed 3 moles of hydrogen by catalytic hydrogenation to give a saturated ketone (VIII), $C_{10}H_{16}O$, whose semicarbazone, m.p. 184°, was identical with that of 6-oxo-*cis*-decahydroazulene reported by Šorm, *et al.*[2]



(I) (II) (III) (IV) (V)

(VI) (VIII) (IX)

(X) (XI) (XII)

After methylation of (VIII) by Grignard reaction, the product, a methylcarbinol (XI), was dehydrogenated with palladium-charcoal in nitrogen atmosphere to give a methylazulene (X). T.N.B complex of (X) showed m.p. 141° and the pure methylazulene regenerated from the T.N.B complex showed m.p. 83°. These melting points together with the absorptions in visible range of the methylazulene showed its identity with

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[9] J.W. Cook, R. Philip, A.R. Sommerville : J. Chem. Soc., **1948**, 164.

[10] Pl. A. Plattner, J. Wyss : Helv. Chim. Acta, **24**, 483(1941).

[11] Pl. A. Plattner, E. Heilbronner : *Ibid.*, **30**, 910(1947).

6-methylazulene reported by both Plattner[11,12] and Šorm.[2]

From the observations described above, it is obvious that on oxidation of (VI) with selenium dioxide, the active methylene group at C-6 is predominantly oxidized to carbonyl group, thus the tropone (VII) and the saturated ketone (VIII) must be represented respectively by the structures 4,5-cyclopentatropone and 6-oxo-decahydroazulene.

The crude ketone fraction (VII′) ($b.p._{0.4}$ 90~100°), on oxidation of (VI) with selenium dioxide before its purification by chromatography and subsequent distillation, consumed 2.6 moles of hydrogen on catalytic hydrogenation. Further, though (VII′) showed an additional maximum at 325 mμ besides that for tropone (VII) (at 252 mμ) in ultraviolet range, the former (as described below, the specific absorption maximum for structure (VIIa)) disappeared after its purification.

These observations could be interpreted by assuming that (VII′) contained a poorly unsaturated ketone than tropone (VII), and that was converted into the latter probably by an automatic oxidative dehydrogenation during further treatment for purification. Thus, (VII′) must be a fraction containing (VII) contaminated with (VIIa) and the oxidation of (VI) with selenium dioxide should have occurred to give (VII) via (VIIa).[13]

In order to have more detailed informations on the structures of compounds (II), (VI), (VII), and (VIIa), their absorption spectra in ultraviolet and infrared ranges were taken and the data for maxima of each compound found are summarized in Table I.

TABLE I. Absorption Spectra

	U. V. (mμ)		I. R. (cm^{-1})		U. V. (mμ)		I. R. (cm^{-1})
	Obsvd.	Calcd.	$\nu_{c=0}$		Obsvd.	Calcd.	$\nu_{c=0}$
(II)	240	239	1705 (cyclopentenone)	(VII)	252	tropone	1652 (tropone) 1702 (weak)[14]
(III)	—	—	1738 (cyclopentanone)	(XII)	292*	—	——
(XI)	248*	—	——	(VIIa)	[325]	328	——
(VI)	255	258	——	(VIII)	—	—	1712 (ketone) 1740 (weak)[14]

* E.E. Tamelen, G.T. Hildahl: J. Am. Chem. Soc., 78, 4405(1956).

According to the rule deduced from unsaturated keto-steroids by Fieser, the expected maximal absorption in the ultraviolet range for (II), which has three substituents at α- and β-positions, is 249 mμ.

However, Gillam reported that the maximum absorption of cyclopentenone appears at the wave length of about 10 mμ more hypsochromic than that for cyclohexenone, so that the real theoretical wave range at which the maximal absorption of (II) appears should be $249-10=239$ mμ. As shown in Table I the datum for (II), 240 mμ, agrees well with the above calculated value.

In the case of the two compounds (VI) and (VII), the values of wave lengths calculated for the given structure based on Fieser's rule are also in good agreement with those found. Thus the compound (VI) having two additional alkyl substituents at the carbon atoms concerned with the conjugated double bond (increment, +5 mμ for each substituent) of (XI), which has a maximum absorption at 248 mμ, must give the absorption at $248+2\times5=258$ mμ. The observed absorption 255 mμ for (VI) is in good agreement with that calculated.

Further, the maximum absorption at 325 mμ appearing in the spectrum of (VII′) is also in good agreement with that calculated for the supposed structure (VIIa), because the latter, which has two additional alkyl substituents at γ- and δ-positions of the dienone

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[12] Pl. A. Plattner, A. Fuerst, A. Studer: Helv. Chim. Acta, **30**, 1091(1947).

[13] The mode of this reaction will again be discussed in the next series of this paper citing selenium dioxide oxidation of 2,4-cycloheptadien-1-one reported by E.E. Tamelen, G.T. Hildahl: J. Am. Chem. Soc., **78**, 4405(1956).

group (increment, +18 mμ for each substituent) in the structure of 2,4-cycloheptadien-1-one (XII), must give the maximum at the range of $292+2\times 18=328$ mμ.

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Experimental

Selenium Dioxide Oxidation of Δ^9-Octahydroazulene (I)—Octahydroazulene (I), obtained by the Clemmensen-Martin reduction of 4-oxo-Δ^9-octahydroazulene, was freed from the starting material by treatment with Girard reagent. The pure (I) showed b.p$_{30}$ 92~93°. A solution of 4.37 g. of SeO_2 in a small quantity of water and 5 cc. of dioxane was poured slowly into 5.35 g. of (I) dissolved in 50 cc. of dioxane under cooling with tap stream. The reaction solution was kept at room temperature for 1 day and then warmed for 2 hrs. on a water bath. After removal of precipitated Se by filtration, the solvent was evaporated *in vacuo*. The dark red residue was extracted with ether, leaving an ether-insoluble pitch. The ethereal extract was washed several times with 5% KCN solution until the aqueous layer did not color with Se. After removal of the solvent from ethereal solution, the residual oil was purified by repeated distillation. The main product with b.p$_{15}$ 138~140°(II) was obtained in a yield of 1.33 g.(23%). U.V. λ_{max}^{EtOH} mμ (log ε) : 240(4.08), 291(2.32). I.R. $\nu_{max}^{capil.}$ 1705 cm^{-1}(C=O of cyclopentenone). *Anal.* Calcd. for $C_{10}H_{14}O$: C, 77.99; H, 9.33. Found : C, 79.75; H, 9.49.

Semicarbazone : m.p. 235~238°(from MeOH). *Anal.* Calcd. for $C_{11}H_{17}ON_3$: N, 20.27. Found: N, 20.34. U.V. λ_{max}^{EtOH} : 280 mμ(log ε 4.20).

2,4-Dinitrophylhydrazone : m.p. 223~225°(from nitromethane). *Anal.* Calcd. for $C_{16}H_{18}O_4N_4$: N, 16.98. Found : N, 17.26. U.V. λ_{max}^{EtOH} 383 mμ (log ε 4.21).

1-Oxo-Δ^9-decahydroazulene (III)—1.30 g. of the keto-ene (II) was reduced with hydrogen and 0.5 g. of Pd-C in EtOH, absorbing 203 cc. of H_2 within an interval of 1.3 hrs. After filtration of the catalyst and removal of solvent, an oily residue was obtained which on distillation gave 1.23 g. of colorless oil (III), b.p$_5$ 100~101°(95% of theory). I.R. $\nu_{max}^{capil.}$ 1739 cm^{-1}(C=O of cyclopentanone).

Semicarbazone : m.p. 226~227°(decomp.) (from hydr. MeOH). *Anal.* Calcd. for $C_{11}H_{19}ON_3$: N, 20.08. Found : N, 19.91.

2,4-Dinitrophenylhydrazone : m.p. 185~188°(from nitromethane). *Anal.* Calcd. for $C_{16}H_{20}O_4N_4$: N, 16.87. Found : N, 16.91.

1-Methyl-decahydro-1-azulenol (IV)—To a Grignard reagent, prepared by vigorous stirring of 0.2 g. of Mg ribbon and 0.5 g. of MeI in dehyd. ether, 1.10 g. of the ketone (III) dissolved in dehyd. ether was added during 1 hr. Stirring was continued for additional 1 hr. and the mixture was shaken with 10% NH_4Cl solution containing pieces of ice. The ethereal layer was separated, washed with water, and dried. Fractionation of the residual oil obtained after removal of the solvent gave an oil (IV), b.p$_{10}$ 95~98°, in a yield of 0.92 g.(76% of theory). *Anal.* Calcd. for $C_{11}H_{20}O$: C, 78.57, H, 11.90. Found : C, 78.82; H, 11.68.

1-Methylazulene (V)—0.80 g. of (IV) was dissolved in 10 cc. of petroleum (b.p. 270~290°) and was dehydrogenated by boiling with 0.8 g. of 10% Pd-C for 4 hrs. in an oil bath at 280°(bath temp.). After filtration of catalyst, the solution of crude azulene contained in petroleum layer was poured into 90% H_3PO_4. The acidic solution was washed with petr. ether, diluted with 3 volumes of ice water, and the azulene regenerated was again taken up in petr. ether. The blue petr. ether solution was washed with water and dried over Na_2SO_4, and the blue solution was chromatographed through an alumina column. A blue oil obtained on evaporation of solvent from the effluent, on treatment with trinitrobenzene, gave 50 mg. of brown crystalline T.N.B. complex (3% of theory). This T.N.B. complex was purified by recrystallization from EtOH and showed m.p. 159~161°. *Anal.* Calcd. for $C_{17}H_{13}O_6N_3$: C, 57.44; H, 3.66. Found : C, 57.27; H, 3.59.

The pure oily azulene was obtained on regeneration from the above T.N.B. complex by chromatography through alumina column using petr. ether as solvent. Visible absorption spectrum: $\lambda_{max}^{petr.\ benzine}$ mμ (ε) : 567(181), 585(216), 609(255), 637(220), 670(182), 705(89), 745(75). The melting point of T.N.B. compelx and the absorption spectrum of pure product showed that the product was 1-methylazulene (V).

$\Delta^{4,9}$-Hexahydroazulene (VI)—(VI) was prepared according to the method reported by Anderson[8] starting from β-decalol via Δ^9-octalin, 1,6-cyclodecanedione, and 4-oxo-Δ^9-octahydroazulene. The final product showed b.p$_{14}$ 87~88°(higher than that given by Anderson of 72° at 10 mm.). *Anal.* Calcd. for $C_{10}H_{14}$: C, 89.55; H, 10.45. Found : C, 89.37; H, 10.41. U.V. λ_{max}^{EtOH} 255 mμ (log ε 3.48).

6-Oxo-$\Delta^{4,7,9}$-tetrahydroazulene (VII) (or 4,5-Cyclopentatropone)—3.0 g. of hexahydroazulene (VI) was oxidized with 2.55 g. of SeO_2, same as in the case of (I). The crude product was an orange-colored oil with b.$p_{0.5}$ 90～100°. The crude oil was treated with Girard reagent to give a ketone which on distillation gave pure product (VII) with b.$p_{0.4}$ 95～96° and the yield of 0.63 g.(19% of theory). *Anal.* Calcd. for $C_{10}H_{10}O$: C, 82.16; H, 6.90. Found : C, 81.97; H, 6.81. U.V. $\lambda_{\max}^{\mathrm{EtOH}}$ 252 mμ (log ε 4.25). I.R. $\nu_{\max}^{\mathrm{capil.}}$ 1652 cm^{-1}(C=O of tropone), 1702 cm^{-1} (weak).14)

6-Oxo-decahydroazulene (VIII)—EtOH solution of 0.43 g. of the tropone (VII) was reduced with H_2 and PtO_2 catalyst, absorbing 160 cc. of H_2 (calcd. for 3 moles of H_2 : 165 cc.). After filtration of the catalyst and removal of the solvent *in vacuo*, the residue was distilled to give the product (VIII) with b.p_5 102～104° and a yield of 0.40 g. *Anal.* Calcd. for $C_{10}H_{16}O$: C, 78.96; H, 10.52. Found : C, 78.77; H, 10.45. I.R. $\nu_{\max}^{\mathrm{capil.}}$ 1712 cm^{-1}(C=O), 1740 cm^{-1} (weak).14)

2,4-Dinitrophenylhydrazone : m.p. 213～216°(from EtOH). *Anal.* Calcd. for $C_{16}H_{20}O_4N_4$: C, 57.82; H, 6.03. Found : C, 57.86; H, 5.79.

Semicarbazone : m.p. 182～184°(from MeOH). *Anal.* Calcd. for $C_{11}H_{19}ON_3$: N, 20.08. Found: N, 19.84.

6-Methyl-decahydro-6-azulenol (IX)—Grignard reagent, prepared from 0.06 g. of Mg ribbon and 0.18 cc. of MeI in 50 cc. of dehyd. ether was reacted with 0.03 g. of azulenone (VIII). After decomposition of the reaction product with 5% NH_4Cl solution, the ether layer was washed with water and dried. The residue, obtained after evaporation of the solvent, was distilled and 0.21 g. of the product (IX), b.p_9 88～92°(yield : 63% of theory), was obtained. *Anal.* Calcd. for $C_{11}H_{20}O$: C, 78.57; H, 11.90. Found : C, 78.89; H, 11.68.15)

6-Methylazulene (X)—Dehydrogenation of 0.20 g. of (IX) was performed similarly as in the case of formation of 1-methylazulene (V). T.N.B. complex obtained from the product (X) was recrystallized from EtOH to brown needles, m.p. 140～141°. Yield, 25 mg.(6% of theory). *Anal.* Calcd. for $C_{17}H_{13}O_6N_3$: C, 57.44; H, 3.66. Found : C, 57.61; H, 3.62.

When a solution of the T.N.B. complex dissolved in petr. ether was chromatographed on an alumina column, the methylazulene (X) fractionated into a blue effluent and after removal of the solvent from the blue effluent and on cooling in an acetone-dry ice bath, the residual oil solidified to scaly violet crystals, m.p. 80～83°. Visible absorption spectrum $\lambda_{\max}^{\mathrm{benzine}}$ mμ (ε) : 528(168), 548(228), 568(295), 590(255), 617(274), 642(134), 680(126).

The metling point of both T.N.B. complex and pure methylazulene as well as the maxima of the latter in visible absorption spectrum indicate that the methylazulene (X) is 6-methylazulene.

Summary

On selenium dioxide oxidation, Δ^9-octahydroazulene gave 1-oxo-Δ^9-octahydroazulene which was converted into 1-methylazulene through Grignard reaction and subsequent dehydrogenation. On similar oxidation, $\Delta^{4,9}$-hexahydroazulene afforded 4,5-cyclopentatropone (or 6-oxo-$\Delta^{4,7,9}$-tetrahydroazulene) via 6-oxo-$\Delta^{4,9}$-hexahydroazulene. The tropone was identified by its derivation into 6-methylazulene.

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14) Absorptions at 1702 and 1740 cm^{-1} must be due to contaminated by-products, 1(or 3)-oxo-$\Delta^{4,9}$-hexahydroazulene and 1(or 3)-oxo-decahydroazulene, respectively.

15) According to Pl. A. Plattner and A. Studer (Helv. Chim. Acta, **29**, 1432(1946)) this carbinol is easily dehydrated to 6-methyl-Δ^5-octahydroazulene.