

Studies on the Synthesis of Pentacyclo (5, 3, 0, 0^{2,5}, 0^{3,9}, 0^{4,8})-decane-6, 10-dione

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Pentacyclo(5, 3, 0, 0^{2,5}, 0^{3,9}, 0^{4,8})-decane-6, 10-dione 의 합성적 연구

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요 약. Cyclopentanone 을 출발 물질로 하여 60%의 좋은 총 수득률로 pentacyclo(5, 3, 0, 0^{2,5}, 0^{3,9}, 0^{4,8})-decane-6, 10-dione 을 합성하였다. Cyclopentanone 으로부터 그의 ethylene ketal(I)을 합성하여 pyridinium bromide perbromide 로서 브롬화시키고 브롬화 ketal(II)을 다시 dehydrobromination 시켜 cyclopentadienone-ethylene ketal의 dimer 를 합성하였다. Ethylene ketal의 dimer(III)를 다시 가수분해시켜 dicyclopentadiene-1, 8-dione(IV)을 합성하고 이 diketone(IV)을 photochemical cyclization 에 의하여 pentacyclo(5, 3, 0, 0^{2,5}, 0^{3,9}, 0^{4,8})-decane-6, 10-dione(V)을 합성하였다.

Abstract. Pentacyclo(5, 3, 0, 0^{2,5}, 0^{3,9}, 0^{4,8})-decane-6, 10-dione was synthesized from the cyclopentanone in good overall yield(60%). Cyclopentanone ethylene ketal(I) was brominated with pyridinium bromide perbromide, and the brominated ketal(II) was converted to the dimer of cyclopentadienone ethylene ketal(III). The ethylene ketal(III) was again converted to the dicyclopentadiene-1, 8-dione(IV). Finally, the pentacyclo(5, 3, 0, 0^{2,5}, 0^{3,9}, 0^{4,8})-decane-6, 10-dione(V) was synthesized from the dicyclopentadiene-1, 8-dione(IV) by photochemical cyclization.

Introduction

The dimer of cyclopentadienone(IV) was prepared as a starting material for the synthesis of pentacyclo(5, 3, 0, 0^{2,5}, 0^{3,9}, 0^{4,8})-decane-6, 10-dione. Several studies¹⁻⁴ of the preparation of cyclopentadienone and its dimer were reported, but the yields were generally low. Cyclopenta-

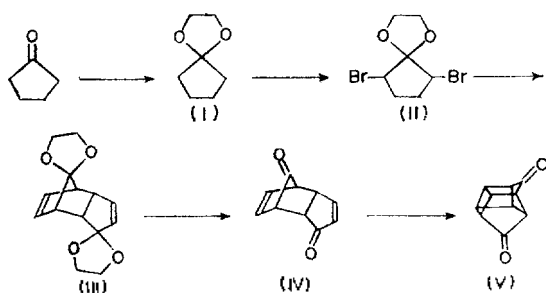
dienone ethylene ketal was first prepared by Salmi⁵, and its dibromo derivative was prepared by Eaton⁶. Depuy and his coworkers⁷ had also prepared the dimer of cyclopentadienone ethylene ketal.

The addition of two molecules of conjugated olefin to form a cyclobutane dimer is one of the oldest and most widely used photochemical reaction⁸, and recently a number of studies of the

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rearrangement^{9,10} and the intramolecular photochemical cyclization¹¹⁻¹⁷ were carried out.

The synthesis of pentacyclo(5, 3, 0, 0^{2,5}, 0^{3,9}, 0^{4,8})-decane-6, 10-dione was attempted from the cyclopentanone by the following scheme, and we had a good overall yield, 60 %, of five steps.



The cyclic ethylene ketal of cyclopentanone(I) was prepared from cyclopentanone and ethylene glycol. The Ketal(I) was brominated with pyridinium bromide perbromide¹⁸, the 2,5-dibromo ketal(II) was converted to the dimer of cyclopentadienone ethylene ketal(III) upon dehydrobromination by double excess of potassium *t*-butoxide in the dry dimethyl sulfoxide. The dimer of cyclopentadienone ethylene ketal(III) was again converted to the dicyclopentadiene-1,8-dione(IV) by hydrolysis. Finally, the diketone(IV) was irradiated with sun lamp for the synthesis of pentacyclo(5, 3, 0, 0^{2,5}, 0^{3,9}, 0^{4,8})-decane-6, 10-dione(V).

Experimental

1) Cyclopentanone-ethylene Ketal(I)

A mixture of 121 g(1.44 moles) of cyclopentanone, 400 ml of benzene, and 0.1 g of *p*-toluenesulfonic acid was placed in an one l of three-necked round bottom flask equipped with additional funnel, Teflon covered magnetic stirrer, and Dean-Stark water separator. The solution was heated to reflux and 96 g(1.53 moles) of ethylene glycol added slowly over a period of 90 min with stirring. After 12 hours of reflux, water separation was completed(27.5 ml. collec-

ted), and the reaction mixture was cooled, washed twice with 100 ml portion of 2 *N*-NaOH solution, once with water, and dried over anhydrous magnesium sulfate. The solvent was evaporated and the ketal(I) was fractionated under reduced pressure through 50 cm Vigreux column. Cyclopentanone-ethylene ketal was collected at 57~57.2 °C(18mm) in yield 160 g(87 %).

2) 2,5-Dibromo Cyclopentanone-ethylene ketal(II)

In a 500 ml. three-necked flask fitted with a calcium chloride tube, dry nitrogen stream, and an 125 ml Erlenmeyer flask containing 64g(0.2 moles) of pyridinium bromide perbromide was placed 12.8 g(0.1 moles) of cyclopentanone-ethylene ketal in 140 ml of dry ethylene glycol. The Erlenmeyer flask was connected to one side arm of the main flask with Tygon tubing, and Tygon tubing was held with clamp holder to control addition of crystal pyridinium bromide perbromide. The solution was stirred with Teflon covered magnetic stirrer. The solid pyridinium bromide perbromide was added in a small portion by shaking the Erlenmeyer flask. The addition was carried out during a period of 45min while the reaction mixture was maintained from 20 to 22 °C. It was stirred at 22 °C for an additional hour after the addition of pyridinium bromide perbromide was completed. The mixture was then poured into a stirred mixture 40 g of anhydrous sodium carbonate and 300 ml of pentane. After stirring for 10 min, 400 ml of water was added. The pentane extract was separated and dried over anhydrous magnesium sulfate, then the solvent was evaporated on a steam bath and the trace of pentane was removed under reduced pressure. The product, weighed 26 g(92 %) had a light yellow color.

3) Dimer of Cyclopentadienone-ethylene Ketal(III)

Method(A). 36 g of potassium *t*-butoxide was

dissolved in 180 ml of dry dimethyl sulfoxide in 500 ml three-necked flask, and 23 g (0.08 moles) of 2,5-dibromocyclopentanone-ethylene ketal(II) in 30 ml of DMSO was added at 18~20 °C. for 30 minutes, and the reaction mixture was stirred an additional hour. The reaction mixture was poured into 200 ml of water. The product was extracted twice with 100 ml of pentane, the pentane extracts were dried over anhydrous magnesium sulfate and let stand overnight for the dimer. The solvent was distilled on the steam bath, the crude product, containing 4 % of monobromo-cyclopentanone ethylene ketal, weighed 9.3 g (89 %). The crude product was recrystallized from hexane, the pure product weighed 8.4 g (90 %), mp. 91°~92 °C.

Method(B). In a 300 ml of three-necked flask equipped with a thermometer, a reflux condenser with calcium chloride drying tube, and nitrogen stream were placed 32.4 g (0.2 moles) of diethylene glycol monobutyl ether (BuOCH₂CH₂OCH₂CH₂OH), 4.6 g (0.2 g atoms) of sodium in 80 ml of dry benzene. The reaction mixture was heated under reflux for 2 days, and 14.3 g (0.05 moles) of the bromo ketal(II) was added dropwise to the solution of BuOCH₂CH₂OCH₂CH₂ONa in benzene for 20 minutes. It was then heated under reflux (85 °C) for 12 hours, and poured into 300 ml of water. The product was extracted twice with 200 ml of hexane. The solvents, benzene and hexane, were removed under reduced pressure, and the crude product with brown color weighed 6 g. The product was recrystallized from hexane, the pure product weighed 2.5 g (40 %).

4) Dimer of Cyclopentadienone(IV)

To 20 ml of dioxane, 20 ml of 10 % HCl aqueous solution was added 5 g of dimer of cyclopentadienone-ethylene ketal, the reaction mixture was heated at 75 °C for 1 hour. The product was extracted three times with 30 ml of

ether, and the ethereal extracts were washed twice with saturated NaCl solution, dried over anhydrous magnesium sulfate. The solvent was removed under reduced pressure. The slightly yellowish white crystal was recrystallized from 1:1 ether and hexane, the pure product, white crystal, weighed 3.2 g (90 %), mp. 103~104 °C. *Anal.* Calcd. for C₁₀H₈O₂: C, 74.97%; H, 5.05%; Found: C, 74.94%; H, 4.96%. The IR-spectrum(KBr) of compound IV showed =CO absorption at 1705 and 1775 cm⁻¹, C=C absorption at 1582 cm⁻¹, C-H absorption at 2998, 1180, 885, and 780 cm⁻¹.

5) Pentacyclo(5, 3, 0, 0^{2,5}, 0^{3,9}, 0^{4,8})-decan-6, 10-dione(V)

5 g of dicyclopentadiene-1,8-dione(IV) was dissolved in 90 ml of dry methanol in 100 ml test tube with water cooling jacket outside. The air in the test tube was replaced with nitrogen, it was then irradiated with sun lamp at 17 °C for 16 hrs. The solvent was removed under reduced pressure, and the residue was sublimed under vacuum (0.5 mm) at 70 °C for 8 hrs. The sublimed product, white waxy crystal, weighed 4.7 g (94 %) which containing 3 % of starting material. The sublimed product was dissolved in 4 ml of acetone, and it was injected into a GPC machine (Autoprep, column 5 % SE-30, 30' × 3/8") for separation of starting material. The product was nicely separated and collected as solid. The pure product(V) weighed 4.25 g (85 %), mp. 176~177 °C. *Anal.* Calcd. for C₁₀H₈O₂: C, 74.99%; H, 5.05%; Found: C, 74.65%; H, 4.85%. The IR-spectrum(KBr) of compound(V) showed =CO absorption at 1774 cm⁻¹, no absorption of conjugated carbonyl at 1704 cm⁻¹, C-H absorption at 2990, 1252, 1125, and 880 cm⁻¹. NMR-spectrum; chemical shift from T.M.S. (in CHCl₃) 9.06, 7.35, and 6.79 corresponding to 4, 2, and 2 protons respectively.

Results and Discussion

It was difficult to remove the trace of starting material from the product in the synthesis cyclopentanone ethylene ketal, but the cyclopentanone could be decreased with excess of ethylene glycol and separated with fractionating column. The pure product of ketal(I) was obtained in good yield(85~90 %).

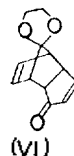
In the synthesis of 2,5-dibromo-cyclopentanone ethylene ketal(II), the cyclopentanone ethylene ketal(I) was dissolved in the dried ethylene glycol and treated with two molar equivalent of pyridinium bromide perbromide at 18~20 °C. An excellent yield(88~95 %) of 2,5-dibromoketal(II) was obtained in the dry nitrogen atmosphere.

Double dehydrobromiantion was carried out by addition of the bromo ketal(II) to a two fold excess of potassium *t*-butoxide in DMSO at 19~20 °C. The pentane extract containing some monomer was let stand for overnight for dimerization of cyclopentadienone ethylene ketal (III). The Diels-Alder dimer, precipitated out as white crystal with mp. 91~92 °C, was collected in good yield(85~90 %). The melting point of compound III was reported as 92 °C by Vogel and Wytes¹⁹, and as 91~92 °C by Depuy and his coworkers.⁷

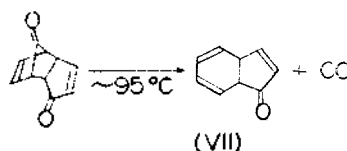
The other method of double dehydrobromination of the bromoketal(II) was attempted, i.e. BuOCH₂CH₂OCH₂CH₂ONa and benzenen were used instead of potassium *t*-butoxide and DM SO. The bromoketal was added dropwise to the BuOCH₂CH₂OCH₂CH₂ONa in benzene at 25 °C, and the reaction mixture was heated under reflux(85 °C) for 12 hrs. The pure product of dimer of cyclopentadienone ethylene ketal(III), mp. 90~91 °C, obtained as 40 % maximum yield. A number of attempts were made to get good yield the product(III) by let

standing more running times, but these attempts were unsuccessful. The yield couldn't be over 40 % maximum, however this procedure could be applied more practical way in the preparation of large scale production of the product(III).

Hydrolysis of the cyclopentadienone ethylene ketal dimer(III) were examined under various reaction conditions. When the hydrolysis were carried out in an aqueous ethanol containing a few drops of conc-HCl at room temperature, only the monoketone, which was identified as dicyclopentadiene-1,8-dione-8-ethylene ketal(VI) from its IR spectra, was obtained.



When the hydrolysis was carried out in aqueous dioxane with 10 % HCl at room temperature, the monoketone, VI, was also obtained in a good yield(90 %) even after one day. The successful hydrolysis toward the diketone(IV) was achieved in aqueous dioxane with 10 % HCl at 75 °C for an hour. The yield of diketone(IV) was 90 %. At the higher temperature, the yield was drastically reduced. The yield of 50 % was obtained at 95 °C. At higher temperature(above 95 °C) the diketone(IV) was unstable and decomposed to 8,9-dihydro-2-indene-1-one(VII) and carbon monoxide as follows.



The IR spectrum of diketone(IV) showed a distinct conjugated carbonyl absorpition at 1705 cm⁻¹, a bridge carbonyl group at 1705 cm⁻¹, and C=C at 1582 cm⁻¹(see Fig.1).

The other preparation path way of the dike-

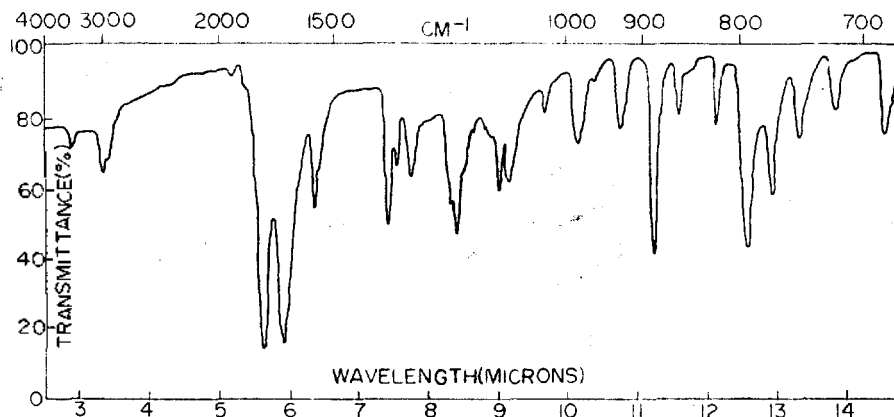
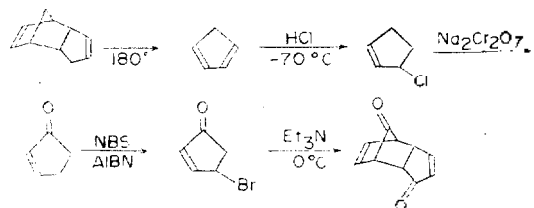


Fig. 1. IR-Spectrum(KBr) of dicyclopentadiene-1, 8-dione.

Table 1. The yields of cage diketone(V) under various reaction conditions

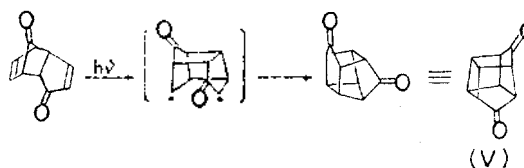
Temp. (°C)	Running times(hr.)	Yield(%)		Temp. (°C)	Running Times(hr.)	Yield(%)	
		Comp. V.	Polymer			Comp. V.	Polymer
29~30	2	45	0	17	2	30	0
29~30	3	65	0	17	4	50	0
29~30	4	75	0	17	7	65	0
29~30	5	81	5	17	10	78	0
29~30	8	85	10	17	13	88	0
29~30	10	85	15	17	16	95	3
29~30	12	80	20	17	20	90	10

tone compound(IV) was also carried out from dicyclopentadiene by the following scheme, but the yields were not so satisfactory.



Various reaction conditions were applied for the synthesis of pentacyclo(5, 3, 0, 0^{2,5}, 0^{3,9}, 0^{4,8})-decane-6, 10-dione(V). The UV irradiation of the diketone(IV) gave the cage diketone(V) as follows.

At the higher temperature(above 30 °C) and for the elongated reaction time, the polymers were obtained with the reduced yield of com-



ound V(see Table 1).

The crude product, containing 5 % of starting material, could be nicely separated by GPC (Autoprep, column 5 % SE-30, 30' × 3/8") in good yield(90 %). The pure product was collected as white solid, mp. 179~77 °C. The best condition for this irradiation was found as follows: reaction temperature, 17 °C by water cooling; running times, 16 hours; solvent, dry methanol. The IR spectrum of the cage diketone(V) shows a distinct absorption band of carbonyl group at 1774 cm⁻¹, and a conjugated carbonyl

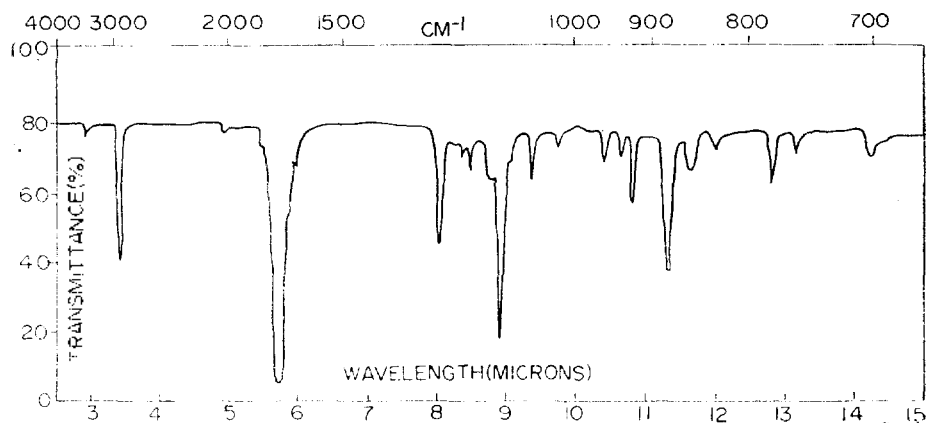


Fig. 2. IR-spectrum(KBr) of pentacyclo(5, 3, 0, 0^{2,5}, 0^{2,9}, 0^{4,8})-decane-6, 10-dione.

group due to C=C bond absorption bands at 1704 and 1585cm⁻¹ were completely disappeared. (see Fig. 2).

The NMR spectrum of the diketone(V) shows chemical shift from TMS(CHCl₃) τ 9.06, 7.35, and 6.70 corresponding to 4, 2, and 2 protons respectively.

References

1. K. Hafner and K. Galiash, *Chem. Ber.*, **94**, 2909(1961).
2. C. H. Depuy and C. E. Lyons, *J. Amer. Chem. Soc.*, **82**, 631(1960).
3. H. W. Wanzlick, *et al.*, *Chem. Ber.*, **88**, 69 (1955).
4. K. Alder and F. H. Flock, *Chem. Ber.*, **87**, 1916 (1954).
5. E. Salmi, *Chem. Ber.*, **71**, 1803(1938).
6. P. E. Eaton and R. A. Hudson, *J. Amer. Chem. Soc.*, **87**, 2769(1963).
7. C. H. Depuy, *et al.*, *J. Org. Chem.*, **29**, 3503 and 3508(1964).
8. Schöberg and Mustofa, *Chem. Rev.*, **40**, 181 (1947).
9. H. E. Zimmerman and J. S. Swenton, *J. Amer. Chem. Soc.*, **89**, 906(1967).
10. L. Ulrich, *et al.*, *Helv. Acta.*, **53**, 1325(1970).
11. Cristol and Snell, *J. Amer. Chem. Soc.*, **80**, 1950 (1958).
12. R. C. Cookson, *et al.*, *J. Chem. Soc.*, 3602 (1964).
13. W. Reusch and D. W. Frey, *Tetrahedron Letter*, 5153(1967).
14. R. Bishop and N. K. Hamer, *J. Chem. Soc. C.*, 1193(1970).
15. W. L. Schreiber and W. C. Agosta, *J. Amer. Chem. Soc.*, **93**, 6292(1971).
16. A. M. Foster and W. C. Agosta, *J. Amer. Chem. Soc.*, **94**, 5100(1972).
17. N. K. Hamer and C. J. Samuel, *J. Chem. Soc., Perkin Trans.*, **2**, 1316(1973).
18. "Experiment of Organic Chemistry", by Fieser P. 65 Published by D. C. Heath and Company, 1957.
19. E. Vogel and E. G. Wyes, *Angew. Chem.*, **74**, 489(1962).