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THERMAL AND PHOTOCHEMICAL SKELETAL TRANSFORMATION REACTIONS OF TRICYCLO[3.2.1.$0^{2,4}$]OCT-6-ENE DERIVATIVES AND RELATED COMPOUNDS[1]

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Abstract—Dimethyl tricyclo[3.2.1.$0^{2,4}$]oct-6-ene-2,4-dicarboxylate (**4**) was synthesized from dimethyl bicyclo[2.2.1]hept-2,5-dien-2,3-dicarboxylate (**1**). Heating or irradiation of **4** afforded its valence isomer—dimethyl tetracyclo[3.3.0.0.$^{2,8}0^{4,6}$]octane-2,4-dicarboxylate (**6**). 2,4-Bis(hydroxymethyl)tricyclo[3.2.1.$0^{2,4}$]oct-6-ene (**7**) upon irradiation afforded its tetracyclic isomer (**8**) corresponding to **6**, while heating has no effect. Thermal and photochemical reactions of some related compounds are reported. Cycloaddition reactions and bromination of **6** were attempted, but no reaction was observed.

The thermally induced intramolecular cyclization of tetracyclo[3.3.2.0.$^{2,4}0^{6,8}$]dec-9-ene derivatives to pentacyclo[3.3.2.0.$^{2,10}0.^{4,9}0^{6,8}$]decane derivatives,[2] is a ($\sigma^2s + \pi^2s$) type process and if concerted is thermally forbidden. Therefore, the valence isomerization occurs stepwise via a 1,3-diradical intermediate. For the purpose of studying the effect of the ring size and substituents on these skeletal transformations, tricyclo[3.2.1.$0^{2,4}$]oct-6-ene derivatives were synthesized and their thermal and photochemical properties investigated. In addition, chemical properties such as cycloaddition reactions and bromination were attempted.

The reaction of dimethyl bicyclo[2.2.1]hept - 2,5 - diene-2,3 - dicarboxylate (**1**)[3] with diazomethane gave two isomeric pyrazoline derivatives (**2** and **3**). Prolonged treatment of **1** with excess diazomethane underwent further addition and afforded a dipyrazoline derivative. The ratio of **2** to **3** was about 4:1, but the separation of **2** and **3** was difficult. Upon irradiation in a Pyrex vessel by high pressure Hg lamp, the mixture of **2** and **3** gave the desired compounds, dimethyl *exo*- and *endo* - tricyclo[3.2.1.$0^{2,4}$]oct - 6 - ene - 2,4 - dicarboxylates (**4** and **5**). Pure **4** (m.p. 44°) could be obtained from mixture of **4** and **5** by alkaline hydrolysis, followed by recrystallization of the free acids and remethylation of the pure *exo*-dicarboxylic acid. The structures of **2**, **3**, **4** and **5** were deduced by inspection of their NMR spectra. Signals of the vinyl protons of **2** and **3** appeared at $\delta 6{\cdot}31$ and $6{\cdot}04$ in *ca.* 4:1 ratio, and those of **4** and **5** at $\delta 6{\cdot}55$ and $5{\cdot}96$ in *ca.* 4:1. The difference of the chemical shift of the vinyl protons between them is very similar to that between *exo*-tricyclo[3.2.1.$0^{2,4}$]oct - 6 - ene - 3 - carboxylate and its *endo*-isomer.[4,5] Not only this similarity, but also a strong NOE was observed between H_{3s} and H_{8s} of **4**. That is the irradiation of H_{3s} (at $\delta 2{\cdot}12$, d, $J = 6{\cdot}0$ Hz) caused *ca.* a 30% increase in intensity of the signals of H_{8s} (at $\delta 1{\cdot}32$, double triplet, $J = 9{\cdot}5$, $1{\cdot}5$, $0{\cdot}5$ Hz) of **4**. Also, the irradiation at $\delta 1{\cdot}32$ caused the intensity increase of the signals at $\delta 2{\cdot}12$. Therefore, the cyclopropane moiety of **4** is *exo*, and the structure of the related compounds (**2**, **3** and **5**) is established. The ratio of **2** to **3** was found equal to those of *exo*- and *endo*-isomers of dimethyl tricyclo[3.2.1.$0^{2,4}$]oct - 6 - ene - 3,3 - dicarboxylates which were obtained from norbornadiene with bis(carbomethoxy)carbene.[5] The preponderance of the *exo* product **2** in the addition reaction was due to the steric effect of the norbornadiene skeleton.

In order to obtain 2,3 - diphenylbicyclo[2.2.1]hept - 2,5 - diene, thermal addition reactions of cyclopentadiene with tolane were investigated, but these were not successful and the starting substances were recovered.

Compound **1** was thermally stable and no decomposition took place below 500°. Pyrolysis of **1** above 700° gave small amounts of cyclopentadiene and dimethyl acetylenedicarboxylate accompanied with a large amount of resinous substance. On the other hand, when mixtures of **2** and **3** were heated above 150°, cyclopentadiene and dimethyl pyrazole-4,5-dicarboxylate were obtained by retro-Diels-Alder reaction, in which case no nitrogen was evolved. The heating of **4** above 170° underwent the skeletal transformation reactions and gave dimethyl tetracyclo[3.3.0.0.$^{2,8}0^{4,6}$]octane - 2,4 - dicarboxylate (**6**) in a good yield. The mixture of **4** and **5**, on the same pyrolysis, afforded only **6**.

In order to investigate the substituent effect on these valence isomerizations, 2,4 - bis(hydroxymethyl) - *exo* - tricyclo[3.2.1.$0^{2,4}$]oct - 6 - ene (**7**) was prepared from **4** by LAH reduction. Compound **7** was thermally stable and was recovered unchanged on heating at 200°. Above 200°, **7** was gradually decomposed but no definite products could be isolated in addition to recovery of **7**.

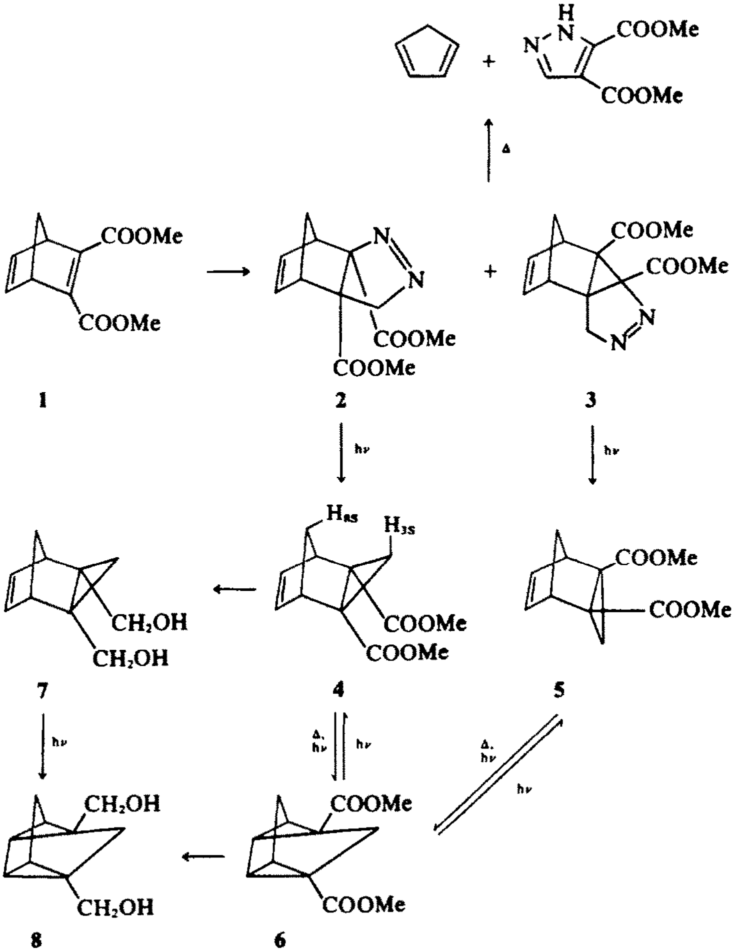
On the other hand, photochemical reactions of **4** and **7** showed a sharp contrast with the above thermal reactions. That is, the irradiation of **4** and **7** by low pressure Hg lamp afforded **6** and 2,4-bis(hydroxymethyl)tetracyclo-[3.3.0.0.$^{2,8}0^{4,6}$]octane (**8**), respectively. Reduction of **6** also afforded **8**. Irradiation of **6** gave **4** in small amount. Thus, photoequilibrium existed between **4** and **6**.

Cycloaddition reactions of **6** with tetracyanoethylene and dimethyl acetylenedicarboxylate resulted in the recovery of the starting compounds. Bromination of **6** also failed. These results are interesting, because quadricyclenes have been known to react with these reagents to give addition products.[6-10]

The above reactions are shown in Scheme 1.

DISCUSSION

The driving force of rather facile retro-Diels-Alder reactions of **2** and **3** can be the formation of a stable aromatic compound—dimethyl pyrazole-4,5-di-carboxy-



Scheme 1.

late. On the other hand, the same type of reaction of **1** and tricyclo[4.2.1.0^{2,5}]nona - 3 - isopropyriden - 7 - en - 4 - one[11] was rather difficult and high temperatures such as 400° and 600° were necessary in which case heteroaromatics could not be expected.

Photochemical skeletal transformation of the tricyclo[3.2.1.0^{2,4}]oct - 6 - ene system to the tetracyclo[3.3.0.0.^{2,8}0^{4,6}]octane system is well known as the [σ^2s + π^2s] type concerted reactions.[12,13] Therefore, photochemical valence isomerization of **4** and **7** to **6** and **8** is a known photoisomerization. However, the [2$_s$ + 2$_s$] type transformation is thermally forbidden. Thus, the thermal isomerization of quadricyclene to norbornadiene is fairly difficult,[6,14] although the transformation releases *ca.* 10 kcal/mol of strain energy.[15] On the other hand, **4** readily isomerized thermally to **6**, whereas **7** did not. The smooth reaction of the former was attributed to the stabilization of the radical by the ester groups which led to the ring cleavage. The hydroxymethyl groups do not have such stabilization. Thus, these substituent effects suggest that the transformation of **4** to **6** proceeded by a two-step process via the 1,3-diradical formed at 2- and 4-positions of **4**.

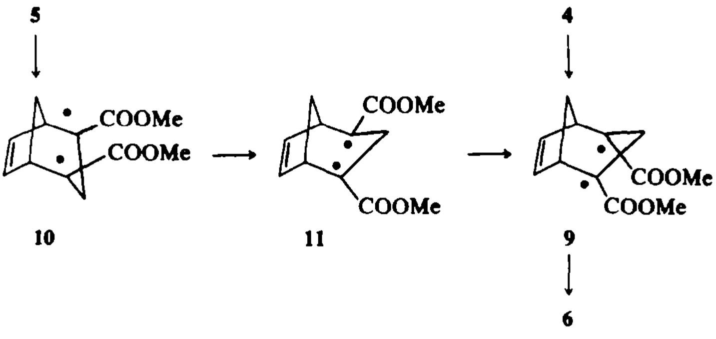
There are a few examples of this type of thermal skeletal transformation of tricyclo[3.2.1.0^{2,4}]oct - 6 - enes to tetracyclo[3.3.0.0.^{2,8}0^{4,6}]octanes[16–18] and tricyclo[3.2.0.0^{2,4}]hept - 6 - enes to quadricyclenes.[19] All the compounds capable of a thermal transformation possessed a phenyl group at 2,4-positions, and without this phenyl group, this type transformation did not take place and other isomerizations occurred.[19b] Phenyl groups are also known to stabilize the radical center. Therefore, the above results can be explained by a stepwise process mechanism in which the *exo*-diradical (**9**) formed from **4** is trapped by the double bond, and also from **5**, the formed *endo*-diradical (**10**) converts to **9** through the planar diradical (**11**) as shown in Scheme 2.

From a stereochemical point of view, the *exo*-diradical (**9**) is necessary for the bond formation between the double bond and the cyclopropane moiety of **4** and **5**. A fairly strong interaction was observed during photoelectron spectroscopy between the double bond and the *exo*-cyclopropane but not the *endo*-one of tricyclo[3.2.1.0^{2,4}]oct - 6 - ene system.[20]

It is noteworthy that thermally the tetracyclo[3.3.0.0.^{2,8}0^{4,6}]octane system is more stable than the tricyclo[3.2.1.0^{2,4}]oct - 6 - ene system.

EXPERIMENTAL

The reaction of **1** *with diazomethane.* To a soln of **1** (24·0 g) in 200 ml ether cooled in an ice bath, an ethereal diazomethane prepared from 25 g nitrosomethyl urea and 300 ml ether was added with stirring. After addition, the mixture was allowed to stand over night in a refrigerator. The ppt formed was separated by filtration and recrystallized from MeOH to give 3·50 g of prisms of a dipyrazoline compound m.p. 173–174°. (Found: C, 53·46; H, 5·74; N, 19·42. Calcd. for $C_{13}H_{16}O_4N_4$: C, 53·42; H, 5·52; N, 19·17%).



Scheme 2.

The ether layer was condensed and the residual oil was distilled under reduced pressure to give the mixture of **2** and **3** (*ca.* 4 : 1 ratio); b.p. 130°/0·3 mmHg, yield 24·8 g; λ_{max}^{MeOH} at 322 nm. (Found: C, 57·17; H, 5·81; N, 11·23. Calcd. for $C_{12}H_{14}O_4N_2$: C, 57·59; H, 5·64; N, 11·20%).

Prolonged treatment of **1** with excess diazomethane caused increased formation of the dipyrazoline compound.

Thermolysis of **1**. A soln of **1** (500 mg) in 2·5 ml of benzene was added dropwise to a quartz pyrolysis tube packed with pieces of quartz (8 mm × 10 cm) under N_2. The speed of the stream was changed from 5 ml to 50 ml/min. Until the temp reached 500°, more than 90% of **1** was recovered unchanged. At 600°, 70% of recovery of **1** and 5% of cyclopentadiene and dimethyl acetylenedicarboxylate were formed together with several unidentified products. Above 650°, the amount of unidentified products was increased.

Thermolysis of **2** *and* **3**. The mixture of **2** and **3** (533 mg) was put in a U shape tube with one end connected to a N_2 gas cylinder and other end to a double trap tube cooled in an acetone-dry ice bath. The tube was heated at 170° (bath) for 15 min and then the product was recrystallized from MeOH-water to give 218 mg of dimethyl pyrazole-4,5-dicarboxylate, m.p. 137–139°, which was identified by comparison of the IR spectrum and mixed m.p. with an authentic sample.

From the trap, 42 mg of cyclopentadiene was obtained; identified by gas chromatograph and IR spectrum.

When the reaction was investigated by NMR, it was found to occur near 150°.

Irradiation of **2** *and* **3**. A soln of the mixture of **2** and **3** (2·08 g) in 300 ml ether in a Pyrex vessel which was fitted with cooling water and N_2 stream bubbler was irradiated by Toshiba H 400p lamp for 3 days. After the ether was removed, the residual oil was distilled under reduced pressure to give 1·85 g of an almost colorless oil; which was the mixture of **4** and **5** in the ratio of *ca.* 4 : 1. (Found: C, 64·59; H, 6·04. Calcd. for $C_{12}H_{14}O_4$: C, 64·85; H, 6·35%).

A mixture of **4** and **5** (1·51 g), KOH (0·8 g) and 10 ml water was heated under reflux for 2 hr and then acidified with conc HCl to give 1·11 g of crystalline material. Repeated recrystallization from MeOH afforded 619 mg of pure *exo* - tricyclo[3.2.1.0^{2,4}]oct - 6 - ene - 2,4 - dicarboxylic acid, m.p. 250° with dec. (Found: C, 61·59; H, 5·41. Calcd. for $C_{10}H_{10}O_4$: C, 61·85; H, 5·19%).

However, *endo*-dicarboxylic acid could not be obtained in a pure state.

Remethylation of the acid with diazomethane gave pure **4**, m.p. 44°, from MeOH-water. (Found: C, 64·72; H, 6·21%).

Thermolysis of **4** *and* **5**. A mixture of **4** and **5** (1·57 g) was heated at 190° (bath) for 5 hr and after cooling the solid mass was recrystallized from MeOH to give 1·10 g of **6**, m.p. 83·5–84°. When the above valence isomerization was checked by NMR, the change occurred gradually above 170° and was completed in a few hr to give the single product, **6**. Also treatment of 200 mg of pure **4** as above gave 175 mg of **6** after purification. (Found: C, 65·12; H, 6·60. Calcd. for $C_{12}H_{14}O_4$: C, 64·85; H, 6·35%).

Irradiation of **4**. A soln of **4** (486 mg) in 100 ml MeOH was irradiated by Ushio low pressure Hg lamp (12 W). After 20 hr, the ratio of **4** and **6** reached *ca.* 1 : 4 by gas chromatograph. The MeOH was removed under reduced pressure and the residue was submitted for TLC (silica gel, benzene) to give 290 mg of **6** and 80 mg of **4**.

Irradiation of **6**. A soln of **6** (50 mg) in 50 ml MeOH was irradiated as described. After 24 hr the ratio of **4** and **6** reached *ca.* 1 : 6 (by gas chromatograph).

Reduction of **4**. To a suspension of LAH (1·52 g) in 20 ml dry THF, a soln of **4** (2·79 g) in 20 ml dry THF was added with stirring. After addition, the mixture was heated under reflux for 20 hr and then excess LAH was decomposed by the addition of EtOAc. The solvent was removed under reduced pressure, and to the residue 2N HCl was added until the inorganic salts were dissolved. The water layer was extracted with EtOAc and the combined EtOAc layers were washed with water, $NaHCO_3$aq, water and then dried over Na_2SO_4. A colorless crystalline substance was obtained after removal of EtOAc under reduced pressure; m.p. 113–114° from acetone, yield, 1·96 g. (Found: C, 71·94; H, 8·54. Calcd. for $C_{10}H_{14}O_2$: C, 72·26; H, 8·49%).

Reduction of **6**. A soln of **6** (120 mg) in 2 ml dry THF was added to a suspension of 10 ml THF which contained a large excess of LAH and refluxed for 48 hr. After the mixture was treated as in the case of the reduction of **4**, a small amount of oily substance, 60 mg, was obtained. This oil was dissolved in 5 ml dry ether and 200 mg phenyl isocyanate was added to the soln. After the mixture was allowed to stand at room temp for 3 days, the solvent and excess phenyl isocyanate were removed under reduced pressure to give a solid residue. Recrystallization of the residue from benzene-cyclohexane afforded 100 mg of di-phenylurethane of **8** as colorless prisms m.p. 128–131°. (Found: C, 71·13; H, 5·89; N, 7·19. Calcd. for $C_{24}H_{24}O_4N_2$: C, 71·27; H, 5·98; N, 6·93%).

Irradiation of **7**. A soln of **7** (150 mg) in 50 ml MeOH was irradiated as in the case of **4**. After 13 hr the starting substance disappeared, checked by gas chromatograph. The MeOH was removed and the oily residue (130 mg) was identical with **8** by a comparison of retention time (gas chromatograph) and IR spectra.

Attempted cycloaddition reactions of **6**

(a) *With tetracyanoethylene*. A soln of **6** (100 mg) and TCNE (65 mg) in 20 ml dry THF was allowed to stand overnight. Since no change was observed by gas chromatograph, the soln was heated under reflux for 20 hr. However, only **6** was identified by gas chromatography. After standing 2 weeks the THF was removed under reduced pressure and **6** (70 mg) was recovered unchanged.

(b) A soln of **6** (110 mg) and dimethyl acetylene-dicarboxylate (110 mg) in 20 ml THF was heated under reflux for 24 hr, but **6** was recovered unchanged almost quantitatively.

A mixture of **6** (100 mg) and dimethyl acetylene-dicarboxylate (105 mg) in a sealed tube was heated at 100° for 2 days. After cooling, the mixture was solidified and recrystallization from MeOH-water gave 80 mg of **6**.

Attempted bromination of **6**. To a soln of **6** (150 mg) in 10 ml chloroform, excess Br_2 was added and allowed to stand overnight at room temp. The chloroform was removed, and the starting material was recovered unchanged. Heating under reflux did not promote any reaction.

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