

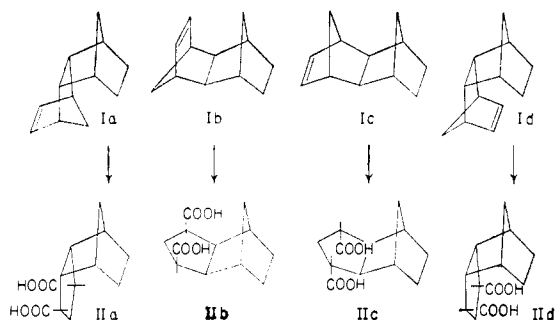
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The Stereochemistry of Fused Norcamphane Systems¹

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Three of the four stereoisomers of octahydro-4,7-methanoindene-*cis*-1,3-dicarboxylic acid have been realized from compounds containing the fused norcamphane system. On the basis of their relationships and manner of preparation the *exo-endo* configuration (Ib) has been tentatively assigned to the adduct formed from cyclopentadiene and bicyclo(2.2.1)-2-heptene.

Alder and Stein recognized the fused norcamphane system in the polymers of cyclopentadiene formed by the diene synthesis² and summarized their findings on the structure and steric relationships of these, as well as other adducts of cyclopentadiene, in a review published in 1934.³ These workers were cognizant of the fact that the adducts formed by the interaction of cyclopentadiene with bicyclo(2.2.1)-2-heptenes could exist in each of four stereoisomeric forms (illustrated, in the simplest case, by 1,2,3,4,4a,5,8,8a-octahydro-1,4,5,8-dimethanonaphthalene (I, a, b, c, d)) but they did not provide experimental results to indicate which of the four stereoisomers had formed in the adduction process. This stereochemical problem has remained unanswered, but with the advent of the two commercially important insecticides, Aldrin and Dieldrin,⁴ which possess the fused norcamphane system as their basic carbon skeleton, interest has been renewed in such systems.



Alder and his co-workers investigated α - and β -tricyclopentadiene² and the adducts formed from two molecules of cyclopentadiene and one molecule of each of the dienophiles maleic anhydride,² acrolein,⁵ vinyl acetate⁶ and vinyl formate⁶ and found that in every case the resultant dimethanonaphthalene nucleus was configurationally identical. This identity was established by relating the adducts to the same octahydro-4,7-methanoindene-*cis*-1,3-dicarboxylic acid (II) of m.p. 216° (α -diacid).² From each of the two tricyclopentadienes the α -diacid was obtained as the sole product by hydrogenation of the bicycloheptene double bond, followed by oxidative degradation of the remaining cyclopentene ring; a similar procedure applied to the other adducts produced the α -diacid or products

known to give this diacid upon further degradation.

These results indicated that the adduction of cyclopentadiene to the bicycloheptene nucleus was highly stereospecific and, further, that it was reasonable to expect that the same mode of adduction occurred generally.

An examination of the stereoisomers of I reveals that direct oxidative cleavage of the double bond would yield the four diacids, II, a, b, c, d, which differ from each other in configuration at the bicycloheptane-cyclopentane ring fusion site, or in the steric relationships of the carboxyl groups to the ring fusion positions, or in both. The double bond which would be cleaved to produce these diacids is located in that part of the molecule which is formed last, *i.e.*, by the adduction of the second molecule of cyclopentadiene. This method of attack is to be differentiated from that of Alder and Stein which comprised the initial hydrogenation of this last-formed double bond and degradation of the other side of the molecule. If the latter approach were capable of application to, say, the molecule Ic, then the resulting diacid IIc would be identical with that obtained by direct cleavage. This fact would be a consequence of the presence in the saturated molecule of a plane of symmetry passing through the two fused carbon atoms and the hydrogen atoms joined to them. However, in the case of dihydro-Ib no such plane of symmetry is present and cleavage of one of the ethanol groups would lead to a diacid different from that obtained by cleavage of the other. Similar considerations show that Ia would also be capable of yielding two diacids, but that Id, analogously to Ic, would permit only of one.

These principles now have been applied to I obtained as a by-product from the reaction between cyclopentadiene and ethylene. Permanganate oxidation of I readily furnished a dicarboxylic acid II which melted at 256° (β -diacid) and was different from the α -diacid obtained by Alder and Stein. This result, together with the plausible assumption that I and the adducts previously studied have the same configuration, indicates that a plane of symmetry through the fused carbon atoms is absent in dihydro-I and, consequently, that I exists as either Ia or Ib. The latter forms are designated *endo-exo* and *exo-endo*, respectively; Ic, *exo-exo*; and Id, *endo-endo*.⁷

(1) Presented before the Organic Chemistry Section of the XIIth International Congress of Pure and Applied Chemistry, New York, N. Y., September 10-13, 1951.

(2) K. Alder, G. Stein, J. Reese and W. Grassman, *Ann.*, **496**, 204 (1932).

(3) K. Alder and G. Stein, *Angew. Chem.*, **47**, 837 (1934).

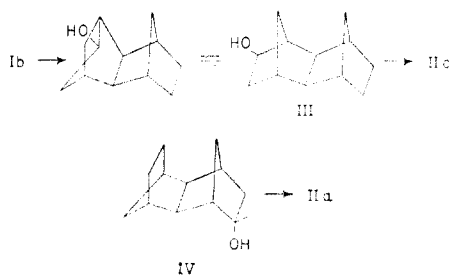
(4) R. E. Lidov, H. Bluestone, S. B. Soloway and C. W. Kearns, *Advances in Chemistry Series*, **1**, 175 (1950).

(5) K. Alder and E. Windemuth, *Ber.*, **71B**, 2409 (1938).

(6) K. Alder and H. F. Rickert, *Ann.*, **643**, 1 (1939).

(7) In the nomenclature adopted to designate the geometrical isomerism of fused norcamphane systems the first prefix mentioned applies to the norcamphane nucleus numbered lowest according to the practice of "Chemical Abstracts" and indicates the positions, *endo* or *exo*, of this lowest numbered nucleus through which the adjoining norcamphane nucleus is fused. The second prefix mentioned, then, applies in the same manner to the adjoining norcamphane nucleus. Thus, these principles permit the complete name, 1,2,3,4,4a,5,8,8a-octahydro-1,4-*exo-endo*-5,8-dimethanonaphthalene, for the stereoisomer Ib which, for short, is designated as the *exo-endo* form.

In view of the indicated existence of an *endo* configuration in I, it appeared that the application of the hydration reaction of Bruson⁸ to I might result in a rearrangement of the carbon skeleton. When I was treated with acetic acid in the presence of sulfuric acid and the resulting ester was saponified, the alcohol, decahydro-1,4-*exo-exo*-5,8-dimethanonaphthalene-*exo*-2-ol⁷ (III), m.p. 78°, was obtained. Direct oxidation of III with permanganate yielded a third dicarboxylic acid having structure II and melting at 236° (γ -diacid). Inasmuch as decahydro-1,4-*exo-endo*-5,8-dimethanonaphthalene-*endo*-2-ol⁷ (IV), m.p. 92°,⁶ prepared from the adduct of two molecules of cyclopentadiene and one of vinyl acetate, furnished the α -diacid upon oxidation, a basic skeletal difference between the two alcohols is apparent. This conclusion is not affected by the steric orientations of the hydroxyl groups, the assignment of which is based on prior investigations.^{8,9}



The realization of the γ -diacid starting from I can be explained on the basis of a Wagner-Meerwein rearrangement of the carbon skeleton. Such a rearrangement in the case of dicyclopentadiene was discovered by Bruson and Riener⁸ and was elucidated by Bartlett and Schneider¹⁰ who showed that the *endo* carbon skeleton of the cyclopentadiene dimer was converted to the *exo* configuration. This skeletal conversion is known only with the compound cited and examples of the reverse process, conversion of the *exo* configuration to the *endo*, in adducts of cyclopentadiene bearing a fused carbon ring do not appear to exist. Thus it may be assumed that in the hydration of I the bicycloheptene moiety had rearranged so that an *exo* configuration had formed from an *endo* one. Applying this restriction to the four stereoisomers of I, it is perceived that only Ib and Id can rearrange in the manner exhibited by dicyclopentadiene. Therefore, because of the limitation to Ia or Ib imposed by the arguments based on molecular symmetry, only Ib remains as the likely stereoisomer of the cyclopentadiene-bicyclo(2.2.1)heptene adduct. This conclusion implies that Ib undergoes rearrangement of its carbon skeleton in forming the alcohol III and that subsequently III yields IIc, the γ -diacid, upon oxidation; also, that the α -diacid is IIa and the β -diacid is IIb.

Experiments are in progress to test the correctness of the assumptions made in these assignments of configuration.

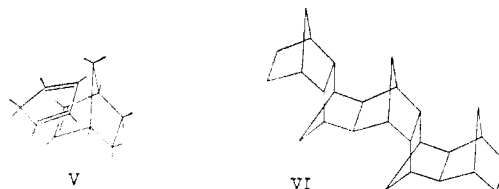
The proposed *exo-endo* configuration (Ib) for

(8) H. A. Bruson and T. W. Riener, *THIS JOURNAL*, **67**, 723 (1945).

(9) K. Alder, G. Stein, S. Schneider, M. Liebmann, E. Rolland and G. Schulze, *Ann.*, **525**, 183 (1936).

(10) P. D. Bartlett and A. Schneider, *THIS JOURNAL*, **68**, 6 (1946).

adducts containing two fused norcamphane nuclei can be visualized as resulting from the attack of cyclopentadiene on the *exo* side of the bicyclo(2.2.1)heptene double bond so that the methylene group of the diene is directed away from the methano bridge of the dienophile (V). An examination of molecular models indicates that there is less steric hindrance in the transition state of an addend on the *exo* side of the bicyclo(2.2.1)heptene double bond than on the *endo* side and that in the transition state represented by V there are fewer atomic interactions than in the three other possible arrangements of the reactants which would lead to different stereoisomers of I (a, c, d). The *exo-cis* mode of addition appears to be general with reagents which normally yield *cis* products, having been found to be the preferred course in reactions with hydrogen⁹ and phenyl azide¹¹ and in hydroxylations with potassium permanganate,¹² and it was this characteristic behavior that led Alder and Stein to conclude⁸ that cyclopentadiene acting as a diene became attached through the *exo* positions of bicyclo(2.2.1)heptenes in the formation of the fused norcamphane system. It is also to be noted that the bicycloheptene nucleus of the *exo-endo* form Ib is fused through its *endo* positions to the norcamphane nucleus. This steric feature conforms to the general course of diene reactions of cyclopentadiene in which products having the *endo* configuration form predominantly.



Extending the concept of *exo-endo* configuration to adducts containing three or more cyclopentadiene residues (VI) and making the reasonable assumption that all of the norcamphane nuclei are alike, one perceives a spatial alternation of the norcamphane nuclei such that the corresponding planes in every other one are parallel. This orientation is independent of the actual bond angles present in norcamphane and results from the geometry of norcamphane which manifests two planes of symmetry perpendicular to each other. An interesting consequence of the parallel orientation of alternate norcamphane nuclei is that an over-all linearity in space is conferred upon the polycyclopentadiene adducts.

Experimental

Octahydro-*endo*-4,7-methanoindene-*trans,trans*-1,3-dicarboxylic Acid¹³ (IIa), α -Diacid.—This acid was originally obtained by oxidative degradation of dihydrotricyclopenta-

(11) K. Alder, G. Stein and S. Schneider, *Ann.*, **515**, 185 (1935).

(12) K. Alder, G. Stein, W. Eckardt, R. v. Buddenbrock and S. Schneider, *ibid.*, **504**, 216 (1933).

(13) The four stereoisomeric octahydro-4,7-methanoindene-*cis*-1,3-dicarboxylic acids are completely named by employing the prefix *endo* or *exo* to represent the manner in which the cyclopentane ring is joined to the norcamphane nucleus and the prefix *cis* or *trans* for each of the carboxyl groups to show their steric positions on the cyclopentane ring with respect to the attached norcamphane nucleus. The latter method of naming is analogous to that recommended for substituted alicyclic compounds; see *Chem. Eng. News*, **28**, 1842 (1950).

diene.³ A specimen was prepared by the treatment of decahydro-1,4-*exo-endo*-5,8-dimethanonaphthalen-*endo*-2-ol⁷ (IV), the alcohol derived from the adduct produced from two molecules of cyclopentadiene and one of vinyl acetate,⁴ with potassium permanganate in boiling aqueous suspension (potassium hydroxide was introduced to help initiate the oxidation). Filtration of the reaction mixture, followed by concentration and acidification gave the crude diacid which was crystallized once from a mixture of acetone and acetonitrile (sparingly soluble in the latter) to yield the pure compound as rhombs, m.p. 214.5–215.5°; lit.² m.p. 216–217°.

Anal. Calcd. for C₁₂H₁₆O₄: C, 64.3; H, 7.19. Found: C, 64.6; H, 7.07.

The α -anhydride was prepared by refluxing the α -diacid in acetic anhydride and removing the excess solvent by vacuum distillation; crystallization of the residue from a mixture of ethyl acetate and benzene (charcoal) yielded the pure compound as square-shaped plates, m.p. 152–153°; lit.² m.p. 154°.

Anal. Calcd. for C₁₂H₁₄O₃: C, 69.9; H, 6.80. Found: C, 69.5; H, 7.00.

1,2,3,4,4a,5,8a-Octahydro-1,4-*exo-endo*-5,8-dimethanonaphthalene¹⁷ (Ib).—This hydrocarbon was obtained as a by-product of the reaction between cyclopentadiene and ethylene¹⁴ and was realized also by the direct interaction of cyclopentadiene and bicyclo(2.2.1)heptene at 180° for 12 hours. The product, a mobile oil, was purified readily by distillation; a heart-cut boiling at 90–93° (11 mm.) was taken for further study; *n*_D²⁰ 1.5197; *d*₄²⁰ 1.006.

Anal. Calcd. for C₁₂H₁₆: C, 90.0; H, 10.0; mol. wt., 160. Found: C, 89.8; H, 10.0; mol. wt. in benzene, 165.

Dihydrophenyltriazole of Ib.—Exactly 3.20 g. of Ib was weighed into a test-tube, 3.0 g. of phenyl azide was added and the mixture was stirred. The resulting solution soon became warm and crystals separated after several minutes. The temperature was controlled by external cooling. After standing for two days the solid mass was triturated with pentane and the crystals were transferred to a tared sintered glass crucible and washed with pentane; a total of 50 ml. of solvent was employed in both processes. The product after oven-drying weighed 4.22 g. (76% yield) and melted at 148.4–149.2°. Crystallization from a mixture of benzene and hexane yielded the compound as elongated prisms, again melting at 148.4–149.2°.

Anal. Calcd. for C₁₈H₁₂N₃: C, 77.4; H, 7.59; N, 15.1. Found: C, 77.7; H, 7.47; N, 15.1.

Octahydro-*exo*-4,7-methanoindene-*cis,cis*-1,3-dicarboxylic Acid¹⁸ (IIb), β -Diacid.—A stirred suspension of 16 g. of Ib in 1500 ml. of water was treated with 43 g. of solid potassium permanganate added in portions over a period of 4 hours; the temperature of the mixture rose only to 35°. After stirring for several hours more, the mixture was filtered and the residue of manganese dioxide was washed with hot water. The combined filtrate and washings were concentrated to 200 ml., charcoaled and filtered. Acidification of the filtrate with dilute hydrochloric acid (6*N*) yielded 8 g. of product melting at 238–240°; one crystallization from water gave the pure compound as prismatic needles, m.p. 256°.

Anal. Calcd. for C₁₂H₁₆O₄: C, 64.3; H, 7.19; neut. equiv., 112. Found: C, 64.0; H, 7.05; neut. equiv., 112, 112.

A mixture with the α -diacid (m.p. 214.5–215.5°) melted at 200–230°.

The β -anhydride was prepared by the procedure employed for the α -anhydride. Crystallization from hexane (charcoal) yielded the pure material as elongated plates, m.p. 179–179.5°.

Anal. Calcd. for C₁₂H₁₄O₃: C, 69.9; H, 6.80. Found: C, 70.0; H, 6.87.

A mixture of the β -anhydride with the α -anhydride (m.p. 152–153°) melted at 125–135°.

Decahydro-1,4-*exo-endo*-5,8-dimethanonaphthalen-*exo*-2-ol⁷ (III) Acetate.—To a solution of 64 g. of Ib in 200 ml. of

acetic acid, 2 ml. of 50:50 sulfuric acid was added and the mixture was heated. At the start of reflux a vigorous reaction set in. External heating was discontinued for a period of 20 minutes; heating was then resumed and the mixture was allowed to reflux overnight. The following day the reaction mixture was poured into one liter of water and the product was separated by extraction with ether. The ethereal solution was washed free of all acids with dilute sodium bicarbonate solution, dried over anhydrous sodium sulfate and evaporated. Distillation of the residue through a modified Claisen flask yielded 64 g. (73% yield) of pure ester, b.p. 88–90° (0.1 mm.); *n*_D²⁰ 1.5028.

Anal. Calcd. for C₁₄H₂₀O₂: C, 76.3; H, 9.15. Found: C, 76.1; H, 9.50.

Decahydro-1,4-*exo-endo*-5,8-dimethanonaphthalen-*exo*-2-ol⁷ (III).—A solution of 21 g. of potassium hydroxide (85%) in 20 ml. of water was added to 60 g. of the acetate of III dissolved in 200 ml. of methanol and the resulting solution was refluxed overnight. After this time the mixture was diluted with water and the precipitated oil was extracted completely with ether. The ethereal solution was washed thoroughly with water, dried over anhydrous sodium sulfate and evaporated. Distillation of the residue yielded 46 g. (96% yield) of alcohol, b.p. 87–90° (0.1 mm.), which solidified in the receiver and melted at 64–67°. An analytical sample was obtained after two recrystallizations from hexane, m.p. 76.5–78°.

Anal. Calcd. for C₁₂H₁₆O: C, 80.9; H, 10.1. Found: C, 81.0; H, 10.1.

A mixture with the alcohol IV (m.p. 87–89°; lit.⁶ m.p. 90–92°) melted at 60–73°.

The 3,5-dinitrobenzoate was prepared by treating 1.78 g. of the crude (distilled) alcohol with 3.5 g. of 3,5-dinitrobenzoyl chloride in 10 ml. of pyridine for one-half hour on the steam-bath. Digestion with aqueous potassium carbonate solution in the cold gave the crude product which, upon crystallization from 40 ml. of acetone (charcoal) at room temperature, yielded 2.40 g. of pure compound as plates, m.p. 161.6–162.4°; a second crop amounted to 0.70 g., m.p. 159–161°. The combined yield was 83%.

Anal. Calcd. for C₁₈H₂₁O₄N₂: C, 61.3; H, 5.38; N, 7.53. Found: C, 61.2; H, 5.33; N, 7.72.

Octahydro-*exo*-4,7-methanoindene-*trans*-1,3-dicarboxylic Acid¹⁸ (IIc), γ -Diacid.—A stirred suspension of 8.9 g. of III in 500 ml. of boiling water containing 5.6 g. of potassium hydroxide (85%) was treated with 22.1 g. of powdered potassium permanganate over a period of three hours. When the pink color of the solution had disappeared the mixture was filtered and the residue of manganese dioxide was washed with water. Both the filtrates and the residue were extracted with ether to yield a total of 2.0 g. of neutral substances. The combined extracted filtrates were concentrated *in vacuo*, charcoaled and filtered. Acidification with concd. hydrochloric acid yielded 5.6 g. of diacid, m.p. 235–236°; crystallization from ethyl acetate yielded flat prisms of unchanged m.p.

Anal. Calcd. for C₁₂H₁₆O₄: C, 64.3; H, 7.19; neut. equiv., 112. Found: C, 64.2; H, 7.32; neut. equiv., 112, 110.

A mixture with the β -diacid (m.p. 256°) melted at 216–236°.

The γ -anhydride was prepared in the same manner as the others, though a relatively long period of time (6 hours) was required to effect ring closure. The crude product was dissolved in ether and crystallized by cooling to 0°; m.p. 107–108°.

Anal. Calcd. for C₁₂H₁₄O₃: C, 69.9; H, 6.80. Found: C, 70.0; H, 7.04.

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