Electrophilic Substitution of 4*H*-Cyclopenta[*def*]phenanthrene. Bromination

Masaaki Yoshida,* Masahiro Minabe, and Kazuo Suzuki

Department of Industrial Chemistry, Faculty of Engineering, Utsunomiya University, Ishiicho, Utsunomiya 321-31, Japan

Received September 18, 1978

The bromiation of 4*H*-cyclopenta[*def*]phenanthrene gave the 1-bromo derivative as a main product accompanied by small amounts of 3- and 8-bromo isomers. The hydrocarbon was transformed into 4-bromo- and 8,9-dibromo-8,9-dihydro-4*H*-cyclopenta[*def*]phenanthrene by radical bromination under exposure to light. Additionally, the reaction of 8,9-dihydro-4*H*-cyclopenta[*def*]phenanthrene and cyclopenta[*def*]phenanthren-4-one with bromine yielded 2- and 8-bromo derivatives in high yields, respectively.

The hydrocarbon 4*H*-cyclopenta[*def*]phenanthrene (**1**)[1] molecule combines characteristic features, such as those of acenaphthene, fluorene, and phenanthrene structures. This may cause some interesting investigations at the active methylene,[2,3] at the localized double bond of C_8-C_9,[4] and on the strained benzenoid rings.[5] Electrophilic substitution of **1** has been reported scarcely.[5,6] Our previous report has been concerned with the nitration of **1**, which gives 1-, 2-, 3-, and 8-nitro derivatives.[7]

The present paper deals with bromination of **1** and its derivatives, **2**[6] and **3**,[1] in connection with nitration of **1**, and some interesting results may be noted.

Results and Discussion

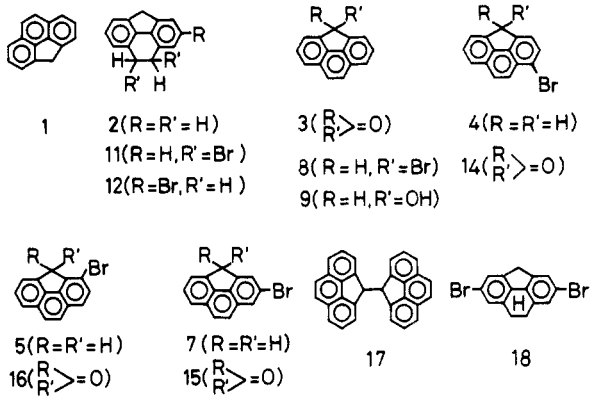
The bromination of **1** in the dark gave the 1-bromo derivative **4** as a main product, accompanied by isomeric **5** and **6**, as shown in Table I.

The structures of bromides **4**, **5**, and **7** were established by stepwise syntheses from the authentic amines.[7,8] Bromide **8** was synthesized by the reactions of the active methylene group of **1** with *N*-bromosuccinimide and also of alcohol **9**[9] with hydrogen bromide. The other monobromide **6** was prepared from the carboxylic acid **10** by a three-step synthesis,[10] as shown in Scheme II.

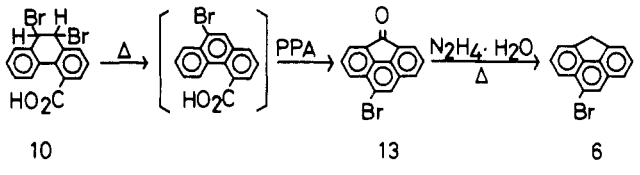
The predominate formation of **4** and a low yield of **5** may be in that order of electron densities in **1**. No formation of the 2 isomer **7** is consistent with the general concept[11] that electrophilic bromination in aromatic compounds shows higher regioselectivity than that observed in nitration.

Bromide **6** might be able to form presumably through the following three sequences: (a) ionic addition of bromine and elimination of hydrogen bromide, (b) radical pathways via addition product **11**, and (c) electrophilic substitution of **1**. However, the ionic addition route (a) is negligible, because addition of hydrogen bromide of **1** has not taken place under these reaction conditions. The radical mechanism (b) may probably be less important than the direct substitution mechanism (c) from the finding that the reaction was slower in a nonpolar solvent (run 6 in Table I) than in a polar solvent (runs 1-4). Therefore, it is reasonable that a part of **6** was formed by the electrophilic substitution (c) of **1** as in the cases of **4** and **5**.

Scheme I



Scheme II



In run 1, change of the reaction time altered the total yield of monobromides and little affected the ratio of isomers. Thus, the distribution of products may be due to the kinetic control which is defined by the polarity of reaction medium. The unusual finding was observed as the increase of yield of monobromides at a low temperature (-60 °C, run 2); it is presumably effected by generating hydrogen bromide in the reaction system.

The reaction of **1** with bromine in nonpolar solvent at a high temperature gave **4**, **6**, and **8** (run 7). If the reaction proceeded under exposure to light, substitution product **8** and addition product **11** were formed immediately, and **11** was gradually converted into **6** and **8**. Dehydrobromination of **11** occurred to give **6** by pyrolysis and also by treatment in the presence of a catalytic amount of aluminum chloride. Debromination of **11** took place under irradiation of light to afford **8**. A solution (C_6D_6) of **11** and

(1) O. Kruber, *Ber. Dtsch. Chem. Ges.*, **67**, 1000 (1934).
(2) T. Kimura, M. Minabe, and K. Suzuki, *J. Org. Chem.*, **43**, 1247 (1978).
(3) T. Kimura, M. Minabe, and K. Suzuki, *Bull. Chem. Soc. Jpn.*, **52**, 1447 (1979).
(4) A. Kadokura, M. Yoshida, M. Minabe, and K. Suzuki, *Chem. Ind. (London)*, 734 (1978).
(5) W. E. Bachmann and J. C. Sheehan, *J. Am. Chem. Soc.*, **63**, 2598 (1941).
(6) L. F. Fieser and J. Cason, *J. Am. Chem. Soc.*, **62**, 1293 (1940).
(7) M. Yoshida, S. Nagayama, M. Minabe, and K. Suzuki, *J. Org. Chem.*, submitted.
(8) A. Sieglitz and W. Schidlo, *Chem. Ber.*, **96**, 1098 (1963).
(9) G. Sugowdz, P. J. Collin, and W. H. F. Sasse, *Tetrahedron Lett.*, 3843 (1969).
(10) L. O. Krbehek, R. R. Riter, R. G. Wagner, and C. W. Huffman, *J. Med. Chem.*, **13**, 234 (1970).
(11) F. Badea, "Reaction Mechanisms in Organic Chemistry", Abacus Press, Tunbridge Wells, 1977, p 364.

0022-3263/79/1944-3029$01.00/0

Table I. Bromination of 4*H*-Cyclopenta[*def*]phenanthrene

run no.	reaction conditions[a] solvent	time, min	catalyst	monobromide isomers yield, %	proportion, % 4	5	6	starting material recovd, %
1	$CHCl_3$	10		65	80	5	15	32
2	$CHCl_3$[b]	10		79	81	3	16	15
3	$MeNO_2$	10		84	77	6	17	15
4	HOAc	10	H_2SO_4	75	71	3	26	22
5	CCl_4	10	I_2	72	64	4	32	26
6	CS_2	4200		80	59	6	35	17
7	CCl_4[c]	60		34	27		38	44

[a] The reaction was carried out in the dark at 20 °C. [b] The reaction temperature was maintained at −60 °C. [c] The reaction was run with refluxing. Also, 8 (12%) was obtained.

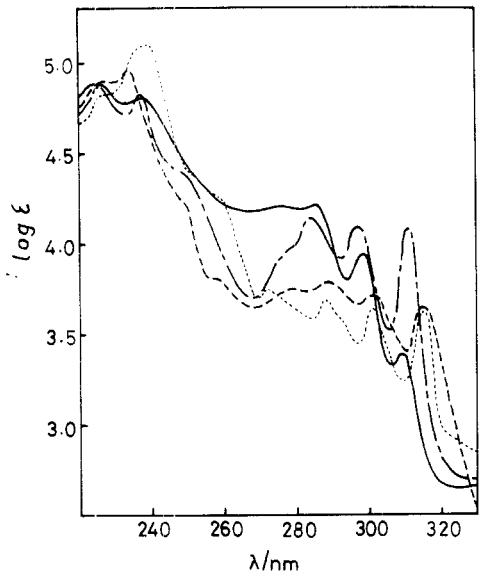


Figure 1. UV spectra of 13 (- - -), 14 (- · -), 15 (···), and 16 (—).

fluorene yielded 1 and 9-bromofluorene[12] under irradiation of UV light; therefore, 11 plays as bromine carrier in radical bromination as *N*-bromosuccinimide. These findings suggest that a part of **6** would be formed by radical addition and ionic dehydrobromination under the conditions shown in Table I (runs 5-7).

The 2-bromo (**12**) and 8-bromo derivatives (**13**) were best prepared by brominations of hydrocarbon **2** and ketone **3**.

Figure 1 shows UV spectra of bromo ketones, **13**, **14**, **15**, and **16**. The characteristic curve of **16** at 250–270 nm may be due to the strong π–π^* absorption band. Also, the spectrum **14** has distinct benzenoid absorptions by comparing it with those of **13** and **15**. The conjugation effect of the carbonyl group may be capable of affecting the bromine atom at the 1 and 3 positions more than that at the 2 and 8 positions. Therefore, the reactivity at the 1 and 3 positions of **3** may decrease because of the carbonyl group in comparison with that of **1**, and the substitution would occur at the 8 position to give **13**.

Experimental Section

All the melting points are uncorrected. The instruments used in this experiment were the same as those described elsewhere.[7] The VPC analyses were run at 125 °C with a JGC-1100 FP gas chromatograph (Jeol) attached to a 1.0-m glass column containing 3% Silicone DC QF-1 on Chromosorb WAW (60-80 mesh). Retention time was confirmed to be at 4.0 min for **1**, 11.0 min for **5**, and 14.0 min for **4**, **6**, and **7**.

Bromination of 4*H*-Cyclopenta[*def*]phenanthrene (1). General Procedure. Hydrocarbon **1** (475 mg, 2.5 mmol) was dissolved in a solvent (15 mL), and, if necessary, catalyst was added (catalyst used was 0.01 mL of H_2SO_4 or 2 mg of I_2). A solution of Br_2 (0.15 mL, 3 mmol) in the solvent (5 mL) was added to the mixture at 20 °C for 5 min in the dark, and the resulting mixture was stirred for an additional 5 min. Upon pouring the mixture into aqueous $NaHSO_3$ (1%, 30 mL), the organic compounds were extracted with benzene (100 mL). The benzene solution was washed with water, dried over Na_2SO_4, and evaporated to dryness. The residue was submitted to a silica gel column chromatography in cyclohexane, and the component of each eluate was determined by comparison of NMR and VPC data with those of authentic specimens. By comparison of methylene protons, **1** and **4** were distinct from the mixture of **5**, **6**, and **7**. The content of **5** was determined on the VPC chromatogram. A sharp signal at 7.88 ppm of **7** was characteristic of the spectra of the other products.

Synthesis of 3-Bromo-4*H*-cyclopenta[*def*]phenanthrene (5). The hydrobromide of 4*H*-cyclopenta[*def*]phenanthren-3-amine[8] (102 mg, 0.5 mmol) in H_2O (150 mL) was diazotized with $NaNO_2$ (5.0 *N*, 0.1 mL) at 0 °C. Then, a cold solution of KBr (2.5 g) and $HgBr_2$ (2.5 g) in H_2O (50 mL) was added rapidly to the diazonium salt solution. The resulting yellow complex was treated with KBr (2.5 g) according to the method described elsewhere,[13] and the product was purified by a silica gel column chromatography in benzene to afford 77 mg (57%) of **5**: mp 81–82 °C (recrystallized from hexane); NMR (CCl_4) δ 4.23 (2 H, s, CH_2) and 7.47–7.81 (7 H, m, Ar-H); mass spectrum *m/e* 270, 268 (M^+), and 189. Anal. Calcd for $C_{15}H_9Br$: C, 66.94; H, 3.37. Found: C, 66.72; H, 3.64.

In the same manner, the following bromides were obtained from the corresponding amines:[7] 1-bromo-4*H*-cyclopenta[*def*]-phenanthrene (**4**) (yield 20%): mp 85.5–86.5 °C (from hexane); NMR δ 4.15 and 7.31–7.81; mass spectrum *m/e* 270, 268 (M^+), and 189. Anal. Found: C, 66.66; H, 3.26.

2-Bromo-4*H*-cyclopenta[*def*]phenanthrene (**7**) (yield 34%): mp 91–92 °C (from HOEt); NMR δ 4.22 and 7.47–7.88; mass spectrum *m/e* 270, 268 (M^+), and 189. Anal. Found: C, 66.64; H, 3.54.

2-Bromo-8,9-dihydro-4*H*-cyclopenta[*def*]phenanthrene (**12**) (yield 40%): mp 93–94 °C (from HOEt); NMR δ 3.06 (4 H, s, CH_2–CH_2), 3.75, and 6.87–7.37 (5 H, m); mass spectrum *m/e* 272, 270 (M^+), and 191. Anal. Calcd for $C_{15}H_{11}Br$: C, 66.44; H, 4.09. Found: C, 66.14; H, 4.36.

8-Bromo-4*H*-cyclopenta[*def*]phenanthrene (6). Powdered 9,10-dibromo-9,10-dihydrophenanthrene-4-carboxylic acid (**10**)[10] (1.8 g, 4.7 mmol) was heated at the melting point until evolution of HBr was no longer detected. The resulting residue was treated with poly(phosphoric acid) (12 g) at 100–120 °C for 40 h, and the mixture was poured into cold water. The precipitate was chromatographed in benzene on a silica gel to give 0.85 g (60% from **10**) of **13**: mp 214–215 °C (from benzene); IR 1705 cm^{-1} (C=O); mass spectrum *m/e* 284, 282 (M^+), and 203. Anal. Calcd for $C_{15}H_7OBr$: C, 63.63; H, 2.50. Found: C, 63.32; H, 2.29.

The Wolff–Kishner reduction of ketone **13** (1.5 g, 5.3 mmol) afforded 420 mg (29%) of **6**: mp 98–99 °C (from HOEt); NMR

(12) J. Thiele and A. Wansheidt, *Justus Liebigs Ann. Chem.*, **376**, 278 (1910).

(13) W. E. Bachmann and C. H. Boatner, *J. Am. Chem. Soc.*, **58**, 2194 (1936).

(CCl_4) δ 4.28 and 7.45-8.01; mass spectrum *m/e* 270, 268 (M^+), and 189. Anal. Calcd for $C_{15}H_9Br$: C, 66.94; H, 3.37. Found: C, 66.66; H, 3.23.

4-Bromo-4*H*-cyclopenta[*def*]phenanthrene (8). (a). A mixture of 1 (950 mg, 5 mmol) and *N*-bromosuccinimide (890 mg, 5 mmol) in benzene (20 mL) was refluxed for 5 h to afford 1.19 g (89%) of 8: mp 130–132 °C dec (from hexane); NMR (CCl_4) δ 6.25 (1 H, s, CH) and 7.39–7.82 (8 H, m, Ar–H); mass spectrum *m/e* 270, 268 (M^+), and 189. Anal. Calcd for $C_{15}H_9Br$: C, 66.94; H, 3.37. Found: C, 66.67; H, 3.39.

(b). A solution of 4*H*-cyclopenta[*def*]phenanthren-4-ol (9) (600 mg, 2.9 mmol) in HOAc (60 mL) was treated with HBr at 20–23 °C for 1 h to yield 490 mg (63%) of 8 as sublimate and 15 mg (3%) of 4,4′-bis(4*H*-cyclopenta[*def*]phenanthrene) (17): mp 232–233 °C dec (from HOAc) as sublimation residue; NMR of 17 (C_6D_6) δ 5.44 (2 H, s) and 6.99–7.70 (16 H, m). Anal. Calcd for $C_{30}H_{18}$: C, 95.21; H, 4.79. Found: C, 95.22; H, 4.73.

Synthesis and Reactions of 8,9-Dibromo-8,9-dihydro-4*H*-cyclopenta[*def*]phenanthrene (11). (a). A mixture of 1 (380 mg, 2 mmol) and Br_2 (0.1 mL, 2 mmol) in CCl_4 (4 mL) was placed in a Pyrex test tube and irradiated with a 40-W fluorescent lamp from a distance of 150 cm for 30 s, and then HBr was removed in vacuo. The NMR spectrum of the resulting mixture showed 1 (58%), 8 (8%), and 11 (34%).

Petroleum ether (bp 60–70 °C, 5 mL) was added to the resulting mixture which was cooled at −20 °C to precipitate 125 mg (18%) of 11 as yellowish needles: mp 86 °C dec; NMR (CCl_4) δ 3.90 (2 H, s, CH_2), 5.83 (2 H, s, CH), and 7.22–7.40 (6 H, m, Ar–H); mass spectrum *m/e* 352, 350, 348 (M^+), 270, 268, and 189.

(b). Bromide 11 (80 mg, 0.23 mmol) was heated in a test tube at 90 °C for 15 min to afford 51 mg (83%) of 6, mp 98–99 °C.

(c). A solution of 11 (80 mg) in $CHCl_3$ (5 mL) was stirred with one drop of concentrated H_2SO_4 for 1 min at room temperature to afford 46 mg (75%) of 6. Similarly, treatments of 11 (80 mg) with I_2 (1 mg) and with $AlCl_3$ (1 mg) gave 6 in yields of 53 mg (86%) and 55 mg (89%), respectively.

(d). A solution of 11 (80 mg) in $CHCl_3$ (5 mL) was placed in a Pyrex test tube and irradiated with a 100-W high-pressure mercury lamp for 1 h giving 48 mg (78%) of 8.

Bromination of 8,9-Dihydro-4*H*-cyclopenta[*def*]phenanthrene (2). A solution of Br_2 (0.85 mL, 16.5 mmol) in CCl_4 (30 mL) was added to a solution of 2 (2.88 g, 15 mmol) in CCl_4 (40 mL) with stirring in the dark at 0 °C for 30 min. After being stirred for an additional 2 h, the resulting mixture was treated with aqueous $NaHSO_3$ (1%) and benzene. The organic layer was chromatographed on silica gel, the eluate was evaporated to dryness, and the residue was sublimed in vacuo at 100 °C to give 3.26 g (83%) of 12, mp 93–94 °C.

The residual part was recrystallized from cyclohexane giving 400 mg (8%) of 2,6-dibromo-8,9-dihydro-4*H*-cyclopenta[*def*]phenanthrene (18): mp 183–184 °C; NMR (C_6D_6) δ 2.44 (4 H, s), 3.11 (2 H, s), 7.02 (2 H, s), and 7.16 (2 H, s); mass spectrum *m/e* 352, 350, 348 (M^+), 271, and 269. Anal. Calcd for $C_{15}H_{10}Br_2$: C, 51.46; H, 2.88. Found: C, 51.76; H, 3.02.

A mixture of 12 (820 mg, 3 mmol) and chloranil (2.0 g) in xylene (30 mL) was refluxed for 45 h to afford 716 mg (88%) of 7, mp 91–92 °C.

Bromination of Cyclopenta[*def*]phenanthren-4-one (3). A solution of 3 (4.00 g, 19.6 mmol) and Br_2 (2.1 mL, 40 mmol) in $CHCl_3$ (240 mL) was stirred for 48 h at room temperature, giving 3.58 g (65%) of 8-bromocyclopenta[*def*]phenanthren-4-one (13), mp 214–215 °C.

1-Bromocyclopenta[*def*]phenanthren-4-one (14). A solution of 4 (135 mg, 0.5 mmol) in benzene (15 mL) was refluxed with activated MnO_2 (5.0 g) for 1 h to give 112 mg (79%) of 14: mp 178–179 °C (from HOEt); IR 1723 cm^{-1} (C=O); mass spectrum *m/e* 284, 282 (M^+), and 203. Anal. Calcd for $C_{15}H_7OBr$: C, 63.63; H, 2.50. Found: C, 63.46; H, 2.37.

2-Bromocyclopenta[*def*]phenanthren-4-one (15) was prepared from 7 in a 59% yield: mp 190.0–190.5 °C (from HOEt); IR 1719 cm^{-1} (C=O); mass spectrum *m/e* 284, 282 (M^+), and 203. Anal. Found: C, 63.89; H, 2.31.

3-Bromocyclopenta[*def*]phenanthren-4-one (16) was also obtained from 5 in a 55% yield: mp 172–173 °C (from HOEt); IR 1714 cm^{-1} (C=O); mass spectrum *m/e* 284, 282 (M^+), and 203. Anal. Found: C, 63.66; H, 2.26.

Registry No. 1, 203-64-5; 2, 27410-55-5; 3, 5737-13-3; 4, 70659-36-8; 5, 70659-37-9; 6, 70659-38-0; 7, 70659-39-1; 8, 70659-40-4; 9, 64884-42-0; 10, 26687-67-2; 11, 70659-41-5; 12, 70659-42-6; 13, 70659-43-7; 14, 70659-44-8; 15, 70659-45-9; 16, 70659-46-0; 17, 70659-47-1; 18, 70659-48-2; 4*H*-cyclopenta[*def*]phenanthren-3-amine HBr, 70659-49-3; 4*H*-cyclopenta[*def*]phenanthren-1-amine, 69706-35-0; 4*H*-cyclopenta[*def*]phenanthren-2-amine, 69706-40-7; 8,9-dihydro-4*H*-cyclopenta[*def*]phenanthren-2-amine, 69706-52-1; 9-bromophenanthrene-4-carboxylic acid, 70659-50-6.

Perhydroazulenes. 2. The 2-*tert*-Butylperhydroazulen-4-one System[1,2]

Herbert O. House,* Cheuk-Chung Yau, and Don VanDerveer

School of Chemistry, Georgia Institute of Technology, Atlanta, Georgia 30332

Received March 7, 1979

After conjugate addition of an allyl group to the enone 5, subsequent hydrobromination and base-induced cyclization formed the cis (1) and trans (2) isomers of the 2-*tert*-butylperhydroazulen-4-one system. Each of these ketones was converted to an appropriate solid derivative, and the structures and conformations of these solid derivatives were established by X-ray crystallography.

Since earlier study[2,3] had developed a route allowing the efficient synthesis of perhydroazulene derivatives, we have been encouraged to prepare several sets of perhydroazulene derivatives with *tert*-butyl or other sterically bulky substituents at selected positions. It is our hope that these perhydroazulene derivatives with bulky substituents will be conformationally homogeneous so that further addition or substitution reactions involving the perhydroazulene ring can be effected with predictable stereochemical outcome. In this paper, we describe the synthesis of the cis (1) and trans (2) isomers (Scheme I) of a 2-*tert*-butylperhydroazulene system and offer evidence concerning the favored conformations of these compounds.

The enone 5 required as a starting material for this synthesis was obtained by the ozonolysis–aldol condensation sequence illustrated in Scheme I. Although this sequence could be run on a sufficient scale to provide adequate amounts of the starting enone 5, the aldol condensation step 4 → 5 formed a relatively complex

(1) This research has been supported by Public Health Service Grant R01-GM-20197 from the National Institute of General Medical Science. The execution of this research was also assisted by Institutional Research Grants from the National Science Foundation for the purchase of a mass spectrometer and a Fourier transform NMR spectrometer.

(2) For the previous paper in this series, see H. O. House, T. S. B. Sayer, and C. C. Yau, *J. Org. Chem.*, **43**, 2153 (1978).

(3) (a) H. O. House, W. V. Phillips, T. S. B. Sayer, and C. C. Yau, *J. Org. Chem.*, **43**, 700 (1978); (b) H. O. House and W. V. Phillips, *ibid.*, **43**, 3851 (1978).

0022-3263/79/1944-3031$01.00/0