The conformational diastereomers of 5-substituted-5*H*-6-chloro-dibenzo[*a*,*c*]cycloheptene

Parviz Rashidi-Ranjbar,[a] Saeed Taghvaei-Ganjali,[a] Sue-Lein Wang,[b] Fen-Ling Liao[b] and Ali Heydari[a]

[a] *Department of Chemistry, Faculty of Science, Tehran University, Tehran, Iran*
[b] *Department of Chemistry, The National Tsing-Hua University, Hsinchu, Taiwan, Republic of China*

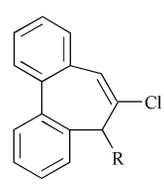
Received (in Cambridge, UK) 20th June 2000, Accepted 30th April 2001
First published as an Advance Article on the web 4th June 2001

Conformational diastereomers of 5-substituted-5*H*-6-chlorodibenzo[*a*,*c*]cycloheptene **1** are observed at room temperature in solution. Empirical force field and the AM1 semi-empirical quantum mechanics calculations indicate that the conformation of the cycloheptatriene ring in **1** is a boat (**B**) form. In the **B** form, the C-5 substituent can be oriented in equatorial (*e*) and axial (*a*) directions. The *e*–*a* interchange involves inversion of the biphenyl moiety in the range of 14.1–17.7 kcal mol^{-1}, determined by ^{1}H-NMR band shape analysis. The free energy difference between the *e*–*a* forms is not reproduced by the AM1 calculations. The *e*–*a* equilibrium in derivatives of **1** depend on the solvent polarity: for **1i** the *e*–*a* ratio in $CDCl_3$ (28 : 72) changes to (55 : 45) in DMSO-d_6.The conformational space of the flexible side chains in all mono-substituted compounds except **1k** is searched by molecular mechanics and the AM1 semi-empirical method and the relative heats of formation of all rotamers are considered in estimation of the *e*–*a* ratio. Many of the rotamers show an internal hydrogen bond calculated by the AM1 method. The diethylamino derivative of **1** (**1l**) was found just in the *e* form. The preferred conformation of **1h** in the solid state was found by X-ray crystallography of a single crystal to be *e* with a strong OH · · · N internal hydrogen bond in the side chain. Dissolution of the **1h** single crystals at low temperature and recording the ^{1}H-NMR spectrum at −60 °C show that assignment of the *e* form as the dominant one at room temperature for **1h** is justified.

Introduction

Stereochemical studies of atropisomeric biaryls have played a leading role in the development of organic stereochemistry.[1–5] The atropisomerism is due to the restricted rotation around the pivot bond either by the bulky groups on the *ortho* positions or by bridging the two *ortho* positions on either ring to form a ring of suitable size. One aspect of biaryl stereochemistry is the possibility of conformational diastereoisomerism. Conformational diastereomerism occurs in biphenyls and terphenyls. In substituted biphenyls with a chiral center, the diastereomerism is due to a combination of the difference in configuration as well as conformation. In the terphenyls, only the conformational difference is responsible for diastereomerism.[6] In biphenyls with a chiral center, two stereogenic units[7] are responsible for diastereomerism, *i.e.* a chiral axis and a chiral center. The barrier presented by the chiral axis, although very high,[8,9] could be overcome, but that of the chiral center could not, except by breaking a bond.

One of us has reported on the absolute configuration and conformational analysis of the conformational diastereomers of dibenzo[*a*,*c*]cyclooctene derivatives.[10–13] In the present work we will discuss the conformation of dibenzo[*a*,*c*]cycloheptene **1** (Scheme 1) and a number of its 5-mono-substituted 6-chloro derivatives in solution and in one case in the solid state.



	R
1a	OMe
1b	OEt
1c	OPr
1d	OBu
1e	OiPr
1f	OiBu
1g	$O(CH_2)_2OH$
1h	$NH(CH_2)_2OH$
1i	$NH(CH_2)_2NH_2$
1j	$NH(CH_2)_3NH_2$
1k	Cl
1l	$N(Et)_2$

Scheme 1

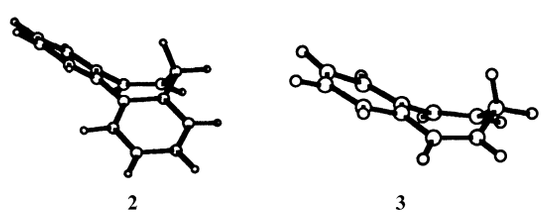


Fig. 1 The structure of **2** and **3** as calculated by the MMP2-87 method.

Results and discussion

Empirical force-field calculations by MMP2–87[14] and calculations by the semi-empirical AM1 method[15] on 5*H*-dibenzo-[*a*,*c*]cycloheptene **2** predict a chiral boat conformation (**B**) with *ca.* 43° dihedral angle between the benzene rings as the only minimum energy (Fig. 1) like the parent hydrocarbon cyclohepta-1,3,5-triene[16] and 5*H*-benzocycloheptene **3**.[17] The chirality of **2** depends on the biphenyl unit as the only stereogenic element. Enantiomerization of the **2** antipodes happens by ring inversion accompanied by rotation around the pivot bond of the biphenyl unit from the dihedral angle of 43° to −43° or *vice versa*. The barrier to this process in **2** is determined by dynamic NMR measurement to be 13.3 kcal mol^{-1}.[17] In the **B** form of **2**, the substituent at the 5 position can be oriented in equatorial (*e*) or axial (*a*) positions. One substitution in the 5 position gives the possibility of two diastereomeric pairs of enantiomers with the configurations *RR*, *SS* and *RS*, *SR* (in the order C5 and

DOI: 10.1039/b004919k

Table 1 Population of the major and minor forms, and $\Delta G°$ (kcal mol^{-1}, room temperature) in $CDCl_3$ and DMSO in substituted **1**. $\Delta\Delta H_f$ is taken from the AM1 calculations

	Major			Minor					
Compound	P_{exp} (%) ($CDCl_3$)	P_{exp} (%) (DMSO)	P_{calcd} (%)	P_{exp} (%) ($CDCl_3$)	P_{exp} (%) (DMSO)	P_{calcd} (%)	$\Delta G°$/kcal mol^{-1} ($CDCl_3$)	$\Delta G°$/kcal mol^{-1} (DMSO)	$\Delta\Delta H_f$/kcal mol^{-1} (AM1)
1a	61.5	50	93.7	38.5	50	6.3	−0.28	−0.01	−1.6
1b	64.0	58	90.0	36.0	42	10.0	−0.34	−0.19	−1.3
1c	59.0	51	90.7	41.0	49	9.2	−0.22	−0.20	−1.4
1d	59.0	51	91.2	41.0	49	8.8	−0.21	−0.02	−1.4
1e	56.0	50	92.4	44.0	50	7.6	−0.17	−0.01	−1.5
1f	56.0	57	87.5	44.0	43	12.5	−0.15	−0.16	−1.2
1g	58.5	67	89.3	41.5	33	10.7	−0.20	−0.59	−1.3
1h	50.5	66	70.4	49.5	34	29.6	−0.01	−0.40	−0.5
1i	72.0	55	99.9	28.0	45	0.1	−0.56	−0.11	−4.7
1j	57.5	69	98.9	42.5	31	1.1	−0.18	−0.48	−2.7
1k	96.0	100	—	—	4	—	−1.88	—	−0.40
1l	100	100	96.7	—	—	3.3	—	—	−2.0

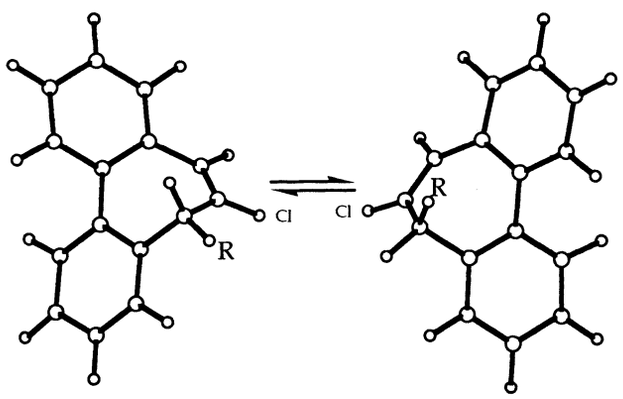


Fig. 2 The conformational equilibrium of the *e* and *a* forms in substituted **1**.

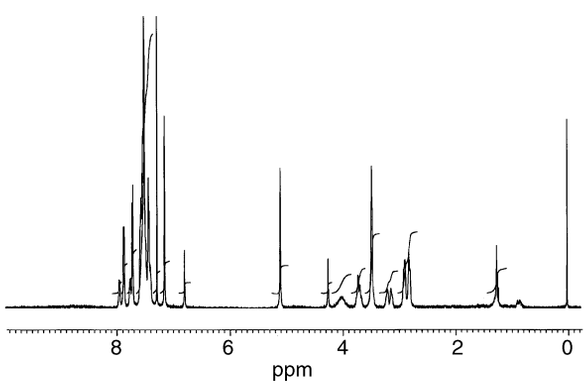


Fig. 3 The 500 MHz ^{1}H-NMR spectrum of **1i** in $CDCl_3$ at room temperature.

biphenyl). Diastereomers could interconvert through the rotation about the pivot bond in the biphenyl unit and thus equilibrium between the $RR \rightleftharpoons RS$ and $SS \rightleftharpoons SR$ could be established. ^{1}H- and ^{13}C-NMR spectra of **1a**–**1j** show two sets of resonances with different intensity corresponding to the two *e* and *a* conformers, see Table 1 and Fig. 2 and 3. Assignments of the *e* and *a* forms are based on the chemical shift and coupling constant analysis of the 500 MHz ^{1}H-NMR spectra of the **1** derivatives. The chemical shift of the equatorial proton (in the *a* form) is assigned at lower field and the axial proton (in the *e* form) at higher field. This is based on comparison to the chemical shifts of the axial and equatorial protons of *cis*-(3,3,4,5,6,6-$^2H_6$)cyclohexene[18,19] and proton chemical shifts at the 6 position in the 6-mono-substituted dibenzo[*a*,*c*]cyclooctenes.[11,13] Anisotropy of the double bond and the aromatic ring might affect the normal shift of axial and equatorial protons; however, further support for the assignments of the *e*

Table 2 Experimental and calculated coupling constants for **1e**. φ* is defined as the angle between the plane of the 6-C=7-C double bond and the plane containing the 5-C–H bond[20]

Conformation	φ*/°	J_{exp}/Hz	J_{calcd}/Hz
e	−60	1.3	1.2
a	160	1.8	2.2

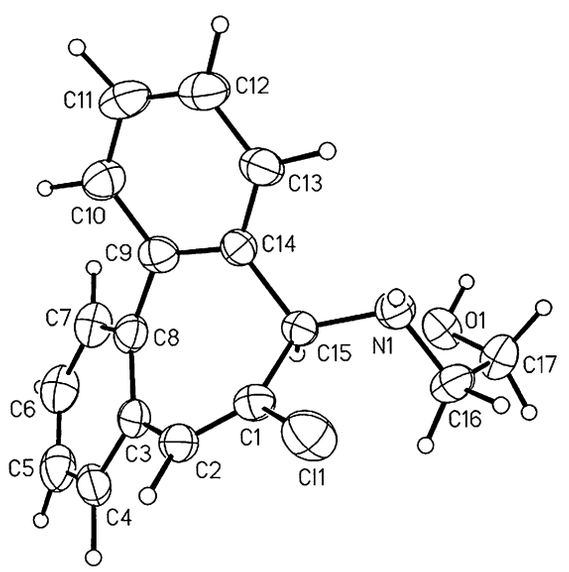


Fig. 4 The structure of the *e* form of **1h** as determined by X-ray crystallography.

and *a* forms comes from a low temperature ^{1}H-NMR spectrum of the **1h** crystals dissolved at low temperature, and the coupling constant analysis of **1e**. The preferred conformation of **1h** in the solid state is shown to be the *e* form (Fig. 4; see below). The same crystals were dissolved in $CDCl_3$ at low temperature and the NMR spectrum was measured at −60 °C. To dissolve the sample it was found to be necessary to allow the solution to warm up. There were found to be two types of signals corresponding to the *e* and *a* forms now with the ratio of 80 : 20. The stronger sets of signals were assigned to the *e* form as that is found to be the preferred structure in the solid state. It is assumed that the *a* form is formed by conversion of the *e* one, due to the warm up procedure. When the sample was allowed to reach room temperature, the ratio of the *e*–*a* forms was found as reported in Table 1.

Analysis of the allylic coupling constants[20] for the two forms in the isopropyl derivative **1e** confirm *e* as the major and *a* the minor form (Table 2). Analysis of the coupling constant in **1h** at −60 °C supports this assignment further. It is therefore safe

Table 3 The chemical shifts of allylic and vinylic protons and the barrier to ring inversion in substituted **1**

	$CDCl_3$				DMSO					
	5-H		7-H		5-H		7-H			
Compound	*e*	*a*	*e*	*a*	*e*	*a*	*e*	*a*	$\Delta G^{\ddagger}$/kcal mol^{-1}	T_c/K
1a	4.99	4.50	6.93	6.93	4.98	4.30	6.98	6.98	14.2 ± 0.2	315[a]
1b	5.06	4.46	6.94	6.78	4.99	4.27	6.96	6.80	14.8 ± 0.2	308
1c	4.99	4.40	6.88	6.73	4.97	4.26	6.98	6.80	15.0 ± 0.2	312
1d	4.92	4.32	6.83	6.66	4.91	4.23	6.92	6.74	15.1 ± 0.2	313
1e	5.07	4.44	6.84	6.65	5.17	4.43	7.04	6.87	17.7 ± 0.2	315[b]
1f	4.91	4.31	6.83	6.66	4.93	4.23	6.95	6.77	15.3 ± 0.2	318
1g	5.03	4.46	6.92	6.68	5.14	4.45	7.07	6.91	15.1 ± 0.2	333[a]
1h	4.21	3.90	6.87	6.76	4.57	4.62	6.99	6.85	15.6 ± 0.2	323
1i	5.08	4.23	7.13	6.77	5.38	4.52	7.32	6.98	15.7 ± 0.2	323
1j	4.52	3.88	6.99	6.77	4.50	3.72	6.97	6.85	17.1 ± 0.2	365
1k	—	5.59	—	6.90	—	6.15	—	6.82	—	
1l	—	4.37	—	6.79	—	4.35	—	6.92	—	

[a] The coalescence temperature of allylic protons. [b] The coalescence temperature of the allylic coupling constant.

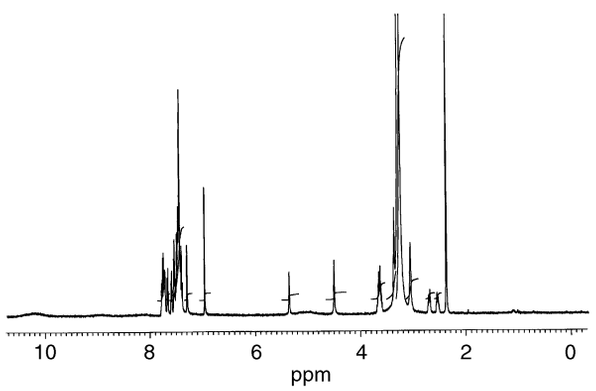


Fig. 5 The 500 MHz ^{1}H-NMR spectrum of **1i** in DMSO-d_6 at room temperature.

enough to assign the observed 5-H proton chemical shift at the higher field to be the *e* form. The chemical shifts of the *a* and *e* hydrogens in all compounds are given in Table 3.

The ratio of the two forms in $CDCl_3$ and DMSO-d_6 could be derived directly from the ^{1}H-NMR spectra. The free energy between the two diastereomers ($\Delta G°$) is calculated by using the equilibrium constant taken as the ratio of major–minor (Table 1).

The *e*–*a* equilibrium constant is found to be quite sensitive to the solvent polarity. The most striking case is found for the compound with $NH(CH_2)_2NH_2$ substitution (**1i**), the *a* form having a population of 72% in $CDCl_3$ (Fig. 3) while this reduces to 45% in DMSO (Fig. 5).

The change in population from $CDCl_3$ to DMSO does not follow the same trend in all compounds, however in compounds with substituents having a hydrogen bond donor group, the population of the *e* form decreases while in other compounds the population of the *e* form increases with increasing solvent polarity. It is expected that in solvents with a high relative permittivity, the diastereomer with the higher dipole moment is more populated. For compounds having a side chain with groups permitting the formation of an internal hydrogen bond it may be put forward that in $CDCl_3$ with a low relative permittivity, the side chain will fold to form the internal hydrogen bond, so this is the preferred conformation which should be considered in $CDCl_3$. AM1 calculations show that one conformation with an internal H bond in the side chain of **1h** has a dipole moment of 1.6 D for the *e* form and 0.45 D for the *a* form. The same side chain could adopt an extended form in DMSO, as there is a possibility of hydrogen bonding with the good acceptor atom in DMSO. The dipole moment of **1h** with an extended side chain is calculated by AM1 to be 1.85 D for the *e* form and 3.32 D for the *a* form.

Table 4 Selected bond lengths (Å) and bond angles (°) for **1h**

Cl(1)–C(1)	1.749(4)	C(10)–C(11)	1.383(6)
N(1)–C(15)	1.454(5)	C(1)–C(15)	1.532(5)
C(1)–C(2)	1.324(5)	C(8)–C(9)	1.477(5)
O(1)–C(17)	1.415(5)	C(9)–C(14)	1.417(5)
N(1)–C(16)	1.485(5)	C(9)–C(10)	1.410(5)
C(16)–C(17)	1.526(6)	C(11)–C(12)	1.381(6)
C(15)–N(1)–C(16)	111.9(3)	Cl(1)–C(1)–C(2)	119.5(3)
Cl(1)–C(1)–C(15)	117.2(3)	C(2)–C(1)–C(15)	123.2(3)
C(1)–C(2)–C(3)	123.5(3)	C(2)–C(3)–C(4)	116.9(3)
C(13)–C(14)–C(15)	122.6(3)	N(1)–C(15)–C(1)	116.0(3)
N(1)–C(16)–C(17)	112.1(3)	C(1)–C(15)–C(14)	105.6(3)
N(1)–C(15)–C(14)	114.1(3)	O(1)–C(17)–C(16)	110.8(3)

No obvious trend could be found in the populations of the two forms in either solvent, for example, the differences between compounds with MeO– and n-PrO– do not follow a simple trend. The population of compounds **1g**, **1h** and **1j** although quite different in DMSO, are similar in $CDCl_3$. This difference might be related to the effect of different conformations of the side chain in chloroform and DMSO as mentioned before.

The question of preferred conformation of *e* or *a* in the solid state could be addressed by preparing suitable crystals; **1h** was crystallized for this purpose. It was quite difficult to prepare single crystals, however by using many different solvents, suitable crystals of **1h** were prepared. X-Ray crystallography shows that the compound adopts a **B** conformation with the 5-substituent in the *e* position (Fig. 4). The side chain in **1h** is folded to form an internal hydrogen bond. The conformation of the five-membered ring formed by the internal hydrogen bond is a twisted one. The selected bond lengths and bond angles for **1h** are given in Table 4.

AM1 calculations were used to estimate the relative stability of the two forms. We had found previously[13] that the AM1 method could produce the relative stability of the conformers correctly although not the real difference between them. The estimated heats of formation by the AM1 are given in Table 5 taking into account the Boltzmann population analysis. The difference between ΔH_f ($\Delta\Delta H_f$) could be compared to both $\Delta G°$ values in $CDCl_3$ and DMSO-d_6. However the calculations are normally performed on the unsolvated molecules (*i.e. in vacuo*), the result of which might more comparable to the $\Delta G°$ values obtained in $CDCl_3$ (the solvent with a relative permittivity of 4.7, which is expected to have less effect on the distribution of population between the *e* and *a* forms). The effect of side chain conformation on the ΔH_f and dipole moment values (calculated by AM1) was considered in all compounds except the chloro derivative.

Table 5 The total number of rotamers, the number of rotamers with an internal hydrogen bond (H_b), population average of heats of formation (kcal mol^{-1}) and dipole moments (debye) for **1a**–**1l**, calculated by the AM1 method

Compound	No. of rotamers		No. of rotamers with internal H_b		$\bar{H}_f$		μ/D	
	e	*a*	*e*	*a*	*e*	*a*	*e*	*a*
1a	2	2			22.13	23.73	1.89	1.18
1b	5	5			16.82	18.11	2.06	1.28
1c	14	14			10.18	11.53	2.11	1.27
1d	40	40			3.85	4.23	1.35	1.08
1e	5	5			12.92	14.40	1.99	1.75
1f	15	15			6.39	7.55	2.00	1.38
1g	35	35	13	9	−28.25	−29.5	2.63	2.01
1h	33	33	14	10	12.42	11.91	2.23	2.17
1i	33	33	18	11	62.62	59.93	1.91	1.83
1j	97	97	14	12	54.42	59.13	2.26	1.28
1k	1	1			53.99	52.84	2.46	1.88
1l	20	20			65.68	—	1.54	—

The conformational space of the side chains was systematically searched by dihedral driving in AM1 calculations; the number of rotamers thus found is given in Table 5. The side chains in **1h**, **1i**, **1j** and **1g** could each form an internal hydrogen bond. In each, more than one rotamer forms by an internal hydrogen bond. It is expected that this type of rotamer is more populated in $CDCl_3$ than in DMSO where the possibility of intermolecular hydrogen bonds to the solvent molecule exists.

Exchange broadening is observed at room temperature for most of the compounds, so that the allylic coupling is collapsed except in **1e**. First order rate constants for major⟶minor exchange were obtained from exchange-broadened spectra by spectra simulation (see Experimental section). The approximate coalescence temperature given in Table 3 was selected by comparing the different spectra taken at the slow and fast exchange limits. The free energy of activation of the major⟶minor form shows a monotonic increase from **1a** to **1e** (including **1f**), corresponding to the increase in steric effect of the substituents. The free energy of activation in **1g** to **1i** is expected to be similar and close to that of the n-PrO substituted compound. The small differences might be due to the contribution of the conformations with the folded side chains. The higher free energy of activation in **1j** might also be attributed to the contribution of the conformation having an internal hydrogen bond in the side chain.

Experimental

All the materials were received from Merck and used without further purification. ^{1}H- and ^{13}C-NMR were recorded on a Bruker Avance 500 MHz spectrometer. Melting points are taken on a Büchi SMP-20 apparatus and are uncorrected.

Crystal structure determination †

A crystal was selected for indexing and intensity data collection on a Siemens Smart-CCD diffractometer equipped with a normal focus, 3 kW sealed tube X-ray source. Intensity data were collected in 1271 frames with increasing ω (width of 0.3 deg per frame). Unit cell dimensions were determined by a least-squares fit of 2686 reflections with $5 < 2\theta < 50°$. Absorption correction was based on 3823 symmetry-equivalent reflections using the SHELXTL-PC program package[21] (T_{min}, $T_{max} = 0.669$, 0.956). On the basis of systematic absences, statistics of intensity distribution, and successful solution and refinement of the structure, the space group was determined to be $P2_1/n$ (No. 14). Crystal data and information about the intensity collection are found in Table 6. The atomic numbering follows from Fig. 4.

Table 6 Summary of crystal data and intensity collection for **1h**

Empirical formula	$C_{17}H_{16}ClNO$
Color; shape	Colorless; columnar
Crystal size/mm	0.03 × 0.08 × 0.40
Space group	$P2_1/n$; monoclinic
Unit cell dimensions	a = 5.6162(4) Å
	b = 13.3544(10) Å
	c = 18.6704(14) Å
	β = 95.744(0)°
Volume	1393.3(6) Å^3
Z	4
Formula weight	285.8
Radiation	Mo-Kα (λ = 0.71073 Å)
Temperature/K	295
Monochromator	Highly oriented graphite crystal
Reflections collected	238020 (5051 ≥ 3.0$\sigma(I)$)
Independent reflections	3029 (1364 ≥ 3.0$\sigma(I)$) (R_{int} = 4.80%)
Final R indices (obs. data)	R = 0.0460, Rw = 0.0508

Computation

Initial estimates of the geometry of structures for semi-empirical calculations were obtained by the MMX molecular mechanics method implemented in PCMODEL software.[22] The semi-empirical AM1 Hamiltonian,[15] implemented in the MOPAC 6.0 program,[23] was used for full minimization. Conformational space of the side chains in substituted **1** was systematically searched by step size of 15 degrees. The local minima thus found were subjected to full minimization by the AM1 method.

Dynamic NMR

The variable temperature NMR spectra of **1a**–**1l** were recorded in DMSO-d_6 except for **1e**, which was recorded in $CDCl_3$ by using the Bruker Avance 500 MHz spectrometer. The dynamic NMR spectra were analyzed by coalescence approximation (**1e**) and line shape analysis. The exchange-broadened spectra of the vinylic protons (except for **1a** and **1e**) were simulated as the X(Y) parts in an AX ⟷ CY system, using the DNMR-5 program.[24] For **1e** the coalescence of the allylic coupling constant was monitored. The evaluation of the transverse relaxation times (T_2) and free energy of activation was performed as described in the literature.[25] The errors in the computed free-energy barriers are mainly due to errors in temperature measurements and are estimated to be less than ±0.2 kcal mol^{-1}. The temperature was calibrated by using an ethylene glycol sample provided by the Bruker Company.

† CCDC reference number 163023. See http://www.rsc.org/suppdata/p2/b0/b004919k/ for crystallographic files in .cif or other electronic format.

General procedure for preparation of 1a–1l

The dichlorocarbene adduct of phenanthrene was synthesized according to the published procedure[17] and purified by column chromatography over silica gel using hexane as eluent. The adduct was dissolved in suitable alcohols or amines and the solution was heated at 130 °C in a sealed tube for at least two hours. The reaction mixture was poured in water and extracted with CH_2Cl_2 and subjected to crystallization to obtain the pure fractions.

Physical and spectral data

6-Chloro-5-methoxy-5*H*-dibenzo[*a*,*c*]cycloheptene (1a). Oily, viscous. Anal. Calcd. for $C_{16}H_{13}ClO$: C, 74.85; H, 5.10. Found: C, 74.5; H, 5.0%.

e form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 3.56 (br, 3H), 4.50 (s, 1H), 6.93 (s, 1H), 7.44–8.09 (m); ^{1}H-NMR (DMSO, 500 MHz) 3.04 (br, 3H), 4.30 (s, 1H), 6.98 (br, 1H), 7.33–7.76 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 58.27, 87.65, 121.72, 124.17, 127.33, 127.38, 128.34, 128.98, 129.52, 130.25, 133.81, 135.67, 138.71, 141.20.

a form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 3.32 (br, 3H), 4.99 (s, 1H), 6.93 (br, 1H), 7.44–8.09 (m); ^{1}H-NMR (DMSO, 500 MHz) 2.97 (br, 3H), 4.98 (s, 1H), 6.98 (br, 1H), 7.33–7.76 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 56.43, 87.65, the aromatic carbons are either hidden under the *e* form resonances or appear as a broad signal together with the *e* form resonances.

6-Chloro-5-ethoxy-5*H*-dibenzo[*a*,*c*]cycloheptene (1b). Oily, viscous. Anal. Calcd for $C_{17}H_{15}ClO$: C, 75.41; H, 5.58. Found: C, 75.2; H, 5.3%.

e form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 1.29 (br, 3H), 3.60 (br, 2H), 4.46 (s, 1H), 6.78 (s, 1H), 7.26–8.04 (m); ^{1}H-NMR (DMSO, 500 MHz) 1.13 (br, 3H), 3.45 (br, 2H), 4.27 (s, 1H), 6.80 (s, 1H), 7.06–8.05 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 15.45, 66.61, 75.97, 123.45, 124.05, 127.51, 127.85, 128.05, 128.36, 128.49, 128.62, 128.86, 129.13, 129.55, 129.84, 130.06, 130.13.

a form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 0.86 (br, 3H), 3.07 (br, 2H), 5.06 (s, 1H), 6.94 (s, 1H), 7.26–8.04 (m); ^{1}H-NMR (DMSO, 500 MHz) 0.61 (br, 3H), 3.07 (br, 2H), 4.99 (s, 1H), 6.96 (s, 1H), 7.06–8.05 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 115.45, 64.20, 86.1, the aromatic carbons are either hidden under the *e* form resonances or appear as a broad signal together with the *e* form resonances.

6-Chloro-5-propoxy-5*H*-dibenzo[*a*,*c*]cycloheptene (1c). Oily, viscous. Anal. Calcd for $C_{18}H_{17}ClO$: C, 75.91; H, 6.01. Found: C, 75.6; H, 5.9%.

e form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 0.99 (br, 3H), 1.72 (br, 2H), 3.42 and 3.67 (br AB, 2H), 4.40 (s, 1H), 6.73 (s, 1H), 7.30–8.00 (m); ^{1}H-NMR (DMSO, 500 MHz) 0.75 (br, 3H), 1.54 (br, 2H), 3.41 (br, 2H), 4.26 (s, 1H), 6.80 (s, 1H), 7.25–8.06 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 10.65, 23.37, 72.83, 76.10, 122.13, 123.46, 124.05, 127.50, 128.37, 128.51, 128.63, 129.15, 129.97, 131.40, 139.14.

a form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 0.36 (br, 3H), 1.23 (br, 2H), 3.20 (br, 2H), 4.99 (s, 1H), 6.88 (s, 1H), 7.30–8.00 (m); ^{1}H-NMR (DMSO, 500 MHz) 0.29 (br, 3H), 1.12 (br, 2H), 3.02 (br, 2H), 4.97 (s, 1H), 6.98 (s, 1H), 7.25–8.06 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 11.04, 23.37, 68.50, 86.03, the aromatic carbons are either hidden under the *e* form resonances or appear as a broad signal together with the *e* form resonances.

6-Chloro-5-butoxy-5*H*-dibenzo[*a*,*c*]cycloheptene (1d). Oily, viscous. Anal. Calcd for $C_{19}H_{19}ClO$: C, 76.37; H, 6.40. Found: C, 75.9; H, 6.2%.

e form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 0.52 (br, 3H), 0.79 (br, 2H), 1.46 (br, 2H), 3.35 and 3.36 (br AB, 2H), 4.32 (s, 1H), 6.66 (s, 1H), 7.16–7.66 (m); ^{1}H-NMR (DMSO, 500 MHz) 0.75 (br, 3H), 0.97 (br, 2H), 1.51 (br, 2H), 3.26 and 3.52 (br AB, 2H), 4.23 (s, 1H), 6.74 (s, 1H), 7.31–7.70 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 13.11, 18.35, 30.90, 69.62, 84.64, 120.60, 122.55, 125.52, 126.87, 128.07, 128.86, 130.19, 133.05, 134.08, 134.71, 140.73.

a form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 0.67 (br, 3H), 1.16 (br, 2H), 1.62 (m, 2H), 3.15 (br, 2H), 4.92 (s, 1H), 6.83 (s, 1H), 7.16–7.66 (m); ^{1}H-NMR (DMSO, 500 MHz) 0.42 (br, 3H), 0.57 (br, 2H), 1.31 (br, 2H), 2.99 and 3.08 (br AB, 2H), 4.91 (s, 1H), 6.92 (s, 1H), 7.31–7.70 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 12.84, 17.61, 30.72, 66.54, 74.64, the aromatic carbons are either hidden under the *e* form resonances or appear as a broad signal together with the *e* form resonances.

6-Chloro-5-isopropoxy-5*H*-dibenzo[*a*,*c*]cycloheptene (1e). Oily, viscous. Anal. Calcd for $C_{18}H_{17}ClO$: C, 75.91; H, 6.01. Found: C, 75.5; H, 5.9%.

e form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 1.06 (d, J = 6 Hz, 3H), 1.25 (d, J = 6 Hz, 3H), 3.69 (m, 1H), 4.44 (d, J = 1.3 Hz, 1H), 6.65 (d, J = 1.3 Hz, 1H), 7.18–7.66 (m); ^{1}H-NMR (DMSO, 500 MHz) 1.02 (d, J = 6 Hz, 3H), 1.24 (d, J = 6 Hz, 3H), 3.68 (m, 1H), 4.43 (d, J = 1.2 Hz, 1H), 6.87 (d, J = 1.2 Hz, 1H), 7.37–7.71 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 23.08, 31.37, 68.39, 82.96, 122.44, 127.11, 127.60, 127.96, 128.06, 128.24, 128.70, 129.30, 131.72, 133.69, 135.46, 137.27, 139.22, 139.54.

a form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 0.65 (d, J = 6.1 Hz, 3H), 0.82 (d, J = 6.1 Hz, 3H), 3.37 (m, 1H), 5.07 (d, J = 1.5 Hz, 1H), 6.84 (d, J = 1.7 Hz, 1H), 7.18–7.66 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 21.37, 22.02, 31.37, 72.13, 73.38, 123.74, 127.30, 127.50, 127.96, 128.33, 128.70, 129.23, 130.02, 131.72, 133.14, 134.53, 136.08, 139.12, 142.64.

6-Chloro-5-isobutoxy-5*H*-dibenzo[*a*,*c*]cycloheptene (1f). Oily, viscous. Anal. Calcd for $C_{19}H_{19}ClO$: C, 76.37; H, 6.40. Found: C, 76.1; H, 6.2%.

e form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 0.81 (br, 6H), 1.47 (br, 1H), 3.12 and 3.45 (br AB, 2H), 4.31 (s, 1H), 6.66 (s, 1H), 7.17–7.66 (m); ^{1}H-NMR (DMSO, 500 MHz) 0.84 (br, 6H), 1.82 (br, 1H), 3.10 and 3.33 (br AB, 2H), 4.23 (s, 1H), 6.77 (s, 1H), 7.29–7.63 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 17.82, 26.07, 73.73, 95.07, 120.64, 122.51, 125.98, 126.07, 126.40, 127.22, 127.64, 128.05, 128.49, 130.21, 133.06, 134.74, 137.67.

a form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 0.25 (br, 3H), 0.40 (br, 3H), 1.95 (br, 1H), 2.90 (br, 2H), 4.91 (s, 1H), 6.83 (s, 1H), 7.17–7.66 (m); ^{1}H-NMR (DMSO, 500 MHz) 0.05 (br, 3H), 0.18 (br, 3H), 1.26 (br, 1H), 2.80 (br, 2H), 4.93 (s, 1H), 6.95 (s, 1H), 7.29–7.63 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 18.37, 27.11, 74.69, 84.61, the aromatic carbons are either hidden under the *e* form resonances or appear as a broad signal together with the *e* form resonances.

2-[(6-Chloro-5*H*-dibenzo[*a*,*c*]cyclohepten-5-yl)oxy]ethan-1-ol (1g). Recrystallized from acetone (yellow crystals, mp 138–139 °C). Anal. Calcd for $C_{17}H_{15}ClO_2$: C, 71.20; H, 5.27. Found: C, 70.9; H, 5.1%.

e form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 1.72 (br, OH), 3.38 (br, 2H), 3.67 (br, 2H), 4.46 (s, 1H), 6.68 (s, 1H), 7.23–7.73 (m); ^{1}H-NMR (DMSO, 500 MHz) 3.19 (br, 2H), 3.51 (br, 2H), 4.45 (s, 1H), 6.91 (s, 1H), 7.44–7.73 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 60.42, 70.83, 74.87, 120.29, 122.88, 126.18, 126.28, 126.60, 127.00, 127.66, 128.09, 130.15, 131.52, 135.43, 137.52.

a form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 2.26 (br, OH), 3.30 (br, 2H), 3.83 (br, 2H), 5.03 (s, 1H), 6.92 (s, 1H), 7.23–7.73 (m); ^{1}H-NMR (DMSO, 500 MHz) 3.19 (br, 2H), 3.69 (br, 2H), 5.14 (s, 1H), 7.07 (s, 1H), 7.44–7.73 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 60.43, 67.80, 84.56, the aromatic carbons are either hidden under the *e* form resonances or appear as a broad signal together with the *e* form resonances.

2-[(6-Chloro-5*H*-dibenzo[*a*,*c*]cyclohepten-5-yl)amino]ethan-1-ol (1h). Recrystallized from acetone–butan-2-one (pale yellow

crystals, mp 101–103 °C). Anal. Calcd for $C_{17}H_{16}ClNO$: C, 71.45; H, 5.64; N, 4.89. Found: C, 71.1; H, 5.5; N, 4.5%.

e form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 2.35 (br, OH, NH), 2.76 and 2.96 (br AB, 2H), 3.64 (br, 2H), 3.90 (s, 1H), 6.76 (s, 1H), 7.33–7.73 (m); ^{1}H-NMR (DMSO, 500 MHz) 2.57 and 2.67 (br AB, 2H), 3.35 and 3.49 (br AB, 2H), 3.79 (s, 1H, OH), 4.62 (s, 1H), 6.85 (s, 1H), 7.35–7.74 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 46.38, 59.07, 67.71, 119.30, 124.57, 125.43, 125.74, 126.68, 127.52, 129.34, 132.04, 133.96, 135.58, 137.74, 139.72.

a form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 2.35 (br, OH, NH), 2.35 and 2.59 (br AB, 2H), 3.33 (br, 2H), 4.21 (s, 1H), 6.87 (s, 1H), 7.33–7.73 (m); ^{1}H-NMR (DMSO, 500 MHz) 2.23 and 2.47 (br AB, 2H), 3.15 and 3.35 (br AB, 2H), 4.27 (s, 1H), 4.57 (s, 1H, OH), 6.99 (s, 1H), 7.35–7.74 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 47.68, 56.53, 59.83, 122.53, 124.72, 125.16, 125.99, 126.20, 126.48, 128.50, 130.13, 132.87, 133.68, 134.37, 136.78.

***N*-(2-Aminoethyl)-*N*-(6-chloro-5*H*-dibenzo[*a*,*c*]cyclohepten-5-yl)amine (1i).** Recrystallized from butan-2-one (yellow crystals, mp 97–100 °C). Anal. Calcd for $C_{17}H_{17}ClN_2$: C, 71.70; H, 6.01; N, 9.83. Found: C, 71.4; H, 5.8; N, 9.4%.

e form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 3.12 and 3.18 (br AB, 2H), 3.71 (br, 2H), 3.98 (br, NH), 4.23 (s, 1H), 6.77 (s, 1H), 7.38–7.86 (m); ^{1}H-NMR (DMSO, 500 MHz) 3.08 and 3.30 (br AB, 2H), 3.40 (br, 2H), 4.52 (s, 1H), 6.99 (s, 1H), 7.42–7.78 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 52.25, 57.60, 60.32, 122.41, 126.40, 127.17, 128.36, 128.64, 128.69, 129.19, 129.53, 130.31, 130.91, 133.47, 134.76, 136.39, 138.56.

a form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 2.80 and 2.87 (br AB, 2H), 3.46 (br, 2H), 3.98 (br, NH), 5.09 (s, 1H), 7.13 (s, 1H), 7.38–7.86 (m); ^{1}H-NMR (DMSO, 500 MHz) 2.57 and 2.74 (br AB, 2H), 3.65 (br, 2H), 5.38 (s, 1H), 7.32 (s, 1H), 7.42–7.78 (m). ^{13}C-NMR ($CDCl_3$, 125 MHz) 49.39, 56.65, 67.70, 126.31, 129.32, 129.44, 129.66, 130.53, 130.59, 130.65, 131.90, 132.08, 132.10, 132.46, 135.86, 137.01.

***N*-(3-Aminopropyl)-*N*-(6-chloro-5*H*-dibenzo[*a*,*c*]cyclohepten-5-yl)amine (1j).** Recrystallized from acetone–butan-2-one (brown crystals, mp 104–107 °C). Anal. Calcd for $C_{18}H_{19}ClN_2$: C, 72.35; H, 6.40; N, 9.37. Found: C, 71.9; H, 6.2; N, 8.9%.

e form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 1.28 (br, 2H), 2.51 (br, 2H), 2.87 (br, 2H), 3.88 (s, 1H), 6.77 (s, 1H), 7.35–8.25 (m); ^{1}H-NMR (DMSO, 500 MHz) 1.98 (br, 2H), 3.08 (br, 2H), 3.41 (br, 2H), 3.72 (s, 1H), 6.85 (s, 1H), 7.32–8.23 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 34.26, 40.66, 46.82, 59.21, 122.01, 125.01, 126.79, 127.19, 127.69, 128.50, 129.16, 130.02, 130.33, 131.80, 134.56, 136.83, 139.32.

a form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 1.42 (br, 2H), 2.37 (br, 2H), 2.62 (br, 2H), 4.52 (s, 1H), 6.99 (s, 1H), 7.35–8.25 (m); ^{1}H-NMR (DMSO, 500 MHz) 2.74 (br, 2H), 3.30 (br, 2H), 3.39 (br, 2H), 4.52 (s, 1H), 6.97 (s, 1H), 7.32–8.29 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 29.73, 40.66, 45.76, 70.41, the aromatic carbons are either hidden under the *e* form resonances or appear as a broad signal together with the *e* form resonances.

5,6-Dichloro-5*H*-dibenzo[*a*,*c*]cycloheptene (1k). Recrystallized from dichloromethane (white crystals, mp 140–143 °C).

e form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 5.59 (s, 1H), 6.90 (s, 1H), 7.18–7.73 (m); ^{1}H-NMR (DMSO, 500 MHz) 6.15 (s, 1H), 6.82 (s, 1H), 7.42–7.72 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 65.40, 125.35, 125.50, 125.88, 126.14, 126.99, 127.05, 127.51, 128.24, 129.24, 129.55, 130.69, 135.13, 135.51, 136.33.

a form. ^{1}H-NMR ($CDCl_3$, 500 MHz) 5.44 (s, 1H), 6.73 (s, 1H), 7.42–7.72 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 58.91, the aromatic carbons are either hidden under the *e* form resonances or appear as a broad signal together with the *e* form resonances.

***N*-(6-Chloro-5*H*-dibenzo[*a*,*c*]cyclohepten-5-yl)-*N*,*N*-diethylamine (1l).** Recrystallized from acetone (brown crystals, mp 132–134 °C). Anal. Calcd for $C_{19}H_{20}ClN$: C, 76.62; H, 6.76; N, 4.70. Found: C, 76.3; H, 6.6; N, 4.4%.

^{1}H-NMR ($CDCl_3$, 500 MHz) 0.60 (t, 6H), 2.28 (q, 4H), 4.37 (s, 1H), 6.79 (s, 1H), 7.22–7.59 (m); ^{1}H-NMR (DMSO, 500 MHz) 0.53 (t, 6H), 2.21 (q, 4H), 4.35 (s, 1H), 6.92 (s, 1H), 7.32–7.63 (m); ^{13}C-NMR ($CDCl_3$, 125 MHz) 10.31, 42.32, 74.33, 126.24, 126.36, 126.42, 127.42, 127.56, 127.93, 128.40, 128.81, 131.23, 133.64, 135.07, 137.22, 139.30, 140.84.

Acknowledgements

Parviz Rashidi-Ranjbar is grateful to the Research Council of Tehran University for financial support.

References

1 R. Kuhn, *Molekulare Asymmetrie*, ed. K. Freudenberg, Stereochemie, Franz Deutike, Leipzig, Germany, 1933, p. 803.
2 K. Mislow, M. A. W. Glass, H. B. Hopps, E. Simon and G. H. Wahl, *J. Am. Chem. Soc.*, 1964, **86**, 1710.
3 G. Krow, *Top. Stereochem.*, 1970, **5**, 31.
4 M. Oki, *Top. Stereochem.*, 1983, **14**, 1.
5 E. L. Eliel, *Stereochemistry of Organic Compounds*, John Wiley & Sons, Inc., New York, 1994, ch. 14.
6 A. E. Knauf, P. R. Shildneck and R. Adams, *J. Am. Chem. Soc.*, 1934, **56**, 2109.
7 K. Mislow and J. Siegel, *J. Am. Chem. Soc.*, 1984, **106**, 3319.
8 P. Rashidi-Ranjbar, M. Yuet-ming, J. Sandstrom and H. N. C. Wong, *J. Org. Chem.*, 1989, **54**, 4888.
9 P. Rashidi-Ranjbar, J. Sandstrom, G. W. Schriver and H. N. C. Wong, *Iran. J. Chem. Chem. Eng.*, 1996, **15**, 18.
10 B. Borecka, S. Cameron, P. Rashidi-Ranjbar and J. Sandstrom, *J. Am. Chem. Soc.*, 1990, **112**, 1185.
11 P. Rashidi-Ranjbar and J. Sandstrom, *J. Chem. Soc., Perkin Trans. 2*, 1990, 901.
12 R. Isaksson, P. Rashidi-Ranjbar and J. Sandstrom, *J. Chem. Soc., Perkin Trans. 1*, 1991, 1147.
13 P. Rashidi-Ranjbar, J. Najafpour and F. Piri, *J. Phys. Org. Chem.*, 1998, **11**, 781.
14 T. Liljefors, J. Tai and N. L. Allinger, *J. Comput. Chem.*, 1987, **8**, 1051. The program is available from the Quantum Chemistry Program Exchange (University of Indiana, Bloomington, IN 47405, USA).
15 M. J. S. Dewar, E. G. Zeobish, E. F. Healy and J. J. P. Stewart, *J. Am. Chem. Soc.*, 1985, **107**, 3902.
16 S. S. Butcher, *J. Chem. Phys.*, 1965, **42**, 1833.
17 K. Mullen, W. Heinz, F. G. Klarner, W. R. Roth, I. Kindermann and O. Adamezac, *Chem. Ber.*, 1990, **123**, 2349.
18 F. A. L. Anet and M. Z. Haq, *J. Am. Chem. Soc.*, 1965, **87**, 3147.
19 F. A. L. Anet, M. Ahmad and A. J. R. Bourn, unpublished results; quoted in ref. 18.
20 I. O. Sutherland and M. V. J. Ramsay, *Tetrahedron*, 1965, **21**, 3401.
21 G. M. Sheldrick, SHELXTL-plus Crystallographic System, version 4, Analytical International Inc., Madison, WI, USA, 1990.
22 Serena Software, PO Box 3076, Bloomington, IN.
23 J. J. P. Stewart, *QCPE 581*, Department of Chemistry, Indiana University, Bloomington, IN.
24 D. S. Stephenson and G. Binsch, *QCPE Bull.*, 1978, **11**, 365.
25 J. Sandstrom, *Dynamic NMR Spectroscopy*, Academic Press, London, 1982, pp. 88 and 96.