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PHOTOCYCLIZATION OF N-[ω-(CYCLOALKEN-1-YL)ALKYL]- AND N-[ω-(INDEN-3-YL)ALKYL]PHTHALIMIDES

SYNTHESIS OF SPIRO-NITROGEN MULTICYCLIC SYSTEMS[1]

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Abstract—Photolysis of the N-[ω-(cycloalken-1-yl)alkyl]phthalimides **6b–e** in each case gave a pair of stereoisomers of spiro-nitrogen multicyclic systems (**9b–e**) in moderate yields, whose stereochemistry was determined by means of chemical and spectroscopic analyses. Similarly, in N-[ω-(inden-3-yl)alkyl]-phthalimides (**8**), spiro-nitrogen macrocycles up to 13-membered **13a–c** were obtained in good yields.

In the search for biologically active substances, target new compounds to be synthesised could be either of an entirely new class or of a group with certain structural characteristics. For example, the involvement of a quaternary carbon as a central atom is known to be essential in designing synthetic narcotic analgesics.[2] For the construction of a quaternary carbon, in photochemical organic syntheses, hydrogen abstraction from a tertiary carbon by an excited carbonyl followed by C—C radical coupling may be one of attractive routes (Eq. (1) in Fig. 1). In fact, we have reported a synthesis of nitrogen-containing spiro-ring systems (**2**) by photocyclisation of N-alkoxyalkyl-phthalimides (**1**) with favoured δ-hydrogen abstraction[3] (Fig. 1).

However, there is another method of C—C bond formation which leads to spiro-systems. We have recently communicated that a phthalimide system (**3**) containing N-cycloalkenyl[4] or N-indenyl[5] group in the N-side chain produces, on excitation, corresponding nitrogen-heterocyclic spiro compounds (**4**) by way of an electron transfer mechanism involving methanol addition (Eq. (2) in Fig. 2). We now report a full account of these results including the stereochemistry of the photoproducts such as the spiro-nitrogen multicyclic heterocycles.

A series of N-[ω-(cycloalken-1-yl)alkyl]phthalimides **6** were prepared from phthalic anhydride and the corresponding amine **5**. 3-(ω-Bromoalkyl)indenes (**7**), prepared from indene and dibromoalkanes, were treated with potassium phthalimide in N,N-dimethylformamide to give N-[ω-(inden-3-yl)alkyl]-phthalimides (**8**). Irradiations of **6** and **8** were carried out in 10 mM solutions of methanol using a 500 W high-pressure mercury lamp for 1–8 hr. Photolysis of **6a** gave two products (**10** and **11**), of which one (**10**) was further converted into **11** by prolonged irradiation. On the treatment with a trace of hydrochloric acid, both compounds (**10** and **11**) were converted into **12** in quantitative yields. By contrast, photolysis of the other substrates **6b–e** in each case, gave a pair of stereoisomers of spiro compounds **9b–e** in moderate yields.

These structures were assigned on the basis of

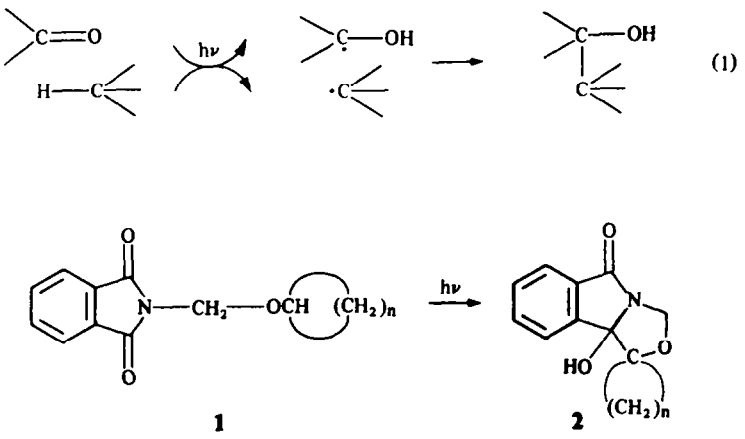


Fig. 1.

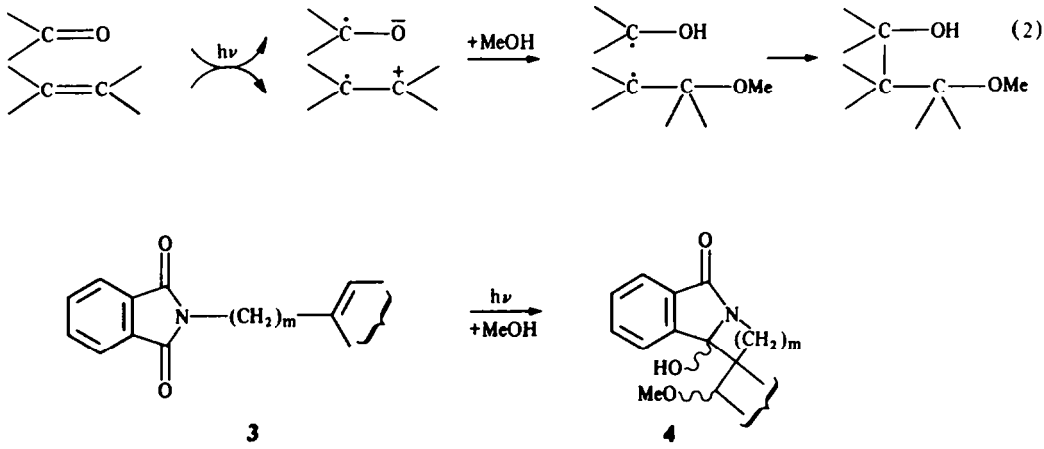
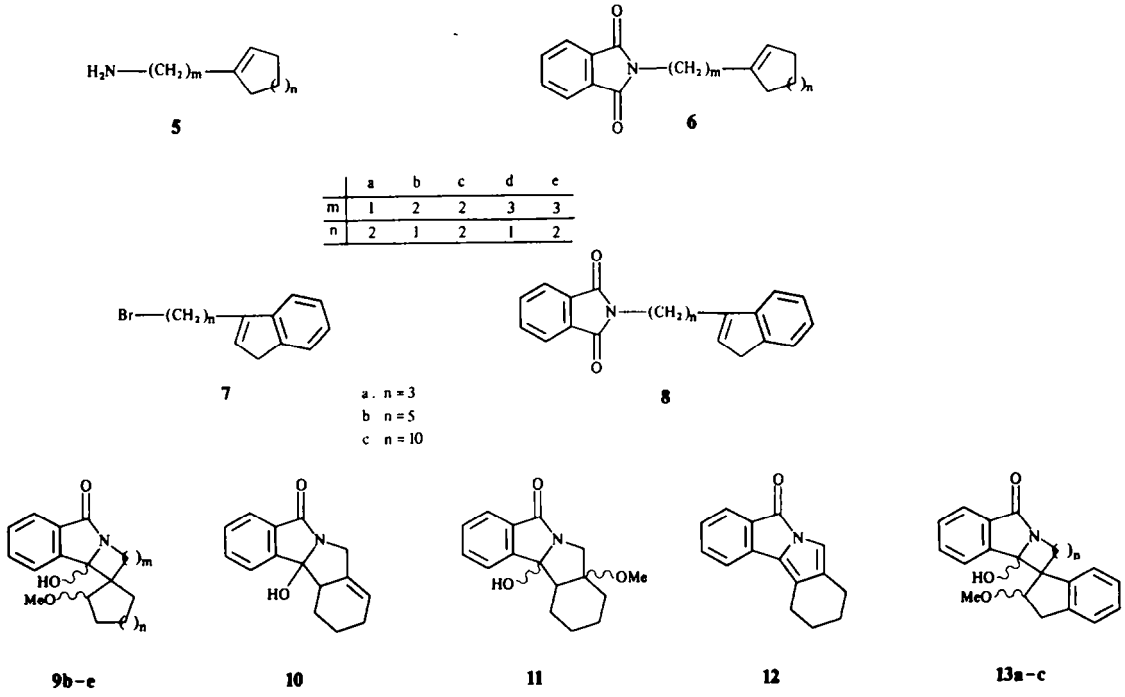


Fig. 2.

spectral data. In the IR spectra of **9**, **10**, **11** and **13**, the bands in the regions of 3200–3450 cm^{-1} and 1670–1700 cm^{-1} indicated the presence of the cyclol and lactam moieties, respectively.[6,7] In the ^{1}H-NMR spectrum of **10**, a singlet peak appeared at 5.75 ppm, indicating the presence of a vinyl proton. The ^{13}C-NMR spectrum also showed the peak due to the olefin carbons at 141 ppm (s) and 120 ppm (d). In the ^{1}H- and ^{13}C-NMR spectra of **11**, the signals due to one olefin proton and two olefin carbons disappeared, and a new signal due to a methoxyl group appeared at 3.50 ppm (s) and 50 ppm (q), respectively. Also the molecular ion peak (M^+ = 273) of **11** indicated the incorporation of a methanol molecule into **10**. In the ^{1}H-NMR spectrum of **12**, derived from both **10** and **11**, a singlet peak appeared at 6.70 ppm, being close to the chemical shift value of an α-proton on a pyrrole ring.[8] In the ^{13}C-NMR spectrum, four triplet peaks appeared at 22.0, 22.4, 22.9 and 23.0 ppm, respectively, indicating the presence of a cyclohexane ring consisting of four almost equivalent carbon atoms not adjacent to a nitrogen atom (Fig. 3).

Four diastereomeric isomers are theoretically possible for each of the tetracyclic spiro photoproducts **9b–e** from **6b–e** (only one of the enantiomers are shown). For example, for product **9c** these four isomers (**9c–i, ii, iii, iv**) are illustrated in Fig. 4. The stereochemistry of the spiro compounds **9b–e** actually obtained was determined on the basis of the ^{1}H-NMR spectra by considering the anisotropic effects of the phenyl ring[6,7] as well as chemical reactions.

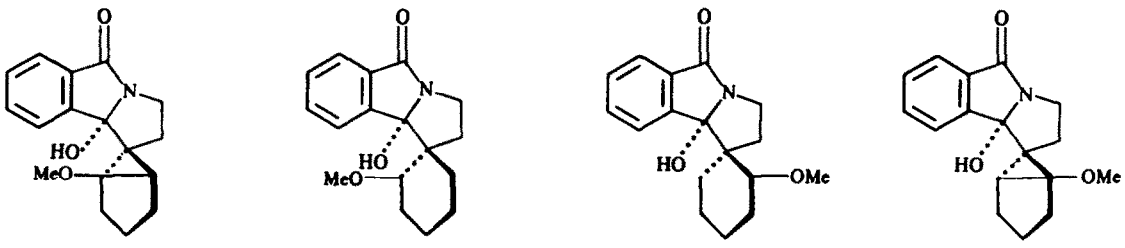
In the ^{1}H-NMR spectra of **9b–e**, the signals due to a methoxyl group appeared at 3.50–3.75 ppm except for



	a	b	c	d	e
m	1	2	2	3	3
n	2	1	2	1	2

a. n = 3
b n = 5
c n = 10

Fig. 3.



9c–i **9c–ii** **9c–iii** **9c–iv**

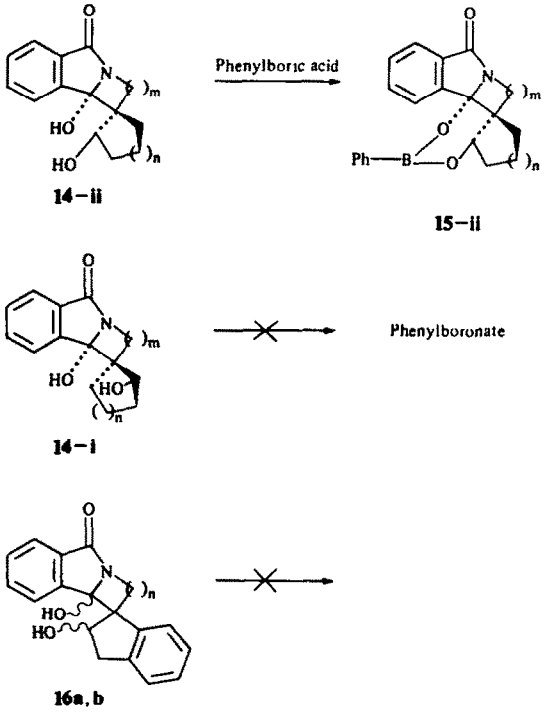
Fig. 4.

ones of **9c-i** and **9e-i**, in both of which the protons of the methoxyl groups showed an up-field shift at 2.30 ppm due to the anisotropic effect of the phenyl ring. This effect indicated *trans* configuration of the hydroxyl group and the carbon having the methoxyl group.[7] No difference was observed for **9b-i** and **9d-i** in which the methoxyl groups are incorporated in the five-membered ring. However, similar effects were also observed for the spectra of one proton of methylene (*) adjacent to the spiro carbon on the spirocycloalkane. Thus in the spectra of **9b-ii**, **9c-ii**, **9d-ii**, and **9e-ii**, the protons showed upfield shift as multiplets at 0.2–1.0 ppm.

On standing in deuterochloroform, compounds **9-i** were easily converted into **9-ii**, giving mixtures of **9-i** and **9-ii**, and *vice versa*. Therefore, compounds **9-i** are epimers of **9-ii** with respect to the hydroxyl group.

To chemically confirm the stereochemistry of these photo-products **9b–e**, the substrates **6b–e** were irradiated in acetonitrile–water. A pair of stereoisomers of diols (**14-i** and **14-ii**) were obtained, which correspond to **9-i** and **9-ii**, respectively. As reported in a previous paper,[7] the *cis* diol compounds (**14-ii**) were readily converted into their cyclic phenylboronates **15**, whereas cyclic phenylboronates were not obtained from the *trans* diol (**14-i**) (Fig. 5, Table 1). The results are consistent with those of ^{1}H-NMR spectroscopy, in which the spectra of the diols (**14-i** and **14-ii**) are analogous to those of the corresponding **9-i** and **9-ii**. respectively, with respect to the methylene protons.

We assigned the stereochemical structures of **9b–e** to the series of **9-i** and **9-ii**, in which the configurations of the hydroxyl group and the carbon having the methoxyl group are *trans* and *cis*, respectively (Fig. 6). The structures **9-iii** and **9-iv** can not be rigorously



14–ii **15–ii**

14–i

16a, b

Fig. 5.

excluded. However, in view of the fact that only one pair of isomers are detected in all the cases, it is likely that the addition of methanol takes place from one side. All of the above experimental results are reasonably explained by the assignments.

Table 1. Properties of phenylboronates (**15-ii**)

Phenylboronate	M.p. (°)	Formula	Analysis (%)[a] C	H	N
15b-ii	126–127	$C_{21}H_{20}BNO_3$	73.07 (73.21)	5.84 (5.92)	4.06 (4.01)
15c-ii	142–146	$C_{22}H_{22}BNO_3$	73.56 (73.82)	6.17 (5.99)	3.90 (3.76)
15d-ii	148–149	$C_{22}H_{22}BNO_3$	73.56 (73.66)	6.17 (6.05)	3.90 (3.81)
15e-ii	121–123	$C_{23}H_{24}BNO_3$	74.01 (74.23)	6.48 (6.58)	3.75 (3.58)

[a] First value calculated. Value in parentheses found.

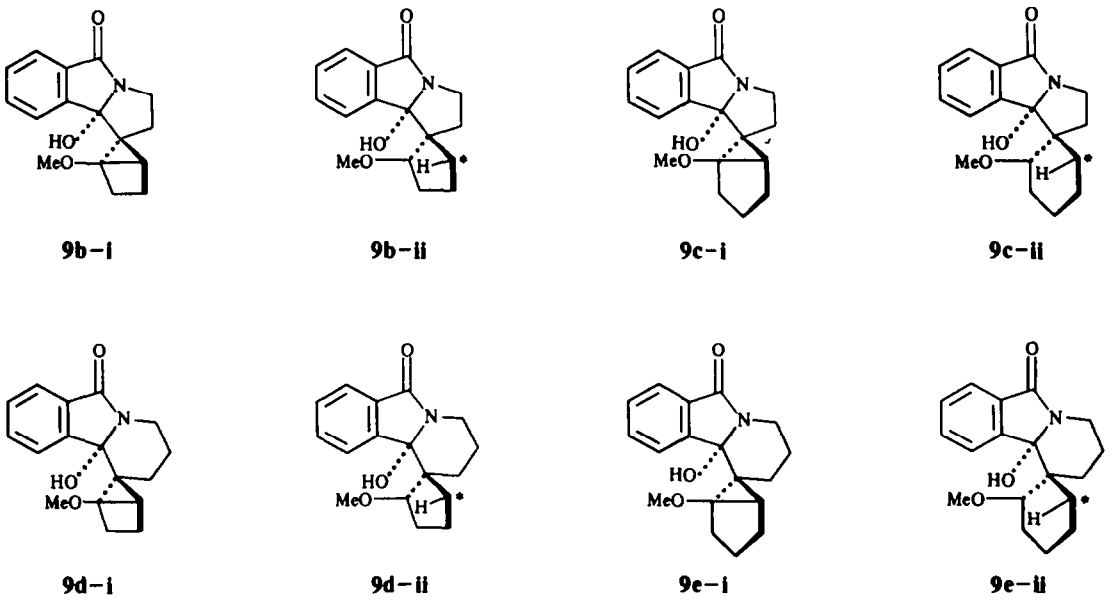


Fig. 6.

On the other hand, irradiation of the N-inden-3-ylalkyl compounds **8a–c** in methanol gave only one stereoisomer (**13a–c**) in good yields, whereas in acetone and acetonitrile, the substrates **8** were quantitatively recovered after irradiation for 10 hr. Since it was difficult to elucidate small chemical shift differences between stereoisomers, further attempt to transform the diols (**16a** and **16b**) to phenylboronates was unsuccessful under the conditions described above, and the stereochemistry of **13a–c** is unknown.

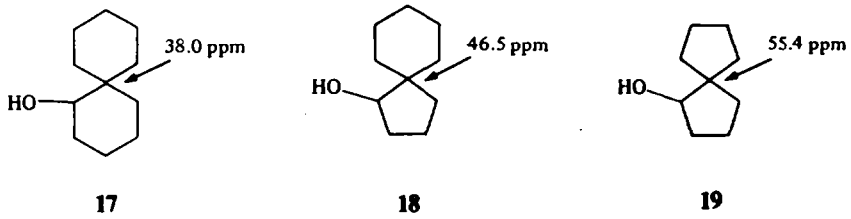
In a previous paper[7] we have reported a useful method to discriminate the structural differences between a series of pyrroloisoindoles and pyridoisoindoles by ^{13}C-NMR spectroscopy. In this experiment, pyrroloisoindole (**9b,c**) and pyridoisoindoles (**9d,e**) were also discriminated by ^{13}C-NMR spectra as shown in Table 2. Thus, for **9b,c** the chemical shift values of carbonyl carbons in the lactam and the tertiary carbon bearing a hydroxyl group were in the regions of 169–171 ppm and 99–100 ppm, and for **9d,e**, 164–165 ppm and 90–93 ppm, respectively. In addition, it was found that the size of two rings involved in the spirane structure has a marked influence on the chemical shift of the spiro carbon atom. These behaviours parallel those of spirobicyclohexane [6,6] (**17**), cyclohexane-spirocyclopentane [6,5] (**18**), and spirobicyclopentane [5,5] (**19**) (Fig. 7).[9]

From the studies[10] of our own and other groups, it has been shown that phthalimides undergo various photoreactions with alkenes, including an electron transfer process (k_{ET}), Paterno–Büchi reaction (k_{PB}), and addition to C(O)—N bond (k_{CN}), as summarised in Fig. 8. Among them, the electron transfer process was affected by reaction media employed and especially favoured in methanol solution, involving the anti-Markovnikov addition of methanol as previously proposed.[7] Further, in a series of N-(3-alkenyl)-phthalimides, we have established that the site of

Table 2. ^{13}C-NMR data for photoproducts

Substrate	Chemical shift (ppm from TMS)		
	O ‖ —C—N	C—OH	Spiro carbon
9b-i	171	100	59 [5, 5]*
9b-ii	169	99	57 [5, 5]
9c-i	169	99	51 [5, 6]
9c-ii	169	100	49 [5, 6]
9d-i	165	91	51 [6, 5]
9d-ii	165	90	51 [6, 5]
9e-i	164	91	46 [6, 6]
9e-ii	165	93	45 [6, 6]

*[5, 5], [5, 6], [6, 5] and [6, 6] express the size of the two rings involved in the spiro system.



17 18 19

Fig. 7. ^{13}C-NMR data for spiro carbons.

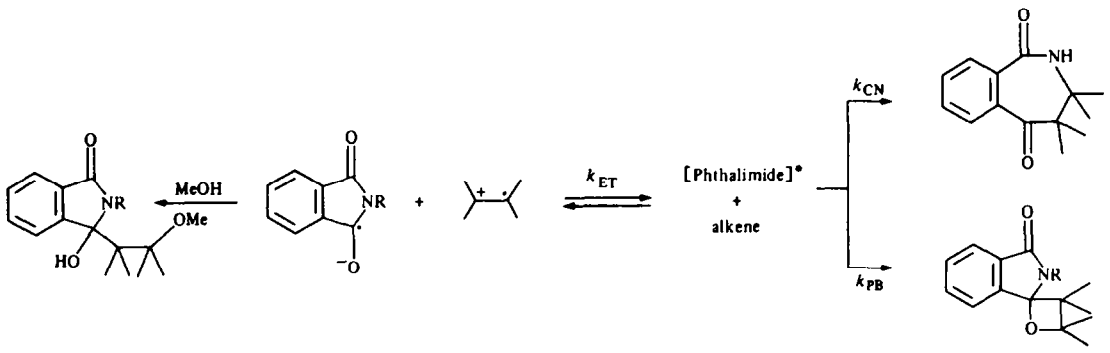


Fig. 8.

photocyclisation of the imide carbonyl toward alkenyl carbons were governed by the number of substituents at the alkenyl carbons, on the basis of the electron transfer mechanism.[7] In the present study, a pair of stereoisomers of the anticipated spiro compounds were predominantly obtained, in support of the proposed electron transfer mechanism (Fig. 8).

Finally, photolysis of N-[ω-(inden-3-yl)alkyl]-phthalimides (**8**) gave the desired spiro compounds, up to and including 13-membered macrocycles in very good chemical yields. We have been studying the application of a common working hypothesis, "photolysis of donor–acceptor pair systems" for general synthetic purposes[3a] (Fig. 9). Several donors have been used such as sulfides,[11] aromatics,[12] anilines,[6] amines[13] and olefins,[14] with the phthalimide as a typical acceptor. The indene is now shown to be an excellent donor in the "photolysis of donor–acceptor pair systems".[3a,5,6]

Thus, photoreaction of phthalimides with cycloalkenyl group in the side chains provides a simple synthetic route to spiro multicyclic systems including macrocycles by selection of the reaction media and the donor in the donor–acceptor pair systems.

EXPERIMENTAL

All m.ps were determined on a Yamato m.p. apparatus (model MP-21) and are uncorrected. IR spectra were recorded on a Shimadzu IR-400 spectrometer. NMR spectra were taken on a Hitachi R-40 spectrometer and a JEOL-FX 60 spectrometer. Chemical shifts are reported in ppm (δ) relative to TMS (0.0 ppm) as an internal standard. The abbreviations used are as follows: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet. Mass spectra (MS) were determined with a gas chromatograph–mass spectrometer (Shimadzu-LKB 9000) with a direct inlet system.

Irradiations of phthalimide derivatives in MeOH (10 mM) were conducted using a 500 W high-pressure mercury lamp and a water-cooled quartz immersion well (Eikosha PIH-500) at room temp. Stirring of the mixture was effected by the introduction of a stream of N_2 at the bottom of the outer jacket. All column chromatography was conducted using silica gel (Merck, Kieselgel 60, 70–230 mesh).

ω-(Cycloalken-1-yl)alkylamines **5**

ω-(Cycloalken-1-yl)alkylamines **5** were prepared as reported previously.[15]

N-[ω-(Cycloalken-1-yl)alkyl]phthalimides **6**

General procedure. Phthalimide derivatives **6** were prepared by fusion of a mixture of a corresponding amine **5** and phthalic anhydride in the usual manner, and recrystallised from EtOH.

Compound **6a**: 86%, m.p. 62–64°. (Calc for $C_{15}H_{15}NO_2$: C, 74.66; H, 6.27; N, 5.81. Found: C, 74.80; H, 6.42; N, 5.68%.)

Compound **6b**: 82%, m.p. 74–76°. (Calc for $C_{15}H_{15}NO_2$: C, 74.66; H, 6.27; N, 5.81. Found: C, 74.42; H, 6.43; N, 5.92%.)

Compound **6c**: 85%, m.p. 77–79°. (Calc for $C_{16}H_{17}NO_2$: C, 75.27; H, 6.71; N, 5.49. Found: C, 75.08; H, 6.88; N, 5.32%.)

Compound **6d**: 78%, oil. (Calc for $C_{16}H_{17}NO_2$: C, 75.27; H, 6.71; N, 4.49. Found: C, 75.50; H, 6.66; N, 5.48%.)

Compound **6e**: 66%, oil. (Calc for $C_{17}H_{19}NO_2$: C, 75.81; H, 7.11; N, 5.20. Found: C, 75.88; H, 7.38; N, 5.08%.)

3-(ω-Bromoalkyl)indenes **7a–c** (n = 3, 5, 10)

Indene derivatives (**7a–c**) were prepared according to the modified method of Makosza.[16] 1,ω-Dibromoalkane (0.11 mol) was added dropwise to a mixture of indene (0.1 mol) and a 50% NaOH aqueous solution (20 ml) in the presence of tetraethylammonium chloride (2 mmol) as a catalyst stirring at 40° for 4 hr, and at 60° for 2 hr. An oily product was purified by distillation *in vacuo*.

3-(3-Bromopropyl)indene **7a**: b.p. 140–142° (5 mmHg) (lit.,[16] 136° (13 mmHg)); 3-(5-Bromopentyl)indene **7b**: b.p. 152–156° (5 mmHg) (lit.,[16] 143° (1 mmHg)); 3-(10-Bromodecyl)indene **7c** was used without further purification.

N-[ω-(Inden-3-yl)alkyl]phthalimides **8a–c**

Phthalimide derivatives **8a–c** were prepared from potassium phthalimide and **7** in N,N-dimethylformamide in the usual manner.[7]

Compound **8a**: 62%, m.p. 117–119°. (Calc for $C_{20}H_{17}NO_2$: C, 79.18; H, 5.65; N, 4.62. Found: C, 79.32; H, 5.55; N, 4.38%.)

Compound **8b**: 68%, m.p. 88–90°. (Calc for $C_{22}H_{21}NO_2$: C, 79.73; H, 6.39; N, 4.23. Found: C, 79.50; H, 6.69; N, 4.48%.)

Compound **8c**: 56%, m.p. 72–73°. (Calc for $C_{27}H_{31}NO_2$: C, 80.76; H, 7.78; N, 3.49. Found: C, 80.82; H, 7.69; N, 3.52%.)

Irradiation of **6**

General procedure. A soln of **6** (5 mmol) in MeOH (500 ml) was irradiated with a 500 W high-pressure mercury lamp for 1 hr under N_2 at room temp. After removal of the solvent *in*

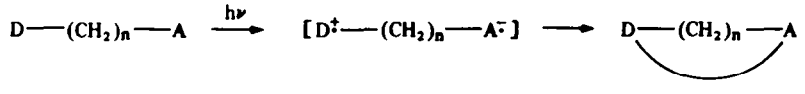


Fig. 9.

vacuo, the residue was chromatographed over silica gel (100 g) using $CHCl_3$–EtOAc (8 : 1, v/v).

Compound **9b-i**: 25%, m.p. 114–116° (hexane), colourless needles. MS *m/z*: 241 ($M^+ - 32$). IR ν_{max}^{KBr} cm^{-1}: 3450, 1690. ^{1}H-NMR ($CDCl_3$): δ 0.8–2.5 (8H, m), 3.60 (3H, s, —OMe), 3.7–3.9 (2H, m, —NH_2), 3.7 (1H, m, —CH—OMe), 4.8 (1H, s, —OH), 7.2–8.0 (4H, m, ArH). (Calc for $C_{16}H_{19}NO_3$: C, 70.31; H, 7.01; N, 5.13. Found: C, 70.25; H, 7.25; N, 5.09%.)

Compound **9b-ii**: 22%, m.p. 111–114° (hexane), colourless needles. MS *m/z*: 241 ($M^+ - 32$). IR ν_{max}^{KBr} cm^{-1}: 3250, 1690. ^{1}H-NMR ($CDCl_3$): δ 0.5–2.5 (8H, m), 2.7–3.1, 3.4–3.8 (2H, m, N—CH_2), 3.50 (3H, s, —OMe), 4.1 (1H, t, J = 7 Hz, CH—OMe), 5.00 (1H, s, —OH), 7.3–7.8 (4H, m, ArH). (Calc for $C_{16}H_{19}NO_3$: C, 70.31; H, 7.01; N, 5.13. Found: C, 70.22; H, 7.16; N, 5.25%.)

Compound **9c-i**: 23%, m.p. 190–194° (benzene–hexane), colourless needles. MS *m/z*: 287 (M^+). IR ν_{max}^{KBr} cm^{-1}: 3300, 1680. ^{1}H-NMR ($CDCl_3$): δ 1.0–2.5 (10H, m), 2.30 (3H, s, —OMe), 3.1–3.8 (3H, m, N—CH_2, CH—OMe), 3.50 (1H, s, —OH), 7.2–7.7 (4H, m, ArH). (Calc for $C_{17}H_{21}NO_3$: C, 71.05; H, 7.37; N, 4.87. Found: C, 70.88; H, 7.25; N, 4.89%.)

Compound **9c-ii**: 18%, m.p. 213–214° (benzene–hexane), colourless needles. MS *m/z*: 287 (M^+). IR ν_{max}^{KBr} cm^{-1}: 3200, 1690. ^{1}H-NMR ($CDCl_3$): δ 0.5–2.5 (10H, m), 2.5–3.8 (3H, m, N—CH_2, CH—OMe), 3.50 (3H, s, —OMe), 7.00 (1H, s, —OH), 7.2–7.8 (4H, m, ArH). (Calc for $C_{17}H_{21}NO_3$: C, 71.05; H, 7.37; N, 4.87. Found: C, 71.11; H, 7.52; N, 4.62%.)

Compound **9d-i**: 18%, m.p. 195–198° (hexane), colourless needles. MS *m/z*: 287 (M^+). IR ν_{max}^{KBr} cm^{-1}: 3300, 1690. ^{1}H-NMR ($CDCl_3$): δ 1.2–2.5 (10H, m), 3.3–3.5, 4.1–4.3 (2H, m, N—CH_2), 3.60 (3H, s, —OMe), 4.4 (1H, t, J = 9 Hz, CH—OMe), 4.90 (1H, s, —OH), 7.4–7.8 (4H, m, ArH). (Calc for $C_{17}H_{21}NO_3$: C, 71.05; H, 7.37. Found: C, 71.24; H, 7.26; N, 4.99%.)

Compound **9d-ii**: 12%, m.p. 192–194° (hexane), colourless needles. MS *m/z*: 287 (M^+). IR ν_{max}^{KBr} cm^{-1}: 3300, 1690. ^{1}H-NMR ($CDCl_3$): δ 0.5–2.5 (10H, m), 2.9–3.3, 4.0–4.5 (2H, m, N—CH_2), 3.50 (3H, s, —OMe), 4.3 (1H, t, J = 9 Hz, CH—OMe), 4.90 (1H, s, —OH), 7.2–7.3 (4H, m, ArH). (Calc for $C_{17}H_{21}NO_3$: C, 71.05; H, 7.37; N, 4.87. Found: C, 71.22; H, 7.16; N, 4.92%.)

Compound **9e-i**: 12%, m.p. 188–190° (EtOAc), colourless needles. MS *m/z*: 301 (M^+). IR ν_{max}^{KBr} cm^{-1}: 3250, 1670. ^{1}H-NMR ($CDCl_3$): δ 1.0–2.5 (12H, m), 2.30 (3H, s, —OMe), 2.8–4.0 (3H, m, N—CH_2, CH—OMe), 4.00 (1H, s, —OH), 7.2–7.7 (4H, m, ArH). (Calc for $C_{18}H_{23}NO_3$: C, 71.73; H, 7.69; N, 4.65. Found: C, 71.58; H, 7.90; N, 4.77%.)

Compound **9e-ii**: 15%, m.p. 181–182° (EtOAc), colourless needles. MS *m/z*: 301 (M^+). IR ν_{max}^{KBr} cm^{-1}: 3250, 1690. ^{1}H-NMR ($CDCl_3$): δ 0.2–2.5 (12H, m), 3.0–4.5 (3H, m, N—CH_2, CH—OMe), 3.75 (3H, s, —OMe), 6.80 (1H, s, —OMe), 7.3–8.0 (4H, m, ArH). (Calc for $C_{18}H_{23}NO_3$: C, 71.73; H, 7.69; N, 4.65. Found: C, 71.58; H, 7.66; N, 4.62%.)

Compound **10**: 28%, m.p. 213–214° (EtOH), colourless needles. MS *m/z*: 241 (M^+), 223 ($M^+ - 18$). IR ν_{max}^{KBr} cm^{-1}: 3300, 1670. ^{1}H-NMR ($CDCl_3$): δ 1.5–2.5 (7H, m), 3.50 (1H, s, —OH), 3.3–4.4 (2H, m, —NCH_2), 5.75 (1H, s, —C=CH), 7.2–7.4 (4H, m, ArH). ^{13}C-NMR (DMSO-d^6): δ 20.7, 20.9, 23.7, 44.5, 47.4, 94.4 (s), 120.1 (s), 140.6 (d), 168.2. (Calc for $C_{15}H_{15}NO_2$: C, 74.66; H, 6.27; N, 5.81. Found: C, 74.82; H, 6.24; N, 5.58%.)

Compound **11**: 16%, m.p. 183–185° (hexane), colourless needles. MS *m/z*: 273 (M^+). IR ν_{max}^{KBr} cm^{-1}: 3450, 1700. ^{1}H-NMR ($CDCl_3$): δ 1.0–2.8 (9H, m), 3.50 (3H, s, —OMe), 3.4–4.2 (2H, m, —NH_2), 5.75 (1H, s, —OH), 7.3–8.0 (4H, m, ArH). ^{13}C-NMR ($CDCl_3$): δ 19.8, 20.4, 24.5, 29.8, 49.5, 49.9 (q), 53.7, 87.8 (s), 96.8 (s), 172.6. (Calc for $C_{16}H_{19}NO_3$: C, 70.31; H, 7.01; N, 5.13. Found: C, 70.16; H, 7.23; N, 5.32%.)

Irradiation of **10**

Irradiation of **10** (50 mg) in MeOH (100 ml) was carried out in a similar manner to that described above. After removal of the solvent, the residue was recrystallised from hexane; yield of **11**, 46 mg (82%).

Dehydration of **10**

A soln of **10** (50 mg) in 10 ml of $CHCl_3$ containing 1 drop of conc HCl was stirred for 2 hr at room temp. After removal of the solvent, the residue was recrystallised from EtOH; yield of **12**, 38 mg (82%), m.p. 113–115°, orange needles. MS *m/z*: 223 (M^+). IR ν_{max}^{KBr} cm^{-1}: 1730, 1630. ^{1}H-NMR ($CDCl_3$): δ 1.5–2.0 (4H, m), 2.4–2.7 (4H, m), 6.70 (1H, s, C=CH). ^{13}C-NMR ($CDCl_3$): δ 22.0, 22.4, 22.9, 23.0, 162 (s). Similarly, treatment of **11** (50 mg) with 1 drop of conc HCl afforded **12** in a 78% yield.

Irradiation of **8**

General procedure. A soln of **8** (5 mmol) in MeOH (500 ml) was irradiated for 5–8 hr, and worked up in a similar manner to that described above.

Compound **13a**: 82%, m.p. 248–249° (EtOAc), colourless needles. MS *m/z*: 335 (M^+). IR ν_{max}^{KBr} cm^{-1}: 3300, 1690. ^{1}H-NMR ($CDCl_3$): δ 1.4–3.1 (6H, m), 3.1–3.5, 4.3–4.7 (2H, m, N—CH_2), 3.70 (3H, s, —OMe), 4.9 (1H, dd, J = 7 Hz, 9 Hz, CH—OMe), 5.10 (1H, s, —OH), 6.7–8.0 (8H, m, ArH). (Calc for $C_{21}H_{21}NO_3$: C, 75.20; H, 6.31; N, 4.18. Found: C, 75.46; H, 6.52; N, 4.20%.)

Compound **13b**: 76%, m.p. 228–230° (EtOAc), colourless needles. MS *m/z*: 363 (M^+). IR ν_{max}^{KBr} cm^{-1}: 3300, 1680. ^{1}H-NMR ($CDCl_3$): δ 0.8–3.0 (10H, m), 3.3–3.7 (2H, m, N—CH_2), 3.70 (3H, s, —OMe), 4.8 (1H, t, J = 9 Hz, CH—OMe), 6.7–8.0 (8H, m, ArH). (Calc for $C_{23}H_{25}NO_3$: C, 76.00; H, 6.93; N, 3.85. Found: C, 75.58; H, 7.22; N, 3.92%.)

Compound **13c**: 86%, m.p. 185–187° (EtOAc), colourless needles. MS *m/z*: 433 (M^+). IR ν_{max}^{KBr} cm^{-1}: 3250, 1680. ^{1}H-NMR ($CDCl_3$): δ 0.8–3.0 (20H, m), 3.3–3.5 (2H, m, N—CH_2), 3.60 (3H, s, —OMe), 5.3 (1H, t, J = 9 Hz, CH—OMe), 6.30 (1H, s, —OH), 6.7–7.5 (8H, m, ArH). (Calc for $C_{28}H_{35}NO_3$: C, 77.56; H, 8.14; N, 3.22. Found: C, 77.35; H, 8.11; N, 3.50%.)

Irradiation of **6** *(and* **8***) in acetonitrile–water*

Irradiation of **6** (10 mM) in acetonitrile–water (8 : 1, v/v) was carried out in a manner similar to that described above. The crude photolysate was chromatographed on 80 g of silica gel, and elution with benzene–EtOAc (8 : 1) gave the diol compounds **14-i** and **14-ii**.

Similarly, irradiation of **8** (10 mM) in tetrahydrofuran–water (2 : 1, v/v) was carried out to give diol **16b**.

Compound **14b-i**: 22%, m.p. 128–130° (hexane), colourless needles. MS *m/z*: 241 ($M^+ - 18$). IR ν_{max}^{KBr} cm^{-1}: 3450, 1700. ^{1}H-NMR ($CDCl_3$): δ 1.0–2.9 (8H, m), 3.50 (1H, s, —OH), 3.5–3.8 (2H, m, —NH_2), 3.7 (1H, m, —CH—OH), 6.20 (1H, s, —OH), 7.4–8.0 (4H, m, ArH). (Calc for $C_{15}H_{17}NO_3$: C, 69.48; H, 6.61; N, 5.40. Found: C, 69.70; H, 6.45; N, 5.26%.)

Compound **14b-ii**: 18%, m.p. 118–119° (benzene–hexane), colourless needles. MS *m/z*: 241 ($M^+ - 18$). IR ν_{max}^{KBr} cm^{-1}: 3250, 1700. ^{1}H-NMR ($CDCl_3$): δ 0.3–2.5 (8H, m), 2.6–3.1, 3.4–3.6 (2H, m, N—CH_2), 3.55 (1H, s, —OH), 4.1–4.3 (1H, m, —CH—OH), 5.00 (1H, s, —OH), 7.3–7.8 (4H, m, ArH). (Calc for $C_{15}H_{17}NO_3$: C, 69.48; H, 6.61; N, 5.40. Found: C, 69.33; H, 6.88; N, 5.33%.)

Compound **14c-i**: 28%, m.p. 192–195° (benzene–hexane), colourless plates. MS *m/z*: 255 ($M^+ - 18$). IR ν_{max}^{KBr} cm^{-1}: 3300, 1690. ^{1}H-NMR ($CDCl_3$): δ 1.0–3.2 (10H, m), 3.4–4.2 (3H, m, N—CH_2, —CH—OH), 3.95 (1H, s, —OH), 5.80 (1H, s, —OH), 7.1–7.7 (4H, s, ArH). (Calc for $C_{16}H_{19}NO_3$: C, 70.31; H, 7.01; N, 5.13. Found: C, 70.18; H, 6.80; N, 5.01%.)

Compound **14c-ii**: 16%, m.p. 162–164° (EtOAc), colourless needles. MS *m/z*: 255 ($M^+ - 18$). IR ν_{max}^{KBr} cm^{-1}: 3300, 1680. ^{1}H-NMR ($CDCl_3$): δ 0.2–2.4 (10H, m), 3.2–3.6 (3H, m, N—CH_2, —CH—OH), 3.75 (1H, s, —OH), 4.20 (1H, s, —OH), 7.2–7.8 (4H, m, ArH). (Calc for $C_{16}H_{19}NO_3$: C, 70.31; H, 7.01; N, 5.13. Found: C, 69.82; H, 6.76; N, 5.27%.)

Compound **14d-i**: 20%, m.p. 188–190° (benzene–hexane), colourless needles. MS *m/z*: 255 ($M^+ - 18$). IR ν_{max}^{KBr} cm^{-1}: 3250, 1690. ^{1}H-NMR ($CDCl_3$): δ 1.0–3.3 (10H, m), 3.3–3.5, 4.1–4.3 (2H, m), 3.55 (1H, s, —OH), 4.2–4.4 (1H, m, CH—OH), 4.90 (1H, s, —OH), 7.4–7.8 (4H, m, ArH). (Calc for $C_{16}H_{19}NO_3$: C, 70.31; H, 7.01; N, 5.13. Found: C, 70.55; H, 6.82; N, 5.36%.)

Compound **14d-ii**: 12%, m.p. 194–195° (benzene–hexane), colourless needles. MS *m/z*: 255 ($M^+ - 18$). IR ν_{max}^{KBr} cm^{-1}: 3300, 1690. ^{1}H-NMR ($CDCl_3$): δ 0.4–2.9 (10H, m), 2.9–3.5, 4.0–4.4 (2H, m, N—CH_2), 3.80 (1H, s, —OH), 4.1–4.4 (1H, m, CH—OH), 5.60 (1H, s, —OH), 7.5–7.9 (4H, m, ArH). (Calc for $C_{16}H_{19}NO_3$: C, 70.31; H, 7.01; N, 5.13. Found: C, 70.22; H, 7.28; N, 5.33%.)

Compound **14e-i**: 18%, m.p. 191–193° (EtOAc), colourless needles. MS *m/z*: 269 ($M^+ - 18$). IR ν_{max}^{KBr} cm^{-1}: 3250, 1690. ^{1}H-NMR ($CDCl_3$): δ 1.0–2.5 (12H), 3.00 (1H, s, —OH), 2.8–4.2 (3H, s, N—CH_2, CH—OH), 4.20 (1H, s, —OH), 7.2–7.7 (4H, m, ArH). (Calc for $C_{17}H_{21}NO_3$: C, 71.05; H, 7.37; N, 4.87. Found: C, 71.23; H, 7.11; N, 4.82%.)

Compound **14e-ii**: 16%, m.p. 185–186° (EtOAc), colourless needles. MS *m/z*: 269 ($M^+ - 18$). IR ν_{max}^{KBr} cm^{-1}: 3250, 1690. ^{1}H-NMR ($CDCl_3$): δ 0.5–2.8 (12H, m), 3.0–4.4 (3H, m, N—CH_2, CH—OH), 3.90 (1H, s, —OH), 6.80 (1H, s, —OH), 7.3–8.0 (4H, m, ArH). (Calc for $C_{17}H_{21}NO_3$: C, 71.05; H, 7.37; N, 4.87. Found: C, 70.95; H, 7.50; N, 4.66%.)

Compound **16a**: 65%, m.p. 221–223° (EtOAc), colourless needles. MS *m/z*: 321 (M^+). IR ν_{max}^{KBr} cm^{-1}: 3300, 1680. ^{1}H-NMR ($CDCl_3$): δ 1.2–3.0 (6H, m), 3.5–4.5 (2H, m, N—CH_2), 3.80 (1H, s, —OH), 4.5–4.8 (1H, m, CH—OH), 5.20 (1H, s, —OH), 6.7–8.0 (8H, m, ArH). (Calc for $C_{20}H_{19}NO_3$: C, 74.75; H, 5.96; N, 4.36. Found: C, 74.66; H, 6.11; N, 4.18%.)

Compound **16b**: 62%, m.p. 215–218° (EtOAc), colourless needles. MS *m/z*: 349 (M^+). IR ν_{max}^{KBr} cm^{-1}: 3300, 1690. ^{1}H-NMR ($CDCl_3$): δ 0.9–3.1 (10H, m), 3.2–3.5 (2H, m, N—CH_2), 3.80 (1H, s, —OH), 4.5–4.6 (1H, m, CH—OH), 5.40 (1H, s, —OH), 6.7–7.8 (8H, m, ArH). (Calc for $C_{22}H_{23}NO_3$: C, 75.62; H, 6.63; N, 4.01. Found: C, 75.44; H, 6.58; N, 3.82%.)

Reaction of **14-ii** *with phenylboric acid*

A mixture of **14-ii** (0.2 mmol) and phenylboric acid (0.2 mmol) in 10 ml of benzene was refluxed for 30 min. The solvent was removed *in vacuo*, and the residue was recrystallised from ethanol to give **15-ii**. Similarly, a mixture of **14-i** and phenylboric acid in benzene was refluxed for 10 hr, but no phenylboronates were obtained and **14-i** was recovered in quantitatively. The phenylboronates are listed in Table 1.

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