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Toward understanding the scope of Baylis–Hillman reaction: synthesis of 3-(2- hydroxyphenyl)indolin-2-ones and polycyclic fused furans

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ABSTRACT

A facile one-pot synthesis of 3-(2-hydroxyphenyl)indolin-2-ones has been developed via the $TiCl_4$-mediated Baylis–Hillman (B–H) reaction of *N*-substituted isatins and cyclohex-2-enone, followed by treatment of the in situ generated B–H alcohols with aq HBr. Baylis–Hillman reaction of aromatic cyclic 1,2-diones with cycloalk-2-enones under the influence of $TiCl_4$ has been successfully performed and the resulting Baylis–Hillman adducts have been conveniently transformed into pentacyclic and hexacyclic fused furan derivatives.

1. Introduction

The Baylis–Hillman reaction is a three component atom economical carbon–carbon bond forming reaction involving coupling of α-position of activated alkenes with electrophiles in the presence of a catalyst or catalytic system, providing an interesting class of densely functionalized molecules, which are usually referred to as the Baylis–Hillman adducts.[1,2] During the last twenty five years Baylis–Hillman reaction has grown with respect to all the three essential components and has now become a versatile and popular synthetic tool in organic chemistry. The Baylis–Hillman adducts have become a valuable source for various organic transformations and have been transformed into a number of carbocycles and heterocyclic frameworks of medicinal importance.[1,2] In continuation of our interest in the Baylis–Hillman reaction[3] and its applications in the synthesis of heterocyclic compounds[4] we herein report a simple and one-pot synthesis of 3-(2-hydroxyphenyl) indolin-2-ones via the Baylis–Hillman reaction of *N*-substituted isatins with cyclohex-2-enone followed by treatment of the in situ formed Baylis–Hillman adducts with aq HBr. A facile synthesis of pentacyclic/hexacyclic fused-furan framework from the Baylis–Hillman adducts derived from cycloalk-2-enones and aromatic 1,2-diones is also described.

3-Aryloxindole skeleton represents an interesting class of nitrogen heterocyclic system because such kind of framework possesses various biological activities like BK channel openers[5] and orally active growth hormone secretagogues.[6] Polycyclic fused-furan framework is another important structural organization present in certain natural products[7] and also some of these frameworks are known to exhibit interesting biological activities, such as inhibition of receptor tyrosine kinase,[8] cytotoxicity,[9] and anticancer activity.[10] Therefore development of facile strategies for synthesis of 3-aryloxindole derivatives[11] and polyfused furans[7a,c,8,9,12] has become an attractive and challenging endeavor in synthetic chemistry. We have therefore directed our efforts toward the development of convenient methodologies for synthesis of both of these frameworks.

2. Results and discussion

During our earlier investigations on the development of Baylis–Hillman reaction, we noticed a remarkable steric direction in the $TiCl_4$-mediated coupling of α-keto esters with cyclohex-2-enone derivatives.[13] Thus, cyclohex-2-enone (**1a**) provided aldol adducts (with *syn* stereochemistry) as major products (along with the Baylis–Hillman adducts as the minor products) when coupled with α-keto esters in the presence of $TiCl_4$ while sterically more demanding 5,5-dimethylcyclohex-2-enone (**1b**) gave exclusively the Baylis–Hillman adducts.[13] We therefore planned to examine the coupling of isatin derivatives (cyclic α-keto amides, which are

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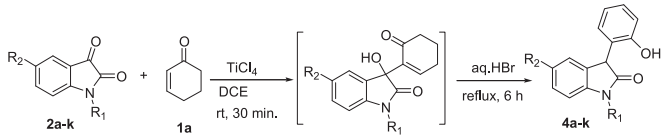
structurally similar to α-keto esters) with cyclohex-2-enone (**1a**) and sterically more demanding **1b** under the influence of $TiCl_4$ with a view to understand the role of steric factors in these reactions. Literature survey reveals that although $TiCl_4$ has been systematically used for coupling of various activated alkenes with several electrophiles, coupling of isatin derivatives with cycloalk-2-enones has not been well studied.[14]

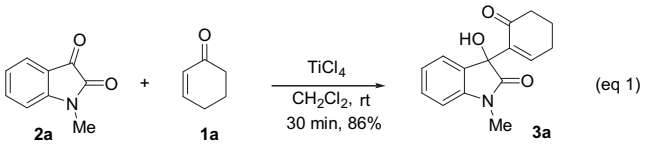
Accordingly, we have first examined the reaction between *N*-methylisatin (**2a**) and **1a** under the influence of $TiCl_4$ and we were pleased to notice the formation of only Baylis–Hillman adduct and complete absence of any aldol product. The best result was obtained when **2a** (1 mmol) was treated with **1a** (1 mmol) in the presence of $TiCl_4$ (1 mmol) in CH_2Cl_2 at room temperature (25–28 °C) for 30 min to provide the corresponding Baylis–Hillman (B–H) alcohol, 3-hydroxy-3-(cyclohex-2-enon-2-yl)-1-methylindolin-2-one, (**3a**) in 86% isolated yield (Eq. 1). Since the product is allylic alcohol, which has the potential to undergo dehydration under acidic conditions leading to aromatization, it occurred to us that the longer reaction time might provide the expected phenolic derivative. Accordingly we continued the reaction for 4 h at room temperature, but did not obtain the expected 3-(2-hydroxyphenyl)-1-methylindolin-2-one (**4a**). During our efforts in achieving aromatization we noticed that the treatment of **3a** with aq HBr, in dichloroethane (DCE) at reflux temperature for 6 h, provided the required aromatized compound **4a** in 89% isolated yield (Eq. 2). Encouraged by this excellent result, we felt that if these two steps can be performed in one-pot without isolating the B–H alcohol, this strategy would lead to a simple and practical procedure for conversion of isatin derivatives into 3-(2-hydroxyphenyl)indolin-2-one derivatives via the Baylis–Hillman protocol. In these efforts the best result was obtained when 1-methylisatin (**2a**, 1 mmol) was treated with cyclohex-2-enone (**1a**, 1 mmol) in presence of $TiCl_4$ (1 mmol) in dichloroethane at room temperature (25–28 °C) for 30 min followed by the treatment of the resulting reaction mixture with aq HBr (5 mmol) at reflux temperature for 6 h, thus providing the desired 3-(2-hydroxyphenyl)-1-methylindolin-2-one (**4a**) in 82% isolated yield (Table 1, entry 1).

Table 1
Synthesis of 3-(2-hydroxyphenyl)indolin-2-ones (**4a**–**k**) via the reaction of isatin derivatives (**2a**–**k**) with cyclohex-2-enone (**1a**)[a]



Entry	R_1	R_2	Isatin	Product[b]	Yield[c] (%)
1	Me	H	**2a**	**4a**	82
2	Me	Cl	**2b**	**4b**[d]	76
3	Et	H	**2c**	**4c**	83
4	Et	Cl	**2d**	**4d**	59
5	CH_2Ph	H	**2e**	**4e**[d]	65
6	CH_2Ph	Cl	**2f**	**4f**	77
7	CH_2Ph	Br	**2g**	**4g**[d]	63
8	CH_2Ph	Me	**2h**	**4h**	85
9	Ph	H	**2i**	**4i**	55
10	Ph	Cl	**2j**	**4j**	51
11	Ph	Me	**2k**	**4k**	54

[a] All the reactions were carried out on 1 mmol scale of isatins (**2a**–**k**) with cyclohex-2-enone (**1a**, 1 mmol) in the presence of $TiCl_4$ (1 mmol) at room temperature (25–28 °C) followed by the treatment with aq HBr (5 mmol) in dichloroethane at reflux temperature.
[b] All the compounds were isolated as solids and fully characterized.
[c] Isolated yields based on isatins (**2a**–**k**).
[d] Structures of the compounds **4b**, **4e**, and **4g** were further confirmed by single crystal X-ray data analysis.[15]



To understand the generality of this strategy we have subjected representative isatin derivatives (**2a**–**k**) to a similar one-pot reaction sequence with cyclohex-2-enone to provide the corresponding 3-(2-hydroxyphenyl)indolin-2-one derivatives (**4a**–**k**) in 51–85% isolated yields (Table 1). Structures of the compounds **4b**, **4e** (Fig. 1), and **4g** (Fig. 2) were also confirmed by single crystal X-ray data analysis.[15]

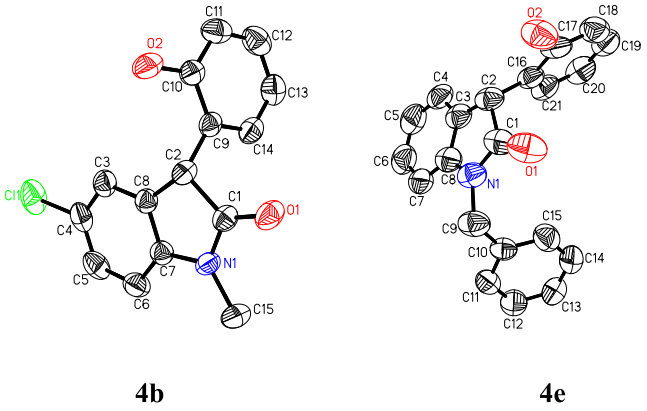


Figure 1. ORTEP diagrams of **4b** and **4e** (Hydrogen atoms are omitted for clarity).

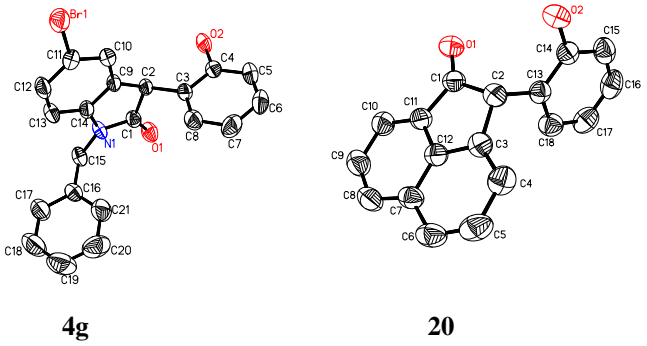
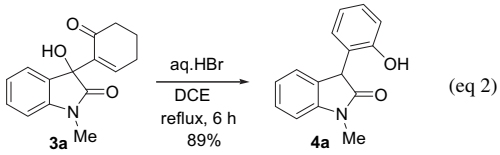
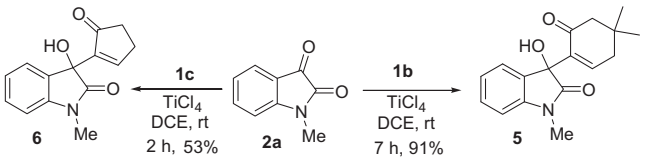


Figure 2. ORTEP diagrams of **4g** and **20** (Hydrogen atoms are omitted for clarity).



We have then examined the reaction of isatin derivative (**2a**) with 5,5-dimethylcyclohex-2-enone (**1b**), in the presence of $TiCl_4$, which as expected provided the Baylis–Hillman adduct (**5**) in 91% isolated yield. Similar reaction of cyclopent-2-enone (**1c**) with **2a** also gave the expected B–H alcohol **6** in 53% isolated yield (Scheme 1).

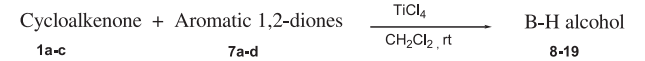
Next we have turned our attention toward the $TiCl_4$-mediated Baylis–Hillman reaction between cyclic aromatic 1,2-diones as electrophiles and cycloalk-2-enones as activated alkenes. We have



Scheme 1. Synthesis of Baylis–Hillman alcohols (**5**, **6**) from 1-methylisatin (**2a**) and cyclic enones (**1b**, **c**) in the presence of $TiCl_4$.

carried out reaction between 1,2-acenaphthenequinone (**7a**, 1 mmol) and cyclohex-2-enone (**1a**, 1 mmol) in presence of $TiCl_4$ (1 mmol) in dichloromethane at room temperature (25–28 °C) for 30 min which afforded the expected Baylis–Hillman adduct, 2-hydroxy-2-(cyclohex-2-enon-2-yl)-2*H*-acenaphthylen-1-one (**8**) in 87% isolated yield (Table 2, entry 1). In order to extend the scope of this reaction we have used representative activated alkenes **1a**–**c** for coupling with electrophiles, **7a**, [9,10]-phenanthrenedione (**7b**), pyrene-[4,5]-dione (**7c**), and 1,2-aceanthrenequinone (**7d**) under the influence of $TiCl_4$ to provide the corresponding B–H alcohols **9**–**19** in 53–90% isolated yields (Table 2, entries 2–12). It is worth mentioning here our earlier research work on the $TiCl_4$-mediated

Table 2
Synthesis of Baylis–Hillman alcohols (**8**–**19**) from the aromatic cyclic 1,2-diones (**7a**–**d**) and cyclic enones (**1a**–**c**) in the presence of $TiCl_4$[a]

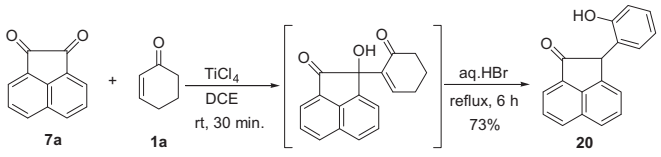


Entry	Dione	Cycloalk-2-enone	*T* (h)	Product[b] yield (%)[c]
1	**7a**	**1a**	0.5	**8** (87%)
2	**7a**	**1b**	1	**9** (78%)
3	**7a**	**1c**	5	**10** (72%)
4	**7b**	**1a**	0.5	**11**(70%)
5	**7b**	**1b**	0.5	**12** (79%)
6	**7b**	**1c**	1	**13** (72%)
7	**7c**	**1a**	12	**14** (61%)
8[d]	**7c**	**1b**	48	**15** (67%)
9[e]	**7c**	**1c**	6	**16** (53%)
10	**7d**	**1a**	6	**17** (90%)
11	**7d**	**1b**	24	**18** (85%)
12	**7d**	**1c**	10	**19** (70%)

[a] All the reactions were carried out on a 1 mmol scale of aromatic 1,2-diones (**7a**–**d**) with cyclic enones [**1a**, **b** (1 mmol) and for **1c** 1.5 mmol] in the presence of $TiCl_4$ (1 mmol) at room temperature (25–28 °C) in CH_2Cl_2 (for **15** and **18** DCE was used).
[b] All compounds were isolated as solids and fully characterized.
[c] Isolated yields based on the aromatic 1,2-diones (**7a**–**d**).
[d] Compound **15** was isolated along with side product (30%) (as shown by ^1H NMR).
[e] Minor side product (presumably aldol product) (**16a**) was also isolated in 19% yield along with compound **16**.

Baylis–Hillman reaction between cyclic aromatic 1,2-diones and alkyl vinyl ketones, which provided fused furan–carboxaldehydes.[16]

With a view to obtain the phenolic derivative (aromatized compound), in one-pot, we have carried out reaction between 1,2-acenaphthenequinone (**7a**, 1 mmol), and cyclohex-2-enone (**1a**, 1 mmol) in presence of $TiCl_4$ (1 mmol) in dichloroethane at room temperature for 30 min followed by the treatment of in situ formed BH-alcohol with aq HBr (5 mmol) at reflux temperature for 6 h as in the case of *N*-substituted isatins. The expected phenolic compound, i.e., 2-(2-hydroxyphenyl)-2*H*-acenaphthylen-1-one (**20**) was obtained in 73% isolated yield (Scheme 2). Structure of compound **20** was further confirmed by single crystal X-ray data analysis (Fig. 2).[15]

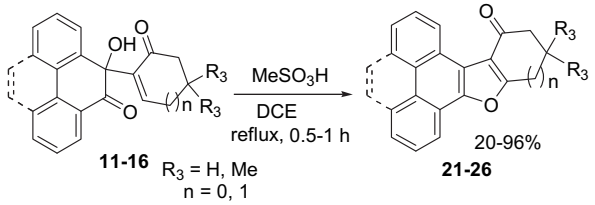


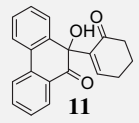
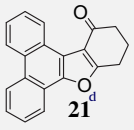
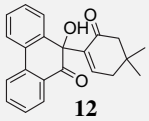
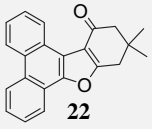
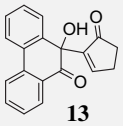
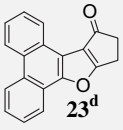
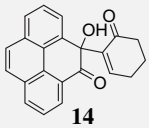
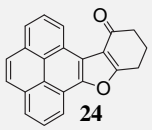
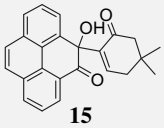
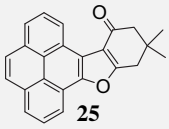
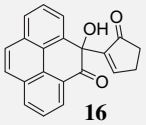
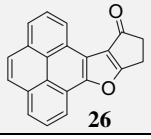
Scheme 2. Synthesis of 2-(2-hydroxyphenyl)-2*H*-acenaphthylen-1-one (**20**) from 1,2-acenaphthenequinone (**7a**) and cyclohex-2-enone (**1a**).

To understand the generality of this strategy we have selected three aromatic 1,2-diones **7b**–**d** as electrophiles for coupling with cyclohex-2-enone in the presence of $TiCl_4$ followed by treatment with aq HBr. Unfortunately these electrophiles, **7b**–**d**, did not provide the expected phenolic derivatives as these reactions were not clean. At this stage, we felt that step-wise strategy might offer better result. Our

attempts to convert alcohols **11**, **14**, and **17** into the corresponding aromatized compounds by treatment with aq HBr were not successful. During these studies we found that the treatment of the allylic alcohol **11** with methanesulfonic acid led to the formation of fused furan derivative (**21**) instead of the phenolic derivative. Thus the treatment of the alcohol (**11**, 1 mmol) with methanesulfonic acid (1 mmol) in dichloroethane at reflux temperature for 30 min provided the furan derivative **21** in 86% isolated yield (Table 3, entry 1). In order to understand the generality of this methodology we have transformed the Baylis–Hillman alcohols **12**–**16** into the fused furan derivatives **22**–**26** in 20–96% isolated yields via the treatment with methanesulfonic acid (Table 3). Structures of the compounds **21** and **23** were also confirmed by single crystal X-ray data analysis (Fig. 3).[15] A plausible mechanism for the transformation of the B–H alcohols into fused-furan framework is given in Scheme 3. However the Baylis–Hillman alcohol **17** failed to provide the corresponding fused furan derivative as this reaction was not clean.

Table 3
Synthesis of furan derivatives (**21**–**26**) from the Baylis–Hillman alcohols (**11**–**16**) via treatment with methanesulfonic acid[a]



Entry	B H alcohol	Product[b]	*T* (min)	Yield[c] (%)
1	 **11**	 **21**[d]	30	86
2	 **12**	 **22**	30	89
3	 **13**	 **23**[d]	30	96
4	 **14**	 **24**	30	50
5[e]	 **15**	 **25**	60	43[f]
6	 **16**	 **26**	60	20

[a] All the reactions were carried out on a 1 mmol scale of Baylis–Hillman alcohols (**11**–**16**) in the presence of methanesulfonic acid (1 mmol) in dichloroethane at reflux temperature.
[b] All the compounds were isolated as solids and fully characterized.
[c] Isolated yields based on the Baylis–Hillman alcohols (**11**–**16**).
[d] Structures of compounds **21** and **23** were further confirmed by single crystal X–ray data analysis.[15]
[e] Baylis–Hillman adduct **15** was used as such along with the minor side product as substrate for treatment with methanesulfonic acid.
[f] Yield was calculated based on the amount of Baylis–Hillman alcohol present in the mixture.

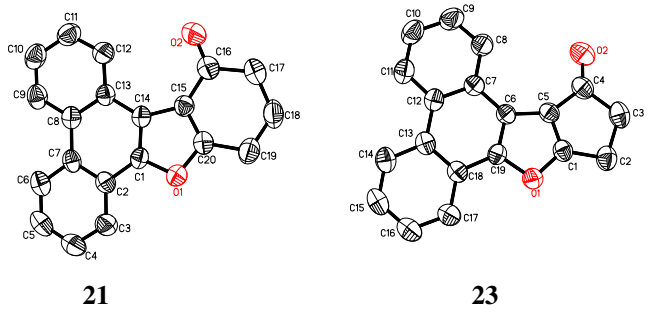
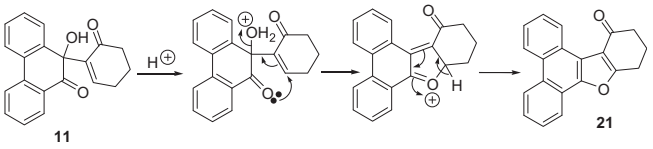
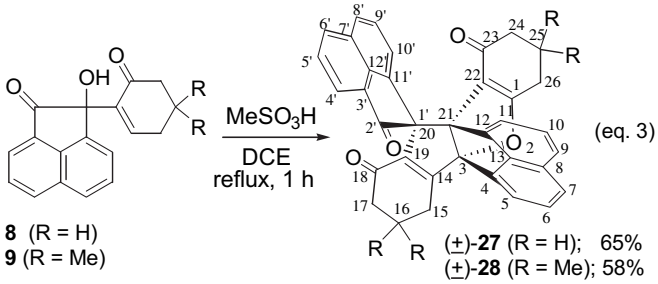


Figure 3. ORTEP diagrams of **21** and **23** (Hydrogen atoms are omitted for clarity).



Scheme 3. Plausible mechanism for synthesis of furan derivatives.

However, similar treatment of the Baylis–Hillman alcohol **8** with methanesulfonic acid did not provide the expected furan derivative. Instead, interesting spiro-fused compound **27** was obtained in 65% isolated yield (Eq. 3) when methanesulfonic acid (3 equiv) was used (1 equiv of methanesulfonic acid gave inferior yield). Structure of **27** and its (±)-cis-cis-cis-stereo-chemistry[17] were determined by the single crystal X-ray data analysis (Fig. 4).[15,18–20] Also the B–H alcohol **9** gave fused furan framework **28** under similar conditions.[20,21] A plausible mechanism is presented in Scheme 4. The furan intermediate **A**, formed in situ, might react with B–H alcohol (Friedel–Crafts reaction) giving rise to the key intermediate (oxonium ion) **B**, which might then undergo ene-type cyclization in a stereoselective manner at C-3 and C-21 with cis orientation because of the presence of acenaphthene rings. The single crystal X-ray structure of the compound **27** clearly shows that the reaction pathway also controls stereochemistry at spiro carbon (C-1′/20) leading to the formation of racemic **27** with cis-cis-cis stereochemistry.



3. Conclusion

In conclusion, we have developed a facile one-pot protocol for transformation of *N*-substituted isatins into 3-(2-hydroxyphenyl)indolin-2-one derivatives via the $TiCl_4$-mediated Baylis–Hillman reaction with cyclohex-2-enone followed by treatment of the in situ generated B–H alcohols with aq HBr. A

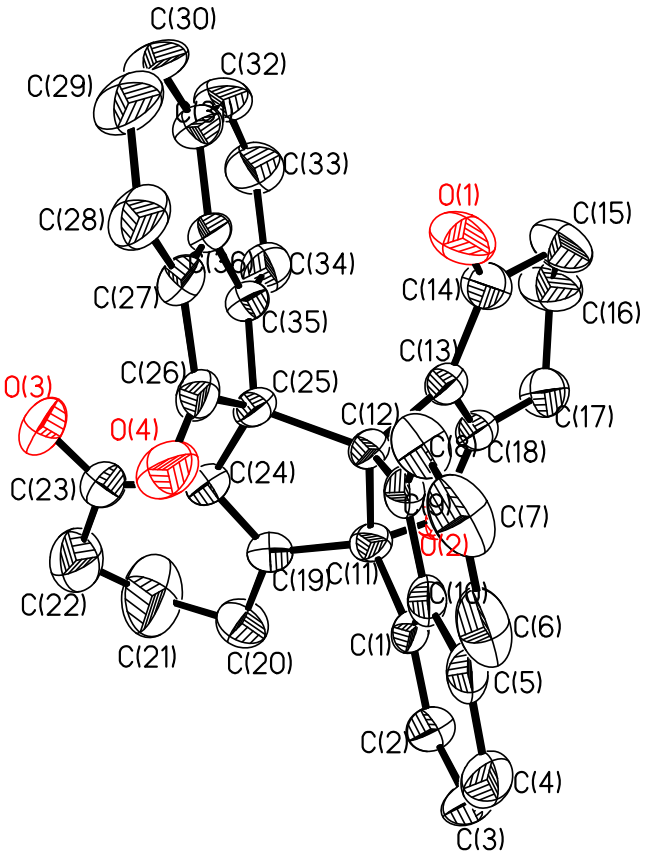


Figure 4. ORTEP diagram of **27** (Hydrogen atoms and one dichloromethane molecule are omitted for clarity).

simple two-step methodology for synthesis of fused-furan framework has also been developed via the treatment of the Baylis–Hillman adducts, obtained by $TiCl_4$-mediated Baylis–Hillman reaction between cyclic aromatic 1,2-diones and cyclic enones, with methanesulfonic acid.

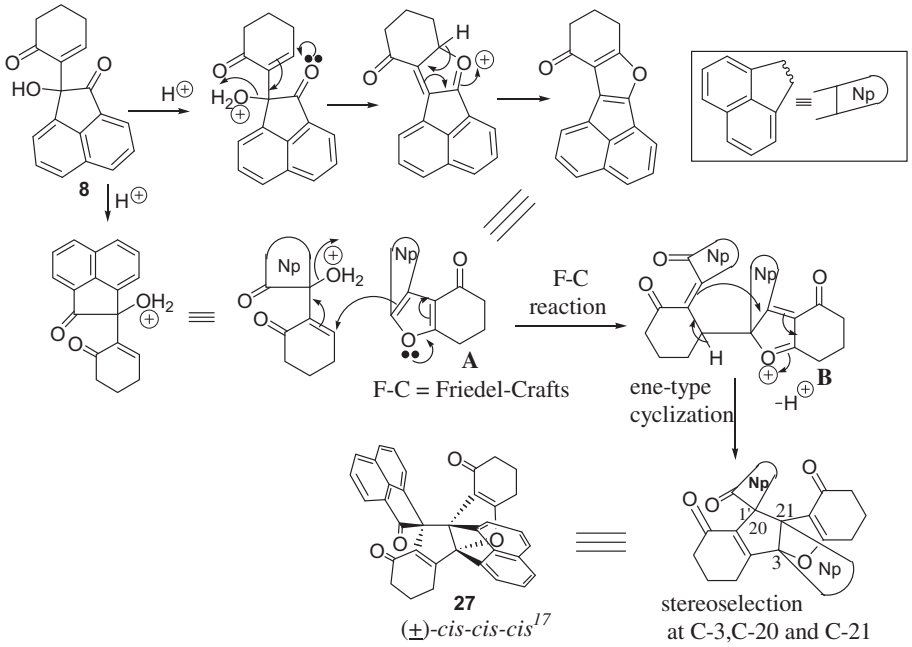
4. Experimental section

4.1. General remarks

Melting points were recorded on a Superfit (India) capillary melting point apparatus and are uncorrected. IR spectra were recorded on a JASCO-FTIR model 5300 spectrometer using solid samples as KBr plates. For all the compounds ^{1}H NMR (400 MHz) and ^{13}C NMR (100 MHz) spectra were recorded in deutero-chloroform ($CDCl_3$) on a Bruker-AVANCE-400 spectrometer using tetramethylsilane (TMS, δ=0) as an internal standard or in DMSO-d_6 at room temperature. Elemental analyses were recorded on a Thermo-Finnigan Flash EA 1112 analyzer. Mass spectra were recorded on Shimadzu-LCMS-2010 A mass spectrometer. The X-ray diffraction measurements were carried out at 298 K on a Bruker SMART APEX CCD area detector system equipped with a graphite monochromator and a Mo-Kα fine-focus sealed tube (λ=0.71073 Å).

4.2. Representative procedure

*4.2.1. Synthesis of 3-hydroxy-3-(cyclohex-2-enon-2-yl)-1-methyl-indolin-2-one (**3a**).* To a stirred solution of 1-methylisatin (**2a**) (1 mmol, 0.161 g) and cyclohex-2-enone (**1a**, 1 mmol, 0.096 g, 0.096 mL) in CH_2Cl_2 (1 mL) $TiCl_4$ (1 mmol, 0.5 mL of 2 M solution in CH_2Cl_2) was added at 0 °C. The reaction mixture was stirred for 30 min at room temperature (25–28 °C). Water (2 mL) was then added to the reaction mixture and extracted with CH_2Cl_2 (3×5 mL). Combined organic layer was dried over anhydrous Na_2SO_4. Solvent was evaporated and the residue, thus obtained, was subjected to column chromatography (silica gel, 60% ethyl acetate in hexanes) to afford the desired product (**3a**) as yellow solid in 86% (0.220 g) isolated yield. R_f (50% EtOAc in hexanes) 0.25; mp: 159–161 °C; IR (KBr): ν 3375, 1703, 1672, 1612 cm^{-1}; ^{1}H NMR (400 MHz): δ 1.85–2.06 (m, 2H), 2.27–2.43 (m, 2H), 2.44–2.52 (m, 2H), 3.22 (s, 3H), 4.08 (br s, 1H), 6.83 (d, 1H, J=7.6 Hz), 6.96–7.04 (m, 1H), 7.13 (d, 1H, J=7.2 Hz), 7.27–7.34 (m, 1H), 7.36–7.43 (m, 1H); ^{13}C NMR (100 MHz): δ 22.39, 25.83, 26.41, 38.37, 76.00, 108.58, 122.81, 123.58, 129.92, 130.09, 138.30, 144.37, 147.74, 176.63, 198.29; LCMS



Scheme 4. Plausible mechanism for synthesis of spiro derivative **27**.

(m/z): 258 $(M+H)^+$; Analysis calcd for $C_{15}H_{15}NO_3$: C, 70.02; H, 5.88; N, 5.44. Found: C, 70.15; H, 5.82; N, 5.55.

*4.2.2. 3-(2-Hydroxyphenyl)-1-methylindolin-2-one (**4a**).* To a stirred solution of 3-hydroxy-3-(cyclohex-2-enon-2-yl)-1-methylindolin-2-one (**3a**) (1 mmol, 0.257 g) in dichloroethane (1 mL) aq HBr (48%, 5 mmol, 0.405 g, 0.271 mL) was added at room temperature (25–28 °C) and the reaction mixture was heated under reflux for 6 h. The reaction mixture was allowed to cool to room temperature and diluted with water (5 mL). Organic layer was separated and aqueous layer was extracted with CH_2Cl_2 (3×5 mL). Combined organic layer was dried over anhydrous Na_2SO_4. Solvent was evaporated and the crude product, thus obtained, was purified through column chromatography (silica gel, 30% ethyl acetate in hexanes) to afford the desired product (**4a**) as yellow solid in 89% (0.212 g) isolated yield. R_f (20% EtOAc in hexanes) 0.28; mp: 150–152 °C; IR (KBr): ν 3180, 1680 cm^{-1}; ^1H NMR (400 MHz): δ 3.24 (s, 3H), 5.11 (s, 1H), 6.77–6.86 (m, 1H), 6.89 (d, 1H, J=7.2 Hz), 6.96 (d, 1H, J=8.0 Hz), 7.05 (d, 1H, J=8.0 Hz), 7.15–7.24 (m, 2H), 7.34 (d, 1H, J=7.2 Hz), 7.38–7.47 (m, 1H), 9.20 (s, 1H); ^{13}C NMR (100 MHz): δ 26.62, 47.92, 109.08, 118.96, 120.75, 123.23, 123.29, 126.13, 126.32, 127.32, 128.74, 129.27, 144.56, 156.20, 178.58; LCMS (m/z): 240 $(M+H)^+$. Analysis calcd for $C_{15}H_{13}NO_2$: C, 75.30; H, 5.48; N, 5.85. Found: C, 75.46; H, 5.50; N, 5.91.

*4.2.3. Representative procedure: one-pot synthesis of 3-(2-hydroxyphenyl)-1-methylindolin-2-one (**4a**).* To a stirred solution of 1-methylisatin (**2a**) (1 mmol, 0.161 g) and cyclohex-2-enone (**1a**, 1 mmol, 0.096 g, 0.096 mL) in dichloroethane (2 mL) $TiCl_4$ (1 mmol, 0.5 mL of 2 M solution in CH_2Cl_2) was added at 0 °C. The reaction mixture was stirred for 30 min at room temperature (25–28 °C). HBr (aq) (48%, 5 mmol, 0.405 g, 0.271 mL) was added to the reaction mixture at room temperature and heated under reflux for 6 h. The reaction mixture was allowed to cool to room temperature and diluted with water (5 mL). Organic layer was separated and aqueous layer was extracted with CH_2Cl_2 (3×5 mL). Combined organic layer was dried over anhydrous Na_2SO_4. Solvent was evaporated and the crude product, thus obtained, was purified through column chromatography (silica gel, 30% ethyl acetate in hexanes) to afford the desired product (**4a**) as yellow solid in 82% (0.195 g) isolated yield. Spectral data (IR, ^1H NMR, ^{13}C NMR and LCMS) and melting point are in complete agreement with that of **4a** prepared in two step procedure.

*4.2.4. 5-Chloro-3-(2-hydroxyphenyl)-1-methylindolin-2-one (**4b**).* Yield: 76%; R_f (20% EtOAc in hexanes) 0.20; light yellow solid; mp: 186–188 °C; IR (KBr): ν 3163, 1680 cm^{-1}; ^1H NMR (400 MHz): δ 3.24 (s, 3H), 5.07 (s, 1H), 6.80–6.93 (m, 3H), 6.95 (d, 1H, J=8.0 Hz), 7.12–7.22 (m, 1H), 7.28 (s, 1H), 7.36 (dd, 1H, J=8.4, 1.6 Hz), 8.67 (s, 1H); ^{13}C NMR (100 MHz): δ 26.77, 47.92, 109.84, 118.73, 120.94, 122.68, 126.26, 127.51, 128.52, 128.66, 128.75, 129.50, 143.09, 155.78, 178.03; LCMS (m/z): 274 $(M+H)^+$, 276 $(M+2+H)^+$. Analysis calcd for $C_{15}H_{12}ClNO_2$: C, 65.82; H, 4.42; N, 5.12. Found: C, 65.68; H, 4.45; N, 5.16.

*4.2.4.1. Crystal data for **4b**.* Empirical formula, $C_{15}H_{12}ClNO_2$; formula weight, 273.71; crystal color, habit: colorless, plate; crystal dimensions, 0.30×0.20×0.12 mm^3; crystal system, triclinic; lattice type, primitive; lattice parameters, a=10.132 (3) Å, b=10.298 (3) Å, c=14.543 (4) Å; α=101.957 (5); β=95.847 (5); γ=114.244 (5); V=1323.5 (7) $Å^3$; space group, $P-1$; Z=4; D_{calcd}=1.374 g/cm^3; F_{000}=568; λ(Mo K_α)=0.71073 Å; R ($I \geq 2\sigma_1$)=0.0436, wR^2=0.1117. Detailed X-ray crystallographic data is available from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK (for compound **4b** CCDC # 753488).

*4.2.5. 1-Ethyl-3-(2-hydroxyphenyl)indolin-2-one (**4c**).* Yield: 83%; R_f (20% EtOAc in hexanes) 0.35; light yellow solid; mp: 126–128 °C; IR (KBr): ν 3271, 1682 cm^{-1}; ^1H NMR (400 MHz): δ 1.28 (t, 3H, J=7.2 Hz), 3.78 (q, 2H, J=7.2 Hz), 5.09 (s, 1H), 6.78–6.86 (m, 1H), 6.90 (d, 1H, J=7.2 Hz), 6.98 (d, 1H, J=8.0 Hz), 7.01–7.08 (m, 1H),* 7.13–7.23 (m, 2H), 7.31–7.44 (m, 2H), 9.20 (br s, 1H); ^{13}C NMR (100 MHz): δ 12.64, 35.26, 48.01, 109.22, 118.98, 120.74, 123.08, 123.31, 126.35, 126.56, 127.32, 128.68, 129.25, 143.67, 156.26, 178.24; LCMS (m/z): 254 $(M+H)^+$. Analysis calcd for $C_{16}H_{15}NO_2$: C, 75.87; H, 5.97; N, 5.53. Found: C, 75.92; H, 6.12; N, 5.50. (*It is unresolved dd).

*4.2.6. 5-Chloro-1-ethyl-3-(2-hydroxyphenyl)indolin-2-one (**4d**).* Yield: 59%; R_f (20% EtOAc in hexanes) 0.22; light yellow solid; mp: 187–189 °C; IR (KBr): ν 3232, 1674 cm^{-1}; ^1H NMR (400 MHz): δ 1.27 (t, 3H, J=7.6 Hz), 3.71–3.84 (m, 2H), 5.05 (s, 1H), 6.78–6.91 (m, 3H), 6.95 (d, 1H, J=8.0 Hz), 7.11–7.19 (m, 1H), 7.28 (s, 1H), 7.34 (dd, 1H, J=8.4, 1.6 Hz), 8.68 (s, 1H); ^{13}C NMR (100 MHz): δ 12.54, 35.40, 47.98, 109.92, 118.64, 120.89, 122.76, 126.41, 127.54, 128.53, 128.57, 128.91, 129.46, 142.17, 155.82, 177.70; LCMS (m/z): 288 $(M+H)^+$, 290 $(M+2+H)^+$. Analysis calcd for $C_{16}H_{14}ClNO_2$: C, 66.79; H, 4.90; N, 4.87. Found: C, 66.65; H, 4.88; N, 4.77.

*4.2.7. 1-Benzyl-3-(2-hydroxyphenyl)indolin-2-one (**4e**).* Yield: 65%; R_f (20% EtOAc in hexanes) 0.38; light yellow solid; mp: 147–148 °C; IR (KBr): ν 3279, 1682 cm^{-1}; ^1H NMR (400 MHz): δ 4.90 and 4.95 (ABq, 2H, J=15.6 Hz), 5.18 (s, 1H), 6.78–6.87 (m, 2H), 6.91 (d, 1H, J=7.2 Hz), 7.01 (d, 1H, J=8.0 Hz), 7.08–7.21 (m, 2H), 7.22–7.34 (m, 7H), 8.96 (br s, 1H); ^{13}C NMR (100 MHz): δ 44.20, 47.93, 110.03, 118.82, 120.84, 123.27, 123.35, 126.08, 126.63, 127.35, 127.55, 127.88, 128.59, 128.93, 129.31, 135.24, 143.70, 156.10, 178.70; LCMS (m/z): 316 $(M+H)^+$. Analysis calcd for $C_{21}H_{17}NO_2$: C, 79.98; H, 5.43; N, 4.44. Found: C, 79.85; H, 5.47; N, 4.40.

*4.2.7.1. Crystal data for **4e**.* Empirical formula, $C_{21}H_{17}NO_2$; formula weight, 315.36; crystal color, habit: colorless, plate; crystal dimensions, 0.22×0.13×0.09 mm^3; crystal system, triclinic; lattice type, primitive; lattice parameters, a=11.102 (8) Å, b=12.101 (8) Å, c=12.537 (9) Å; α=89.327(13); β=78.942 (13); γ=84.167 (13); V=1644.5 (19) $Å^3$; space group, $P-1$; Z=4; D_{calcd}=1.261 g/cm^3; F_{000}=664; λ(Mo K_α)=0.71073 Å; R ($I \geq 2\sigma_1$)=0.0664, wR^2=0.1807. Detailed X-ray crystallographic data is available from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK (for compound **4e** CCDC # 753489).

*4.2.8. 1-Benzyl-5-chloro-3-(2-hydroxyphenyl)indolin-2-one (**4f**).* Yield: 77%; R_f (20% EtOAc in hexanes) 0.33; light yellow solid; mp: 158–161 °C; IR (KBr): ν 3190, 1693 cm^{-1}; ^1H NMR (400 MHz): δ 4.89 and 4.95 (ABq, 2H, J=15.6 Hz), 5.14 (s, 1H), 6.72 (d, 1H, J=8.0 Hz), 6.81–6.98 (m, 3H), 7.12–7.37 (m, 8H), 8.46 (s, 1H); ^{13}C NMR (100 MHz): δ 44.30, 47.94, 110.81, 118.45, 120.98, 122.73, 126.13, 127.30, 127.85, 128.02, 128.49, 128.75, 128.92, 129.01, 129.54, 134.89, 142.12, 155.62, 178.11; LCMS (m/z): 350 $(M+H)^+$, 352 $(M+2+H)^+$. Analysis calcd for $C_{21}H_{16}ClNO_2$: C, 72.10; H, 4.61; N, 4.00. Found: C, 72.18; H, 4.55; N, 4.12.

*4.2.9. 1-Benzyl-5-bromo-3-(2-hydroxyphenyl)indolin-2-one (**4g**).* Yield: 63%; R_f (20% EtOAc in hexanes) 0.31; light yellow solid; mp: 179–180 °C; IR (KBr): ν 3188, 1687 cm^{-1}; ^1H NMR (400 MHz): δ 4.89 and 4.95 (ABq, 2H, J=16.0 Hz), 5.15 (s, 1H), 6.68 (d, 1H, J=8.4 Hz), 6.81–6.89 (m, 1H), 6.91 (d, 1H, J=6.4 Hz), 6.96 (d, 1H, J=8.0 Hz), 7.12–7.21 (m, 1H), 7.22–7.43 (m, 7H), 8.41 (s, 1H); ^{13}C NMR (100 MHz): δ 44.28, 47.90, 111.28, 116.04, 118.44, 121.02, 122.75, 127.30, 127.89, 128.02, 128.85, 129.01, 129.31, 129.54, 131.39, 134.88, 142.64, 155.59, 177.95; LCMS (m/z): 394 $(M+H)^+$, 396 $(M+2+H)^+$.

Analysis calcd for $C_{21}H_{16}BrNO_2$: C, 63.97; H, 4.09; N, 3.55. Found: C, 63.85; H, 4.13; N, 3.62.

*4.2.9.1. Crystal data for **4g**.* Empirical formula, $C_{21}H_{16}BrNO_2$; formula weight, 394.26; crystal color, habit: colorless, plate; crystal dimensions, $0.40\times0.15\times0.05$ mm^3; crystal system, triclinic; lattice type, primitive; lattice parameters, a=8.024 (3) Å, b=10.882 (4) Å, c=11.554 (4) Å; α=101.870 (7); β=105.925 (7); γ=102.388 (7); V=909.2 (6) Å^3; space group, $P-1$; Z=2; D_{calcd}=1.438 g/cm^3; F_{000}=400; λ(Mo K$_\alpha$)=0.71073 Å; R ($I\geq2\sigma_1$)=0.0658, wR^2=0.1404. Detailed X-ray crystallographic data is available from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK (for compound **4g** CCDC # 753,490).

*4.2.10. 1-Benzyl-3-(2-hydroxyphenyl)-5-methylindolin-2-one (**4h**).* Yield: 85%; R_f (20% EtOAc in hexanes) 0.38; orange solid; mp: 101–103 °C; IR (KBr): ν 3273, 1682 cm^{-1}; ^{1}H NMR (400 MHz): δ 2.34 (s, 3H), 4.88 and 4.92 (ABq, 2H, J=16.0 Hz)$^{\#}$, 5.16 (s, 1H), 6.72 (d, 1H, J=8.0 Hz), 6.79–6.88 (m, 1H), 6.93 (d, 1H, J=7.2 Hz), 7.00–7.10 (m, 2H), 7.11–7.38 (m, 7H), 9.00 (br, 1H); ^{13}C NMR (100 MHz): δ 21.23, 44.20, 48.00, 109.81, 118.92, 120.82, 123.48, 126.47, 126.90, 127.32, 127.50, 127.85, 128.91, 129.28, 132.97, 135.30, 141.30, 156.17, 178.64; LCMS (m/z): 330 (M+H)$^+$. Analysis calcd for $C_{22}H_{19}NO_2$: C, 80.22; H, 5.81; N, 4.25. Found: C, 80.35; H, 5.76; N, 4.36. $^{\#}$ long peaks of both the parts of ABq merge and appear as a single peak at δ 4.90.

*4.2.11. 3-(2-Hydroxyphenyl)-1-phenylindolin-2-one (**4i**).* Yield: 55%; R_f (20% EtOAc in hexanes) 0.33; light yellow solid; mp: 125–127 °C; IR (KBr): ν 3304, 1693 cm^{-1}; ^{1}H NMR (400 MHz): δ 5.27 (s, 1H), 6.83–6.95 (m, 2H), 6.99–7.09 (m, 2H), 7.17–7.27 (m, 2H), 7.28–7.35 (m, 1H), 7.36–7.47 (m, 4H), 7.49–7.58 (m, 2H), 8.78 (br, 1H); ^{13}C NMR (100 MHz): δ 48.28, 110.38, 119.11, 120.98, 123.41, 123.69, 126.19, 126.38, 126.50, 126.63, 127.65, 128.67, 129.45, 129.82, 133.86, 144.76, 156.11, 178.10; LCMS (m/z): 302 (M+H)$^+$. Analysis calcd for $C_{20}H_{15}NO_2$: C, 79.72; H, 5.02; N, 4.65. Found: C, 79.56; H, 5.08; N, 4.61.

*4.2.12. 5-Chloro-3-(2-hydroxyphenyl)-1-phenylindolin-2-one (**4j**).* Yield: 51%; R_f (20% EtOAc in hexanes) 0.30; light yellow solid; mp: 128–130 °C; IR (KBr): ν 3339, 1701 cm^{-1}; ^{1}H NMR (400 MHz): δ 5.19 (s, 1H), 6.80 (d, 1H, J=8.4 Hz), 6.84–6.95 (m, 2H), 7.00 (d, 1H, J=7.2 Hz), 7.12–7.20 (m, 1H), 7.22–7.27 (m, 1H), 7.28 (s, 1H), 7.34–7.47 (m, 3H), 7.48–7.58 (m, 2H), 8.18 (s, 1H); ^{13}C NMR (100 MHz): δ 48.24, 111.02, 118.38, 120.98, 122.82, 126.17, 126.55, 128.15, 128.46, 128.77, 128.84, 129.00, 129.58, 129.90, 133.78, 143.14, 155.50, 177.45; LCMS (m/z): 334 (M-2+H)$^+$, 336 (M+H)$^+$, 338 (M+2+H)$^+$. Analysis calcd for $C_{20}H_{14}ClNO_2$: C, 71.54; H, 4.20; N, 4.17. Found: C, 71.65; H, 4.25; N, 4.07.

*4.2.13. 3-(2-Hydroxyphenyl)-5-methyl-1-phenylindolin-2-one (**4k**).* Yield: 54%; R_f (20% EtOAc in hexanes) 0.35; light yellow solid; mp: 174–175 °C; IR (KBr): ν 3300, 1695 cm^{-1}; ^{1}H NMR (400 MHz): δ 2.36 (s, 3H), 5.22 (s, 1H), 6.78 (d, 1H, J=8.0 Hz), 6.81–6.90 (m, 1H), 6.96 (d, 1H, J=7.6 Hz), 7.01 (d, 1H, J=7.6 Hz), 7.08 (d, 1H, J=8.0 Hz), 7.11–7.25 (m, 2H), 7.34–7.44 (m, 3H), 7.45–7.57 (m, 2H), 8.78 (s, 1H); ^{13}C NMR (100 MHz): δ 21.20, 48.22, 109.98, 118.69, 120.74, 123.51, 126.50, 126.64, 126.85, 127.82, 128.43, 128.83, 129.28, 129.71, 133.34, 134.10, 142.26, 156.01, 178.05; LCMS (m/z): 316 (M+H)$^+$. Analysis calcd for $C_{21}H_{17}NO_2$: C, 79.98; H, 5.43; N, 4.44. Found: C, 79.85; H, 5.36; N, 4.53.

*4.2.14. 3-Hydroxy-3-(5,5-dimethylcyclohex-2-enon-2-yl)-1-methylindolin-2-one (**5**).* Yield: 91%; R_f (50% EtOAc in hexanes) 0.40; reaction time: 7 h, white solid; mp: 144–146 °C; IR (KBr): ν 3342, 1701, 1670, 1630, 1610 cm^{-1}; ^{1}H NMR (400 MHz): δ 0.98 (s, 3H), 1.02 (s, 3H), 2.17 and 2.24 (ABq, 2H, J=16.0 Hz), 2.36 (d, 2H, J=4.0 Hz), 3.22 (s, 3H), 4.02 (s, 1H), 6.84 (d, 1H, J=7.6 Hz), 6.95–7.03 (m, 1H), 7.12 (d, 1H, J=6.8 Hz), 7.24–7.34 (m, 2H); ^{13}C NMR (100 MHz): δ 26.41, 27.90, 28.36, 34.03, 39.87, 51.92, 75.92, 108.64, 122.84, 123.46, 129.94, 130.06, 137.41, 144.42, 145.41, 176.57, 198.35; LCMS (m/z): 286 (M+H)$^+$. Analysis calcd for $C_{17}H_{19}NO_3$: C, 71.56; H, 6.71; N, 4.91. Found: C, 71.35; H, 6.78; N, 4.98.

*4.2.15. 3-Hydroxy-3-(cyclopent-2-enon-2-yl)-1-methylindolin-2-one (**6**).* Yield: 53%; R_f (50% EtOAc in hexanes) 0.15; reaction time: 2 h, gray solid; mp: 136–138 °C; IR (KBr): ν 3350, 1697, 1687, 1610 cm^{-1}; ^{1}H NMR (400 MHz): δ 2.42–2.49 (m, 2H), 2.59–2.67 (m, 2H), 3.22 (s, 3H), 4.57 (br, 1H), 6.86 (d, 1H, J=7.6 Hz), 7.02–7.12 (m, 1H), 7.30–7.38 (m, 2H), 7.52 (t, 1H, J=2.8 Hz); ^{13}C NMR (100 MHz): δ 26.47, 26.75, 35.36, 75.20, 108.71, 123.31, 124.54, 129.04, 130.32, 143.87, 144.11, 160.42, 175.42, 208.19; LCMS (m/z): 244 (M+H)$^+$. Analysis calcd for $C_{14}H_{13}NO_3$: C, 69.12; H, 5.39; N, 5.76. Found: C, 69.21; H, 5.33; N, 5.72.

*4.2.16. 2-Hydroxy-2-(cyclohex-2-enon-2-yl)-2H-acenaphthylen-1-one (**8**).* Yield: 87%; R_f (50% EtOAc in hexanes) 0.50; reaction time: 30 min yellow solid; mp: 177–178 °C; IR (KBr): ν 3427, 1712, 1666, 1604 cm^{-1}; ^{1}H NMR (400 MHz): δ 1.87–2.05 (m, 2H), 2.23–2.39 (m, 2H), 2.40–2.50 (m, 2H), 3.92 (br s, 1H), 7.36 (t, 1H, J=4.4 Hz), 7.42 (d, 1H, J=6.8 Hz), 7.56–7.62 (m, 1H), 7.70–7.78 (m, 1H), 7.86 (d, 1H, J=8.0 Hz), 7.99 (d, 1H, J=6.8 Hz), 8.09 (d, 1H, J=8.0 Hz); ^{13}C NMR (100 MHz): δ 22.39, 25.87, 38.21, 79.88, 120.30, 122.30, 125.76, 128.40, 128.47, 130.81, 131.45, 131.72, 139.39, 139.75, 141.58, 147.99, 198.65, 202.61; LCMS (m/z): 279 (M+H)$^+$. Analysis calcd for $C_{18}H_{14}O_3$: C, 77.68; H, 5.07. Found: C, 77.56; H, 5.12.

*4.2.17. 2-Hydroxy-2-(5,5-dimethylcyclohex-2-enon-2-yl)-2H-acenaphthylen-1-one (**9**).* Yield: 78%; R_f (50% EtOAc in hexanes) 0.66; reaction time: 1 h, gray solid; mp: 176–177 °C; IR (KBr): ν 3325, 1709, 1666, 1602 cm^{-1}; ^{1}H NMR (400 MHz): δ 0.98 (s, 3H), 1.02 (s, 3H), 2.16, and 2.21 (ABq, 2H, J=16.0 Hz), 2.35 (d, 2H, J=4.4 Hz), 3.84 (s, 1H), 7.19–7.31 (m, 1H), 7.42 (d, 1H, J=6.8 Hz), 7.53–7.65 (m, 1H), 7.70–7.78 (m, 1H), 7.86 (d, 1H, J=8.4 Hz), 7.99 (d, 1H, J=7.2 Hz), 8.09 (d, 1H, J=8.0 Hz); ^{13}C NMR (100 MHz): δ 28.12, 28.18, 34.05, 39.96, 51.81, 79.83, 120.20, 122.34, 125.81, 128.42, 128.50, 130.89, 131.48, 131.77, 138.52, 139.75, 141.67, 145.65, 198.78, 202.59; LCMS (m/z): 305 (M−H)$^+$. Analysis calcd for $C_{20}H_{18}O_3$: C, 78.41; H, 5.92. Found: C, 78.49; H, 5.84.

*4.2.18. 2-Hydroxy-2-(cyclopent-2-enon-2-yl)-2H-acenaphthylen-1-one (**10**).* Yield: 72%; R_f (50% EtOAc in hexanes) 0.43; reaction time: 5 h, gray solid; mp: 152–154 °C; IR (KBr): ν 3427, 1728, 1674, 1610 cm^{-1}; ^{1}H NMR (400 MHz): δ 2.40–2.52 (m, 2H), 2.53–2.66 (m, 2H), 4.95 (br s, 1H), 7.30–7.41 (m, 1H),* 7.57–7.70 (m, 2H), 7.71–7.80 (m, 1H), 7.91(d, 1H, J=8.0 Hz), 7.99 (d, 1H, J=7.2 Hz), 8.13 (d, 1H, J=8.4 Hz); ^{13}C NMR (100 MHz): δ 26.84, 35.29, 79.19, 121.24, 122.74, 125.93, 128.59, 128.88, 130.64, 130.79, 132.05, 138.80, 141.74, 144.53, 160.54, 201.95, 208.95; LCMS (m/z): 265 (M+H)$^+$. Analysis calcd for $C_{17}H_{12}O_3$: C, 77.26; H, 4.58. Found: C, 77.09; H, 4.63. (* It is unresolved triplet).

*4.2.19. 10-Hydroxy-10-(cyclohex-2-enon-2-yl)-10H-phenanthren-9-one (**11**).* Yield: 70%; R_f (50% EtOAc in hexanes) 0.58; reaction time: 30 min, yellow solid; mp: 110–112 °C; IR (KBr): ν 3431, 1703, 1668, 1601 cm^{-1}; ^{1}H NMR (400 MHz): δ 1.70–1.99 (m, 2H), 2.15–2.44 (m, 4H), 4.77 (s, 1H), 6.78 (t, 1H, J=4.0 Hz), 7.33–7.48 (m, 3H), 7.57–7.70 (m, 2H), 7.82–7.95 (m, 3H); ^{13}C NMR (100 MHz): δ 22.21, 26.09, 38.74, 78.54, 122.86, 123.87, 127.71, 127.89, 128.53, 128.90, 129.19, 129.39, 130.85, 134.27, 136.76, 137.73, 140.88, 148.78, 198.56, 200.08; LCMS (m/z): 303 (M−H)$^+$. Analysis calcd for $C_{20}H_{16}O_3$: C, 78.93; H, 5.30. Found: C, 78.81; H, 5.36.

*4.2.20. 10-Hydroxy-10-(5,5-dimethylcyclohex-2-enon-2-yl)-10H-phenanthren-9-one (**12**).* Yield: 79%; R_f (50% EtOAc in hexanes) 0.74; reaction time: 30 min, yellow solid; mp: 76–78 °C; IR (KBr): ν 3429,

1705, 1668, 1599 cm^{-1}; ^1H NMR (400 MHz): δ 0.69 (s, 3H), 0.96 (s, 3H), 2.01–2.28 (m, 4H), 4.71 (s, 1H), 6.61 (t, 1H, J=4.8 Hz), 7.32–7.48 (m, 3H), 7.57–7.70 (m, 2H), 7.81–7.90 (m, 3H); ^{13}C NMR (100 MHz): δ 26.98, 28.59, 33.87, 40.03, 52.24, 78.56, 122.86, 123.96, 127.50, 127.67, 128.50, 128.89, 129.15, 129.60, 130.95, 134.17, 136.73, 137.58, 140.00, 146.78, 198.64, 200.35; LCMS (m/z): 331 $(M-H)^+$. Analysis calcd for $C_{22}H_{20}O_3$: C, 79.50; H, 6.06. Found: C, 79.39; H, 6.12.

*4.2.21. 10-Hydroxy-10-(cyclopent-2-enon-2-yl)-10H-phenanthren-9-one (**13**).* Yield: 72%; R_f (50% EtOAc in hexanes) 0.53; reaction time: 1 h, gray solid; mp: 108–110 °C; IR (KBr): ν 3466, 1699, 1682, 1599 cm^{-1}; ^1H NMR (400 MHz): δ 2.22–2.47 (m, 4H), 5.40 (s, 1H), 6.97 (s, 1H) [unresolved triplet], 7.33–7.50 (m, 3H), 7.60–7.70 (m, 1H), 7.72–7.80 (m, 1H), 7.82–7.96 (m, 3H); ^{13}C NMR (100 MHz): δ 26.15, 35.55, 77.76, 123.00, 123.97, 127.30, 128.07, 128.30, 128.65, 128.95, 129.59, 129.97, 134.91, 137.21, 137.83, 145.30, 162.17, 198.99, 207.16; LCMS (m/z): 289 $(M-H)^+$. Analysis calcd for $C_{19}H_{14}O_3$: C, 78.61; H, 4.86. Found: C, 78.79; H, 4.91.

*4.2.22. 5-Hydroxy-5-(cyclohex-2-enon-2-yl)-5H-pyren-4-one (**14**).* Yield: 61%; R_f (50% EtOAc in hexanes) 0.54; reaction time: 12 h, yellow solid; mp: 191–192 °C; IR (KBr): ν 3391, 1668, 1662, 1620 cm^{-1}; ^1H NMR (400 MHz): δ 1.81–2.05 (m, 2H), 2.18–2.52 (m, 4H), 4.02 (s, 1H), 7.18 (t, 1H, J=4.0 Hz), 7.60–7.68 (m, 1H), 7.69–7.77 (m, 2H), 7.78–7.84 (m, 2H), 7.86 (d, 1H, J=7.6 Hz), 8.13 (d, 1H, J=8.0 Hz), 8.36 (dd, 1H, J=7.6, 0.8 Hz); ^{13}C NMR (100 MHz): δ 22.30, 25.87, 38.47, 76.92, 124.71, 126.36, 126.46, 126.74, 127.03, 127.50, 127.59, 127.73, 128.16, 129.40, 131.22, 131.73, 133.97, 137.79, 142.65, 146.91, 198.35, 198.42; LCMS (m/z): 327 $(M-H)^+$. Analysis calcd for $C_{22}H_{16}O_3$: C, 80.47; H, 4.91. Found: C, 80.35; H, 4.84.

*4.2.23. 5-Hydroxy-5-(5,5-dimethylcyclohex-2-enon-2-yl)-5H-pyren-4-one (**15**).* This B–H adduct was obtained as a major product along with a minor side product in 70:30 ratio (on the basis of NMR studies) in 67% isolated (mixture) yield. This was used as such for the next step. R_f (50% EtOAc in hexanes) 0.64; Reaction time: 48 h, yellow solid; mp: 172–174 °C; IR (KBr): ν 3429, 1693, 1658, 1620 cm^{-1}; ^1H NMR (400 MHz): δ 0.90 (s, 3H), 1.01 (s, 3H), 2.09 and 2.17 (ABq, 2H, J=16.0 Hz), 2.27 and 2.35 (dABq, 2H, J=4.0, 19.2 Hz), 3.95 (s, 1H), 7.08 (t, 1H, J=4.0 Hz), 7.59–7.96 (m, 6H)*, 8.13 (d, 1H, J=8.0 Hz), 8.35 (d, 1H, J=7.2 Hz). In addition to the above peaks (due to the Baylis–Hillman adduct) peaks at δ 1.15 (s), 1.23 (s), 2.52 and 2.57 (ABq, J=16.0 Hz), 3.65 (s), 7.14 (s), 8.19 (d, J=8.0 Hz), 8.41 (d, J=7.2 Hz) appeared and these are attributed to the side product. *This multiplet also contains peaks relating to the side product; ^{13}C NMR (100 MHz): δ 25.44, 26.07, 28.10, 34.09, 39.90, 46.02, 51.96, 75.39, 76.74, 124.27, 124.71, 126.32, 126.48, 126.74, 126.81, 126.95, 127.03, 127.14, 127.22, 127.51, 127.56, 127.59, 127.71, 128.19, 129.01, 129.33, 129.41, 131.23, 131.43, 131.79, 132.17, 133.98, 134.73, 134.91, 135.95, 137.71, 141.75, 144.66, 154.98, 196.67, 197.13, 198.31, 198.44, 202.97 (mixture of two compounds).

*4.2.24. 5-Hydroxy-5-(cyclopent-2-enon-2-yl)-5H-pyren-4-one (**16**).* Reaction between pyrene-(4,5)-dione (**7c**) and cyclopent-2-enone (**1c**) following the procedure as described for compound **3a** provided the desired B–H alcohol (**16**) as a major product in 53% isolated yield along with the minor product (presumably aldol product) (**16a**) in 19% isolated yield (these were separated by silica gel column chromatography using 30% EtOAc in hexanes as a solvent system). Yield: 53%; R_f (50% EtOAc in hexanes) 0.48; reaction time: 6 h, brown solid; mp: 77–79 °C; IR (KBr): ν 3458, 1693, 1680, 1620 cm^{-1}; ^1H NMR (400 MHz): δ 2.19–2.45 (m, 4H), 5.64 (s, 1H), 6.64–6.72 (m, 1H), 7.63–7.73 (m, 2H), 7.74–7.84 (m, 2H), 7.87 (d, 1H, J=8.0 Hz), 7.94 (d, 1H, J=7.6 Hz), 8.10 (d, 1H, J=8.0 Hz), 8.24 (d, 1H, J=7.2 Hz); ^{13}C NMR (100 MHz): δ 26.13, 35.54, 78.60, 124.13, 125.81, 126.35, 127.01, 127.05, 127.15, 127.58, 127.97, 128.17, 129.54, 131.00, 131.59, 134.22, 137.89, 145.53, 161.63, 198.36, 207.34; LCMS (m/z): 313 $(M-H)^+$. Analysis calcd for $C_{21}H_{14}O_3$: C, 80.24; H, 4.49. Found: C, 80.45; H, 4.43.

*4.2.25. 5-Hydroxy-5-(cyclopent-2-enon-5-yl)-5H-pyren-4-one (**16a**)$^{\$}$.* Yield: 19%; R_f (50% EtOAc in hexanes) 0.66; reaction time: 6 h, brown solid; mp: 160–162 °C; IR (KBr): ν 3472, 1693 cm^{-1}; ^1H NMR (400 MHz): δ 2.09–2.40 and 2.70–3.01 (2 m, 3H)$^{\#}$, 4.48 and *5.46* (2s, 1H), *6.02–6.09* and 6.12–6.19 (2 m, 1H), 7.39–8.40 (m, 9H)$^{\#}$ [The underlined peaks with low intensity may be due to the presence of minor isomer of aldol adduct. (major–minor=76:24). $^{\#}$also contains peaks belonging to the minor product]; ^{13}C NMR (100 MHz): δ 31.33, 31.52, 53.20, 54.81, 79.80, 80.78, 123.82, 123.94, 124.15, 126.04, 126.18, 126.45, 126.60, 126.73, 127.05, 127.22, 127.40, 127.48, 127.53, 127.83, 127.94, 128.14, 129.06, 129.34, 129.77, 130.11, 130.75, 131.19, 131.83, 132.05, 133.42, 134.13, 134.64, 135.75, 137.76, 139.80, 162.92, 164.54, 200.14, 203.22, 206.70, 207.98 (mixture of diastereomers); LCMS (m/z): 313 $(M-H)^+$. $ tentatively assigned structure.

*4.2.26. 2-Hydroxy-2-(cyclohex-2-enon-2-yl)-2H-aceanthrylen-1-one (**17**).* Yield: 90%; R_f (50% EtOAc in hexanes) 0.59; reaction time: 6 h, yellow solid; mp: 204–206 °C; IR (KBr): ν 3404, 1703, 1670, 1649 cm^{-1}; ^1H NMR (400 MHz): δ 1.89–2.07 (m, 2H), 2.27–2.52 (m, 4H), 4.27 (s, 1H), 7.34 (t, 1H, J=4.0 Hz), 7.42 (d, 1H, J=6.8 Hz), 7.49–7.65 (m, 2H), 7.66–7.78 (m, 1H), 7.93 (d, 1H, J=8.8 Hz), 8.12 (d, 1H, J=8.4 Hz), 8.65 (s, 1H), 9.10 (d, 1H, J=8.4 Hz); ^{13}C NMR (100 MHz): δ 22.44, 25.97, 38.47, 80.29, 119.96, 124.65, 124.79, 125.90, 126.53, 127.66, 128.47, 128.74, 129.15, 129.38, 132.64, 133.72, 139.06, 140.18, 143.60, 148.16, 199.13, 202.76; LCMS (m/z): 327 $(M-H)^+$. Analysis calcd for $C_{22}H_{16}O_3$: C, 80.47; H, 4.91. Found: C, 80.59; H, 4.99.

*4.2.27. 2-Hydroxy-2-(5,5-dimethylcyclohex-2-enon-2-yl)-2H-aceanthrylen-1-one (**18**).* Yield: 85%; R_f (50% EtOAc in hexanes) 0.71; reaction time: 24 h, yellow solid; mp: 176–178 °C; IR (KBr): ν 3404, 1707, 1668, 1620 cm^{-1}; ^1H NMR (400 MHz): δ 1.00 (s, 3H), 1.03 (s, 3H), 2.20 and 2.25 (ABq, 2H, J=16.4 Hz), 2.35 (d, 2H, J=4.4 Hz), 4.13 (s, 1H), 7.22 (t, 1H, J=4.4 Hz), 7.43 (d, 1H, J=6.4 Hz), 7.52–7.67 (m, 2H), 7.69–7.80 (m, 1H), 7.95 (d, 1H, J=8.8 Hz), 8.14 (d, 1H, J=8.4 Hz), 8.67 (s, 1H), 9.12 (d, 1H, J=8.8 Hz); ^{13}C NMR (100 MHz): δ 28.13, 28.19, 34.04, 39.99, 52.01, 80.14, 119.77, 124.70, 124.82, 125.90, 126.51, 127.64, 128.50, 128.72, 129.10, 129.36, 132.59, 133.69, 138.18, 140.19, 143.63, 145.78, 199.12, 202.69; LCMS (m/z): 355 $(M-H)^+$. Analysis calcd for $C_{24}H_{20}O_3$: C, 80.88; H, 5.66. Found: C, 80.71; H, 5.72.

*4.2.28. 2-Hydroxy-2-(cyclopent-2-enon-2-yl)-2H-aceanthrylen-1-one (**19**).* Yield: 70%; R_f (50% EtOAc in hexanes) 0.43; reaction time: 10 h, dark solid; mp: 216–217 °C; IR (KBr): ν 3501, 1693, 1620 cm^{-1}; ^1H NMR (400 MHz): δ 2.46–2.54 (m, 2H), 2.56–2.64 (m, 2H), 5.01 (br s, 1H), 7.35 (t, 1H, J=4.0 Hz), 7.56–7.69 (m, 3H), 7.71–7.81 (m, 1H), 7.99 (dd, 1H, J=1.6, 7.2 Hz), 8.15 (d, 1H, J=8.4 Hz), 8.71 (s, 1H), 9.10 (d, 1H, J=8.8 Hz); ^{13}C NMR (100 MHz): δ 26.80, 35.40, 79.34, 120.87, 123.69, 124.79, 126.07, 126.76, 127.94, 128.40, 128.81, 129.46, 129.51, 133.26, 133.75, 139.18, 143.89, 144.44, 160.42, 201.85, 209.25; LCMS (m/z): 315 $(M+H)^+$. Analysis calcd for $C_{21}H_{14}O_3$: C, 80.24; H, 4.49. Found: C, 80.44; H, 4.53.

*4.2.29. 2-(2-Hydroxyphenyl)-2H-acenaphthylen-1-one (**20**).* This compound was prepared following the same procedure as described for compound **4a**: Yield: 73%; R_f (20% EtOAc in hexanes) 0.47; white solid; mp: 194–196 °C; IR (KBr): ν 3287, 1695 cm^{-1}; ^1H NMR (400 MHz): δ 5.43 (s, 1H), 6.76–6.85 (m, 1H), 6.89 (d, 1H, J=7.6 Hz), 7.08 (d, 1H, J=7.6 Hz), 7.15–7.23 (m, 1H), 7.55 (d, 1H, J=6.8 Hz), 7.66–7.85 (m, 2H), 7.93 (d, 1H, J=8.4 Hz), 7.98–8.04 (m,

2H), 8.19 (d, 1H, J=8.0 Hz); ^{13}C NMR (100 MHz): δ 53.98, 118.79, 121.08, 122.98, 123.03, 124.80, 124.84, 127.99, 128.54, 128.79, 129.09, 131.09, 132.14, 132.72, 136.46, 143.12, 155.59, 206.67; LCMS (m/z): 261 $(M+H)^+$. Analysis calcd for $C_{18}H_{12}O_2$: C, 83.06; H, 4.65. Found: C, 82.90; H, 4.71.

4.2.29.1. Crystal data for ***20****.* Empirical formula, $C_{18}H_{12}O_2$; formula weight, 260.28; crystal color, habit: colorless, block; crystal dimensions, 0.50×0.28×0.26 mm^3; crystal system, triclinic; lattice type, primitive; lattice parameters, a=7.9386 (16) Å, b=8.9357 (18) Å, c=10.627 (2) Å; α=68.928 (3); β=79.267 (3); γ=65.496 (3); V=639.5 (2) Å^3; space group, $P\bar{1}$; Z=2; D_{calcd}=1.352 g/cm^3; F_{000}=272; λ(Mo K$_\alpha$)=0.71073 Å; R ($I\geq 2\sigma_1$)=0.0405, wR^2=0.1069. Detailed X-ray crystallographic data is available from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK (for compound **20** CCDC # 753,491).

*4.2.30. Representative procedure: synthesis of 2-oxapentacyclo [15.4.0.0.^{3,16}0.^{4,9}0.^{10,15}]henicosan-1(17),3(16), 4(9),5,7,10(15),11,13-octaen-18-one (****21****).* To a stirred solution of 10-hydroxy-10-(cyclohex-2-enon-2-yl)-10*H*-phenanthren-9-one (**11**) (1 mmol, 0.304 g) in dichloroethane (2 mL) methanesulfonic acid (1 mmol, 0.096 g, 0.065 mL) was added at room temperature (25–28 °C) and the reaction mixture was heated under reflux for 30 min. The reaction mixture was allowed to cool to room temperature and diluted with water (3 mL) and extracted with CH_2Cl_2 (3×5 mL). Combined organic layer was dried over anhydrous Na_2SO_4. Solvent was evaporated and the residue, thus obtained, was subjected to column chromatography (silica gel, 5% ethyl acetate in hexanes) to provide the desired product (**21**) as yellow solid in 86% (0.247 g) isolated yield. R_f (20% EtOAc in hexanes) 0.44; mp: 160–162 °C; IR (KBr): ν 1666, 1618 cm^{-1}; ^{1}H NMR (400 MHz): δ 2.18–2.34 (m, 2H), 2.66 (t, 2H, J=6.0 Hz), 3.04 (t, 2H, J=6.0 Hz), 7.53–7.64 (m, 3H), 7.65–7.73 (m, 1H), 8.09–8.20 (m, 1H), 8.52–8.68 (m, 2H), 9.62 (d, 1H, J=8.0 Hz); ^{13}C NMR (100 MHz): δ 22.19, 24.36, 39.18, 117.37, 119.50, 120.41, 121.34, 122.85, 123.24, 125.80, 126.37, 126.90, 127.14, 127.36, 128.47, 128.77, 129.54, 148.75, 169.53, 194.28; LCMS (m/z): 287 $(M+H)^+$. Analysis calcd for $C_{20}H_{14}O_2$: C, 83.90; H, 4.93. Found: C, 83.73; H, 4.88.

4.2.30.1. Crystal data for ***21****.* Empirical formula, $C_{20}H_{14}O_2$; formula weight, 286.31; crystal color, habit: colorless, block; crystal dimensions, 0.28×0.25×0.18 mm^3; crystal system, monoclinic; lattice type, primitive; lattice parameters, a=7.5443 (7) Å, b=18.8155 (17) Å, c=10.1375 (9) Å; α=90.00, β=106.017 (2); γ=90.00; V=1383.2 (2) Å^3; space group, $P2$ (1); Z=4; D_{calcd}=1.375 g/cm^3; F_{000}=600; λ(Mo K$_\alpha$)=0.71073 Å; R ($I\geq 2\sigma_1$)= 0.0418, wR^2=0.0838. Detailed X-ray crystallographic data is available from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK (for compound **21** CCDC # 754,879).

*4.2.31. 20,20-Dimethyl-2-oxapentacyclo[15.4.0.0.^{3,16}0.^{4,9}0.^{10,15}]henicosan-1(17),3(16),4(9),5,7,10(15),11,13-octaen-18-one (****22****).* Yield: 89%; R_f (20% EtOAc in hexanes) 0.63; reaction time: 30 min, white solid; mp: 178–180 °C; IR (KBr): ν 1,666, 1,610 cm^{-1}; ^{1}H NMR (400 MHz): δ 1.22 (s, 6H), 2.57 (s, 2H), 2.97 (s, 2H), 7.58–7.67 (m, 3H), 7.68–7.76 (m, 1H), 8.20–8.28 (m, 1H), 8.63–8.73 (m, 2H), 9.65 (dd, 1H, J=0.8, 8.0 Hz); ^{13}C NMR (100 MHz): δ 28.47, 34.65, 38.12, 53.36, 117.36, 118.36, 120.44, 121.43, 122.90, 123.29, 125.87, 126.37, 126.95, 127.21, 127.41, 128.50, 128.79, 129.48, 149.14, 168.66, 193.70; LCMS (m/z): 315 $(M+H)^+$. Analysis calcd for $C_{22}H_{18}O_2$: C, 84.05; H, 5.77. Found: C, 84.12; H, 5.71.

*4.2.32. 2-Oxapentacyclo[15.3.0.0.^{3,16}0.^{4,9}0.^{10,15}]cosan-1(17), 3(16),4(9),5,7,10(15),11,13-octaen-18-one (****23****).* Yield: 96%; R_f (20% EtOAc in hexanes) 0.42; reaction time: 30 min, brown solid; mp: 209–211 °C; IR (KBr): ν 1699, 1618 cm^{-1}; ^{1}H NMR (400 MHz): δ 3.00–3.12 (m, 4H), 7.52–7.72 (m, 4H), 8.02–8.11 (m, 1H), 8.49–8.60 (m, 2H), 8.63 (d, 1H, J=7.6 Hz); ^{13}C NMR (100 MHz): δ 22.82, 41.62, 116.19, 120.38, 121.89, 122.87, 123.40, 126.19, 126.31, 126.46, 126.78, 127.05, 127.47, 127.98, 128.14, 129.52, 154.96, 184.27, 194.69; LCMS (m/z): 273 $(M+H)^+$. Analysis calcd for $C_{19}H_{12}O_2$: C, 83.81; H, 4.44. Found: C, 83.75; H, 4.48.

4.2.32.1. Crystal data for ***23****.* Empirical formula, $C_{19}H_{12}O_2$; formula weight, 272.29; crystal color, habit: yellow, plate; crystal dimensions, 0.25×0.18×0.15 mm^3; crystal system, monoclinic; lattice type, centro symmetric; lattice parameters, a=24.610 (2) Å, b=5.4124 (4) Å, c=19.5981 (16) Å; α=90.00, β=95.0210 (10); γ=90.00; V=2600.4 (4) Å^3; space group, $C2/c$; Z=8; D_{calcd}=1.391 g/cm^3; F_{000}=1136; λ(Mo K$_\alpha$)=0.71073 Å; R ($I\geq 2\sigma_1$)=0.0434, wR^2=0.0945. Detailed X-ray crystallographic data is available from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK (for compound **23** CCDC # 754,880).

*4.2.33. 2-Oxahexacyclo[15.4.0.0.^{3,16}1.^{4,8}2.$^{4(8),11}$2.$^{4(8),15}$]tricosane-1(17),3(16),4(22),5,7,9,11,13,15(23)-nonaen-18-one (****24****).* Yield: 50%; R_f (20% EtOAc in hexanes) 0.45; reaction time: 30 min, yellow solid; mp: 181–183 °C; IR (KBr): ν 1662, 1618 cm^{-1}; ^{1}H NMR (400 MHz): δ 2.26–2.42 (m, 2H), 2.73 (t, 2H, J=6.0 Hz), 3.11 (t, 2H, J=6.0 Hz), 7.89–8.20 (m, 6H), 8.31 (d, 1H, J=7.6 Hz), 9.85 (d, 1H, J=8.0 Hz); ^{13}C NMR (100 MHz): δ 22.32, 24.45, 39.21, 116.93, 118.08, 119.88, 120.66, 123.06, 123.63, 124.81, 125.26, 125.86, 126.32, 126.39, 126.47, 126.69, 128.46, 131.38, 131.63, 149.38, 169.70, 194.38; LCMS (m/z): 311 $(M+H)^+$. Analysis calcd for $C_{22}H_{14}O_2$: C, 85.14; H, 4.55. Found: C, 85.25; H, 4.49.

*4.2.34. 20,20-Dimethyl-2-oxahexacyclo[15.4.0.0.^{3,16}1.^{4,8}2.$^{4(8),11}$ 2.$^{4(8),15}$]tricosane-1(17),3(16),4(22),5,7,9,11,13,15(23)-nonaen-18-one (****25****).* The Baylis–Hillman alcohol (**15**) was used as such [along with the minor side product (30%)] and the yield of fused furan **25** is calculated on the basis of actual amount of alcohol present. Yield: 43%; R_f (20% EtOAc in hexanes) 0.67; reaction time: 60 min, white solid; mp: 216–218 °C; IR (KBr): ν 1664, 1610 cm^{-1}; ^{1}H NMR (400 MHz): δ 1.25 (s, 6H), 2.61 (s, 2H), 3.02 (s, 2H), 7.96–8.22 (m, 6H), 8.44 (d, 1H, J=7.6 Hz), 9.89 (d, 1H, J=8.0 Hz); ^{13}C NMR (100 MHz): δ 28.61, 34.87, 38.34, 53.49, 117.03, 118.16, 118.84, 120.88, 123.16, 123.69, 124.90, 125.36, 126.00, 126.44, 126.51, 126.81, 128.54, 131.48, 131.76, 149.87, 168.94, 193.92; LCMS (m/z): 339 $(M+H)^+$. Analysis calcd for $C_{24}H_{18}O_2$: C, 85.18; H, 5.36. Found: C, 85.00; H, 5.41.

*4.2.35. 2-Oxahexacyclo[15.3.0.0.^{3,16}1.^{4,8}2.$^{4(8),11}$2.$^{4(8),15}$]docosane -1(17),3(16),4(21),5,7,9,11,13,15(22)-nonaen-18-one (****26****).* Yield: 20%; R_f (20% EtOAc in hexanes) 0.33; reaction time: 60 min, yellow solid; mp: 185–186 °C; IR (KBr): ν 1693, 1600 cm^{-1}; ^{1}H NMR (400 MHz): δ 3.05–3.17 (m, 4H), 7.88–8.06 (m, 4H), 8.07–8.17 (m, 2H), 8.24 (d, 1H, J=7.6 Hz), 8.84 (d, 1H, J=7.6 Hz); ^{13}C NMR (100 MHz): δ 22.94, 41.68, 116.67, 117.14, 121.07, 122.48, 123.59, 125.08, 125.19, 125.21, 125.68, 126.02, 126.62, 127.15, 128.11, 131.34, 131.66, 155.54, 184.40, 194.82; LCMS (m/z): 297 $(M+H)^+$. Analysis calcd for $C_{21}H_{12}O_2$: C, 85.12; H, 4.08. Found: C, 85.02; H, 4.15.

*4.2.36. Representative procedure: synthesis of {2-oxaheptacyclo-[20.4.0.0.^{3,21}0.^{4,13}0.^{8,13}0.^{12,13} 0.^{14,19}]hexacosane-1(22),4,6,8(13),9,11,14(19)-heptaen-18,23-dione}-20-spiro-1′-acenaphthylen-2′-one (****27****) (Racemic compound with cis-cis-cis configuration)*[17]*.* To a stirred solution of 2-hydroxy-2-(cyclohex-2-enon-2-yl)-2*H*-acenaphthylen-1-one (**8**) (1 mmol, 0.278 g) in dichloroethane (2 mL) methanesulfonic acid (3 mmol, 0.288 g, 0.194 mL) was added at room temperature (25–28 °C) and the reaction mixture was heated under reflux for 1 h. The reaction mixture was allowed to

cool to room temperature and diluted with water (3 mL) and extracted with CH_2Cl_2 (3×5 mL). Combined organic layer was dried over anhydrous Na_2SO_4. Solvent was evaporated and the residue, thus obtained, was subjected to column chromatography (silica gel, 45% ethyl acetate in hexanes) to provide the desired product (**27**) as white solid in 65% (0.169 g) isolated yield. R_f (50% EtOAc in hexanes) 0.47; mp: 280 °C (dec); IR (KBr): ν 1726, 1684, 1653, 1614 cm^{-1}; ^1H NMR (400 MHz): δ 1.72–2.05 (m, 4H), 2.10–2.46 (m, 5H), 2.52–2.70 (m, 1H), 2.91–3.24 (m, 2H), 7.06 (d, 1H, J=6.8 Hz), 7.27 (d, 1H, J=6.4 Hz), 7.37–7.44 (m, 1H), 7.46–7.55 (m, 1H), 7.56–7.65 (m, 1H), 7.67 (d, 1H, J=8.0 Hz), 7.71 (d, 1H, J=6.8 Hz), 7.74–7.81 (m, 1H), 7.82–7.91 (m, 2H), 7.94 (d, 1H, J=7.2 Hz), 8.13 (d, 1H, J=8.0 Hz); ^{13}C NMR (100 MHz): δ 21.29, 22.85, 22.95, 24.61, 36.42, 37.90, 69.95, 74.69, 113.50, 116.77, 120.18, 120.58, 121.97, 123.86, 125.00, 127.14, 127.56, 128.30, 128.84, 130.56, 131.55, 131.88, 133.51, 137.30, 137.88, 140.97, 141.65, 142.27, 142.84, 158.94, 174.70, 192.64, 195.72, 201.99; ^{13}C NMR (DMSO-d_6, 100 MHz): δ 20.81, 22.24, 22.60, 23.72, 35.90, 37.43, 69.36, 73.98, 112.70, 115.51, 120.99, 121.08, 121.34, 122.94, 123.53, 124.49, 126.78, 127.74, 128.10, 128.17, 128.33, 130.02, 131.23, 131.44, 133.03, 136.56, 137.51, 139.87, 141.20, 142.03, 142.28, 159.44, 175.22, 192.18, 195.82, 201.70; LCMS (m/z): 519 $(M-H)^+$. Analysis calcd for $C_{36}H_{24}O_4$: C, 83.06; H, 4.65. Found: C, 83.13; H, 4.62.

4.2.36.1. Crystal data for **27**.* Empirical formula, $C_{37}H_{26}Cl_2O_4$; formula weight, 605.48; crystal color, habit: colorless, block; crystal dimensions, 0.41×0.35×0.25 mm^3; crystal system, monoclinic; lattice type, primitive; lattice parameters, a=11.0046 (13) Å, b=24.044 (3) Å, c=11.4448 (13) Å; α=90.00, β=97.252 (2); γ=90.00; V=3004.0 (6) $Å^3$; space group, $P2_1(1)/n$; Z=4; D_{calcd}=1.339 g/cm^3; F_{000}=1256; λ(Mo K_α)=0.71073 Å; R ($I \geq 2\sigma_1$)= 0.0911, wR^2=0.2574. Detailed X-ray crystallographic data is available from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK (for compound **27** CCDC # 754,881). *Crystal contains one disordered CH_2Cl_2 molecule.

*4.2.37. {16,16,25,25-Tetramethyl-2-oxaheptacyclo[20.4.0.0.^{3,21}0.^{4,13}0.^{8,13}0.^{12,13}0.^{14,19}]hexacosane-1(22),4,6,8(13),9,11,14(19)-heptaen-18,23-dione}-20-spiro-1′-acenaphthylen-2′-one (**28**) (racemic compound with cis-cis-cis configuration)*[17]. Yield: 58%; R_f (50% EtOAc in hexanes) 0.66; reaction time: 1 h, yellow solid; mp: 196–198 °C; IR (KBr): ν 1724, 1682, 1664, 1616 cm^{-1}; ^1H NMR (400 MHz): δ 0.67 (s, 3H), 1.10 (s, 3H), 1.11 (s, 3H), 1.21 (s, 3H), 1.66 and 1.84 (ABq, 2H, J=16.0 Hz), 2.10–2.28 (m, 3H)*, 2.47 (d, 1H, J=18.0 Hz)*, 2.91 and 2.97 (ABq, 2H, J=18.0 Hz), 7.03 (d, 1H, J=6.8 Hz), 7.20 (d, 1H, J=7.2 Hz), 7.32–7.40 (m, 1H), 7.42–7.51 (m, 1H), 7.53–7.67 (m, 2H), 7.68–7.79 (m, 2H), 7.80–7.93 (m, 3H), 8.11 (d, 1H, J=8.0 Hz) [*The doublet at δ 2.47 is part of ABq whose other two peaks merged with the multiplet at δ 2.10–2.28]; ^{13}C NMR (100 MHz): δ 27.54, 28.09, 29.37, 29.75, 33.48, 34.99, 36.92, 38.30, 50.98, 51.76, 69.70, 74.98, 113.54, 115.40, 120.03, 120.51, 121.90, 123.40, 123.87, 124.95, 127.10, 127.38, 127.51, 128.24, 128.81, 130.63, 131.52, 131.88, 133.52, 137.17, 138.03, 139.79, 141.46, 142.45, 142.82, 157.04, 173.89, 192.17, 195.65, 201.80; LCMS (m/z): 577 $(M+H)^+$. Analysis calcd for $C_{40}H_{32}O_4$: C, 83.31; H, 5.59. Found: C, 83.41; H, 5.51.

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15. Detailed X-ray crystallographic data is available from the CCDC, 12 Union Road, Cambridge CB2 1EZ, UK. CCDC numbers for compounds **4b**, **4c**, **4g**, **20**, **21**, **23**, and **27** are 753,488, 753,489, 753,490, 753,491, 754,879, 754,880, and 754,881, respectively.
16. The TiCl4-mediated B–H reaction between aromatic 1,2-diones [(9,10)-phenanthrenedione and pyrene-(4,5)-dione] and alkyl vinyl ketones at room temperature (35–37 °C) (summer time room temperature in Hyderabad) provided fused furan derivatives. Ref: Basavaiah, D.; Sreenivasulu, B.; Rao, J. S. *Tetrahedron Lett.* **2001**, *42*, 1147–1149. During the present study, we noticed that the TiCl4-mediated B–H reaction of [9,10]-phenanthrenedione with MVK at 25–28 °C (winter time room temperature in Hyderabad) for 3 h provided the fused furan derivatives (40%) along with the corresponding B–H alcohols (30%). At 35 °C we obtained the fused furan derivative in 68% isolated yield.
17. cis-cis-cis-Stereochemistry is assigned to the compounds **27** and **28** as they contain C–C bonds (C3–C4, C12–C21, C1′–C2′), connecting acenaphthene rings, on the same side. Compounds **27** and **28** are racemic [1:1 mixture of compounds with 3*R*,20(1′)*R*,21*S*, and 3*S*,20(1′)*S*,21*R* stereochemistry] and only one form is shown in the structures.
18. Single crystal of **27** contains one disordered CH_2Cl_2 molecule.
19. ^{13}C NMR spectrum of the compound **27** in $CDCl_3$ showed 34 signals in which two signals, at δ 123.86 and δ 127.14, were more intense (long peaks) indicating that each of these signals arose due to two carbons (total four carbons). Thus total number of signals (36) and total number of carbons (36) match perfectly. This has been further confirmed when we recorded ^{13}C NMR spectrum of the compound **27** in DMSO-d_6, which showed 36 signals for 36 carbons. From these studies it looks clear that one of the quaternary aliphatic carbons (probably C-3 because it is benzylic, allylic, tertiary and α to oxygen) appears at downfield region (beyond δ 113.00).
20. We thank one of the referees for suggestions in understanding the stereochemistry of these compounds.
21. Structure of this compound **28** was assigned in analogy with that of **27**.