A Formylation–Cyclisation Method of Synthesis of Cycloalkenones from Unsaturated Ketones. Part 3.[1] Simple Synthesis of some Functionalised Angularly Fused Cyclopentenone and Cyclopentanone Derivatives

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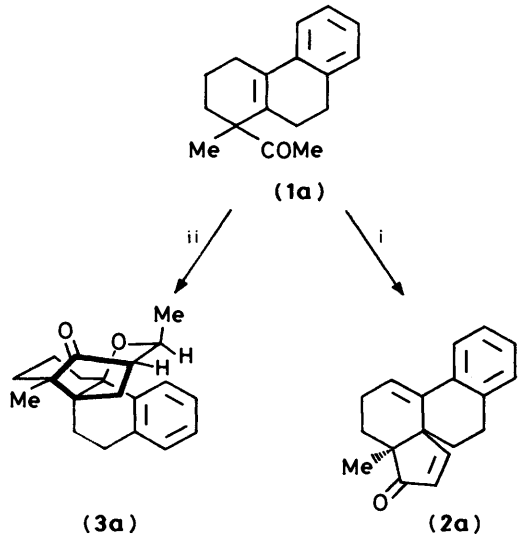
The potential generality of a two-step formylation–cyclisation reaction of a few rigid β,γ-unsaturated methyl ketones as a route to some functionalised, angularly fused cyclopentenone and cyclopentanone derivatives has been examined. Thus, perchloric acid-catalysed reaction of the β-diethoxyethyl ketones (**4a**—**c**) and (**4d**) derived from the 1-acetyl-1-methylhexahydrophenanthrenes (**1a**—**c**) and 1-acetyl-1-methyltetrahydrofluorene (**1d**) afforded the corresponding angularly fused styrenoid cyclopentenones (**2a**—**c**) and (**2d**) in good yields. Under similar conditions, the methoxytetrahydrofluorene analogue (**4e**) produced 1-methyl-7-methoxyfluorene (**11**). While repetition of the reaction of the β-diethoxyethyl ketones (**4a**) and (**4c**) with perchloric acid in the presence of triethyl orthoformate produced the respective pentacyclic pyranocyclopentanones (**3a**) and (**3c**) in excellent yields, the *p*-methoxystyrenoid ketone (**4b**) gave the cyclopentenone (**2b**). The carbonyl-conjugated double bond in the dienones (**2a**—**c**) undergoes chemoselective catalytic hydrogenation using piperidine and palladium–charcoal, affording the respective styrenoid cyclopentanones (**16a**—**c**). The methoxycyclopentanone (**16b**) has been transformed to the tetracyclic keto phenol (**17**), representing a highly degenerated estrone molecule.

Some years ago we discovered[2] a new cyclohexenone and cyclopentenone annulation method involving a few rigid γ,δ- and β,γ-unsaturated methyl ketones through reaction with triethyl and trimethyl orthoformates in the presence of perchloric acid in a one-pot operation. More recently[1] we have developed a highly efficient two-step formylation–cyclisation route to some functionalised bicyclo[3.3.1]nonane derivatives from γ,δ-unsaturated methyl ketones. It has also been reported[2] that the behaviour of the rigid β,γ-unsaturated methyl ketone (**1a**) towards acid-catalysed formylation is even more complex. Thus, interaction of (**1a**) with trimethyl orthoformate in the presence of perchloric acid gives the angularly fused cyclopentenone derivative (**2a**), whereas the acid-catalysed reaction with triethyl orthoformate produces the highly complex pyranocyclopentanone derivative (**3a**) (Scheme 1).

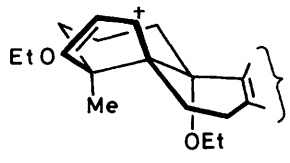


Scheme 1. *Reagents:* i, $CH(OMe)_3$, $HClO_4$; ii, $CH(OEt)_3$, $HClO_4$

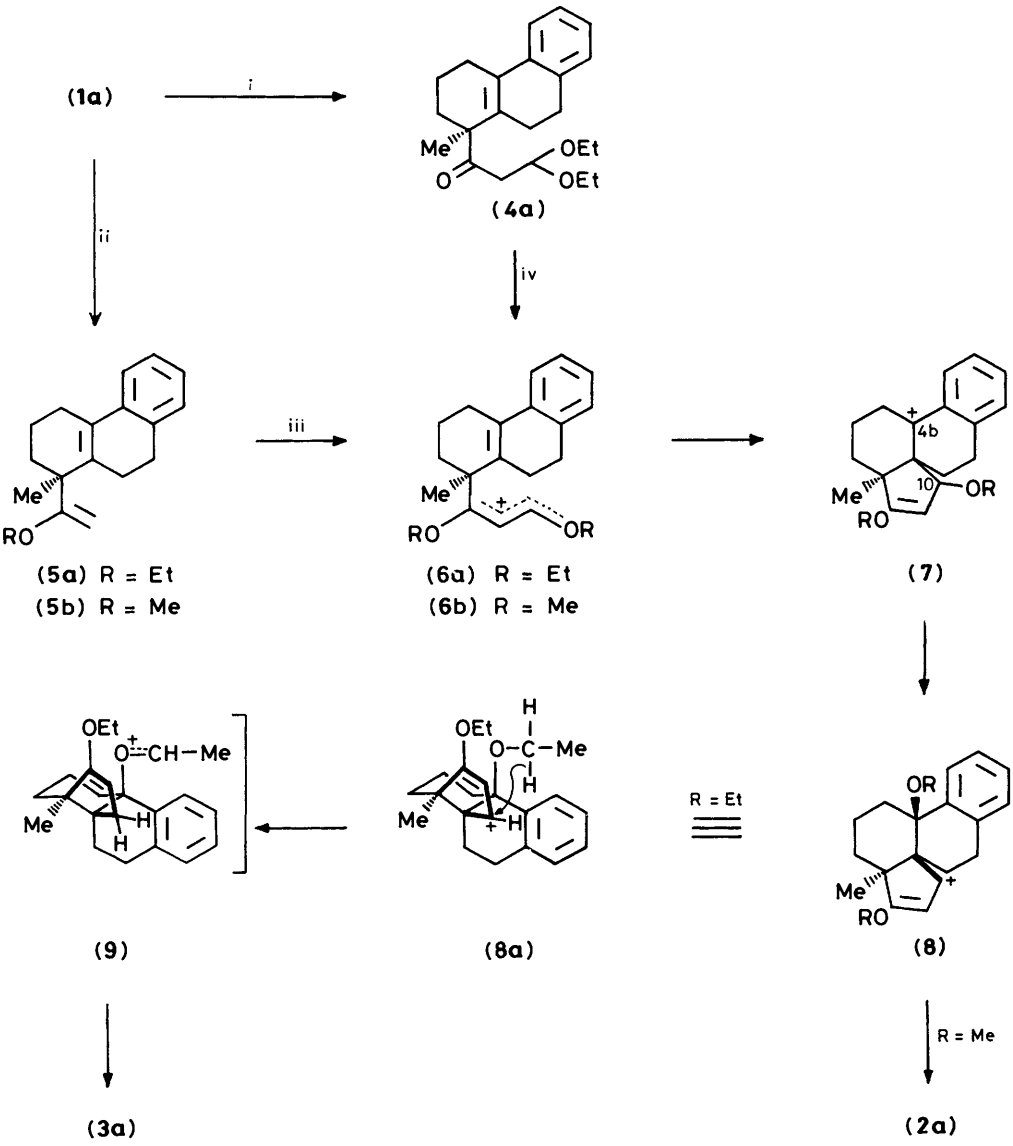
In close analogy to the bicyclo[3.3.1]nonane annulation reactions,[1] the mechanism for the formylation–cyclisation reaction of (**1a**) has been presumed[2] (Scheme 2) to involve formation of the respective 1,3-dialkoxyallyl cation[3] (**6a**) and (**6b**) through the corresponding enol ether (**5a**) and (**5b**). This undergoes electrophilic cyclisation to give the benzylic cation (**7**) which on intramolecular alkoxy-group migration† produces the key intermediate cation (**8**). In the case where triethyl orthoformate is used, a 1,5-hydride transfer from one of the ethoxy α-protons to the C-10 of the allylic cation (**8**) generates the intermediate species (**9**) which then interacts with the proximate enol ether, resulting in a new carbon–carbon bond formation leading to the pentacyclic keto ether (**3a**). In the case of methyl orthoformate, the respective cation leads to the dienone (**2a**), arising from the loss of methanol as expected, due to the relatively lower hydride-donor ability of the OCH_3 moiety (Scheme 2).

Since this annulation reaction appeared quite attractive and interesting, a study of its versatility and limitations was undertaken. The results of this investigation leading to the development of an efficient two-step formylation–cyclisation

† Whereas the alkoxylation of the benzyl cation (**7**) could occur, in principle, also by interaction with the orthoformic ester or the alcohol liberated in the reaction sequence, such reaction can be expected to be slow and to lead preponderantly to benzyl ether intermediates (**8ai**), epimeric with intermediates (**8a**), at the benzyl carbon site and thus to substances unable to engage in the subsequent intramolecular hydride-transfer process [(**8a**) ⟶ (**9**)]. This was also supported by recovery of the cyclopentenone (**2a**) on treatment with triethyl orthoformate in the presence of perchloric acid under the reaction conditions.



(**8ai**)



Scheme 2. *Reagents:* i, $(EtO)_2CH^+$, BF_4^-, $EtNPr^i_2$; ii, $HC(OR)_3$, H^+; iii, $(EtO)_2CH^+$; iv, $HC(OEt)_3$, H^+

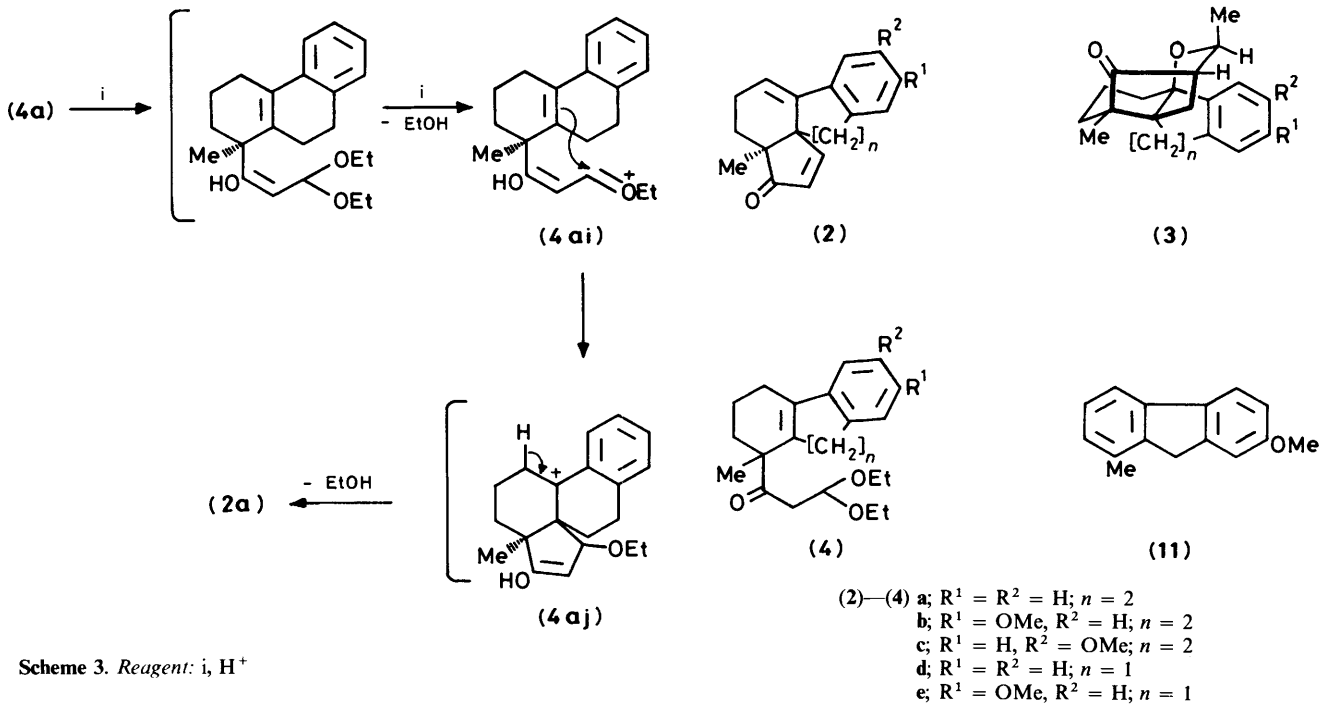
route to a few angularly fused cyclopentenones are described here. The present work also provides direct evidence in support of the proposed mechanism (Scheme 2).

Results and Discussions

In order to probe the intermediacy of the 1,3-dialkoxyallyl cation (**6a**/**6b**) in the acid-catalysed orthoformate-induced annulation, detailed study was first undertaken with the methyl ketone (**1a**). The reaction of (**1a**) with diethoxycarbonium fluoroborate according to Mock and Tsou[4] afforded the β-diethoxyethyl ketone (**4a**) in excellent yield. This relatively unstable intermediate, characterised by spectral data, on cyclisation with perchloric acid (70%) in benzene gave the angularly fused cyclopentenone (**2a**) in a much improved yield (77%) in comparison with that obtained in the one-pot reaction (41%).[2] Obviously, unlike the complex path followed in the formation of cyclopentenone (**2a**) directly from the ketone (**1a**),[2] where the excess of trimethyl orthoformate has an important role in transforming (**1a**) to the presumed intermediate (**6b**) through the enol ether (**5b**) prior to its cyclisation (Scheme 2), perchloric acid-catalysed reaction of (**4a**) involves a simple electrophilic cyclisation of (**4ai**)* followed by elimination of the β-ethoxy group from the intermediate (**4aj**) (Scheme 3). In contrast, cyclisation of the diethoxyethyl ketone (**4a**) with an excess of triethyl orthoformate in the presence of perchloric acid[3] proceeds through the initial transformation to the intermediate 1,3-dialkoxyallyl cation (**6a**), which then undergoes the sequence of reactions depicted in Scheme 2 leading to the known pentacyclic keto ether (**3a**) in 80% yield.

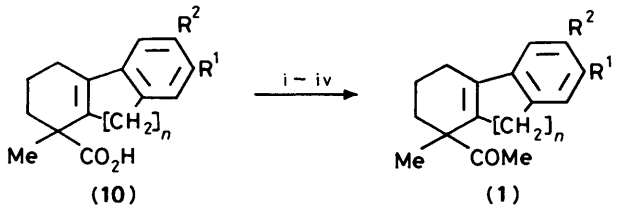
Having ascertained the optimal conditions for synthesis of the cyclopentenone (**2a**) and cylopentanone (**3a**) by the two-step process, we investigated this sequence on the rigid hexahydrophenanthrene and tetrahydrofluorene methyl ketones (**1b**,**c**) and (**1d**,**e**) respectively. The ketones (**1b**), (**1c**), and (**1e**) were readily obtained in good yields by condensation of the acid chlorides, prepared from the acids (**10b**), (**10c**), and (**10e**), with diethyl ethoxymagnesiomalonate[5] followed by hydrolytic decarboxyl-

* We thank one of the referees for the suggestion of the involvement of the enol intermediate (**4ai**)



Scheme 3. *Reagent:* i, H^+

(2)—(4) **a**; $R^1 = R^2 = H$; $n = 2$
b; $R^1 = OMe$, $R^2 = H$; $n = 2$
c; $R^1 = H$, $R^2 = OMe$; $n = 2$
d; $R^1 = R^2 = H$; $n = 1$
e; $R^1 = OMe$, $R^2 = H$; $n = 1$



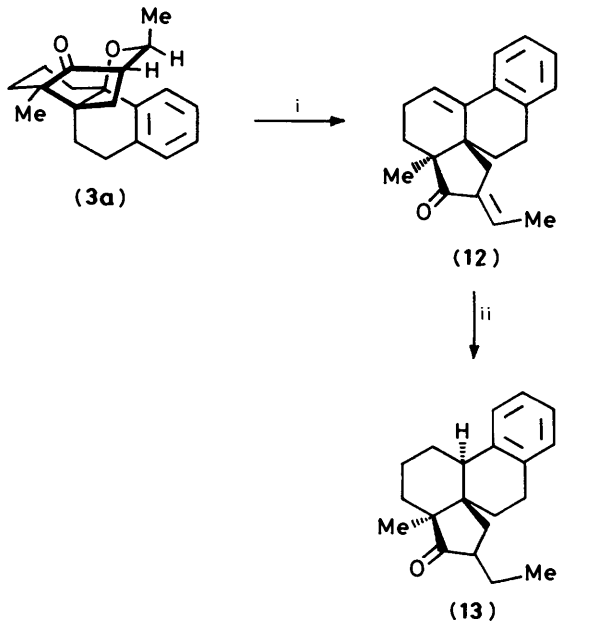
a; $R^1 = R^2 = H$; $n = 2$
b; $R^1 = OMe$, $R^2 = H$; $n = 2$
c; $R^1 = H$, $R^2 = OMe$; $n = 2$
d; $R^1 = R^2 = H$; $n = 1$
e; $R^1 = OMe$, $R^2 = H$; $n = 1$

Scheme 4. *Reagents:* i, NaOMe–MeOH; ii, $(COCl)_2$, pyridine, C_6H_6; iii, $EtOMgCH(CO_2Et)_2$, Et_2O; iv, HOAC–H_2O–H_2SO_4 (8:5:1)

ation with acetic acid and dilute sulphuric acid (Scheme 4), and the ketone (**1d**) was reported earlier.[2]

Initially, each of the gem-acetylmethyl substrates (**1b—e**) was converted into the respective β-diethoxyethyl ketone (**4b—e**) in the same procedure as for (**4a**), which could be characterised spectroscopically. When submitted to cyclisation with perchloric acid (70%) in benzene, compounds (**4b—d**) furnished the corresponding cyclopentanones (**2b**), (**2c**), and (**2d**) in 56, 62, and 55% yield respectively. Surprisingly, attempted cyclisation of the methoxyhydrofluorene analogue (**4e**) under similar conditions led to the aromatised product (**11**) possibly arising from cleavage of the acyl moiety. Repetition of the reaction under various other conditions also did not produce any fruitful result. Repetition of the cyclisation of the diethoxyethyl ketones (**4b**) and (**4c**) with excess of triethyl orthoformate in the presence of perchloric acid produced the cyclopentenone (**2b**) (50%) and the pentacyclic keto ether (**3c**) (69%) respectively. However, under identical conditions the fluorenes (**4d**) and (**4c**) led to an intractable mixture of products.

Although the presence of the rather uncommon ether linkage in (**3a**) was confirmed unequivocally from its spectral data[2] (^1H and ^{13}C n.m.r.), its existence was also established by its cleavage with toluene-*p*-sulphonic acid (PTSA) in refluxing benzene to give the olefinic product (**12**), which was then hydrogenated over palladium–charcoal in ethanol to give the cyclopentanone (**13**) in excellent yield (Scheme 5).

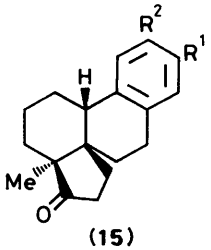


Scheme 5. *Reagents:* i, PTSA, C_6H_6; ii, H_2, Pd–C (10%), EtOH

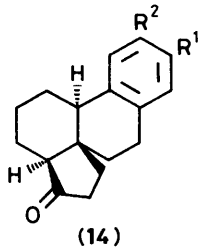
The present experiments clearly indicate that the reactions of (**4a—d**) with perchloric acid, in the absence of triethyl orthoformate, proceed through a normal electrophilic cyclisation followed by elimination of ethanol from the respective β-ethoxy ketone intermediates. On the other hand, when the reaction is carried out in the presence of triethyl orthoformate, a 1,3-diethoxyallyl cation (**6a**) (as depicted in Scheme 2) is generated which then undergoes electrophilic cyclisation. The 1,3-migration of the OC_2H_5 group from C-10 to C-4b in intermediate (**7**) (Scheme 2) is possibly facilitated by the

geometry and the stability of the cation (**8**) over that of (**7**). However, the presence of a *p*-methoxy group in the aromatic substrate [for example as in (**4b**)] decreases the electrophilicity (or increases stability) of the benzylic cation relative to (**7**) and would thus possibily block the transfer of the alkoxy group from C-10 to C-4b. So, in contrast to the demethoxy and the 3-methoxy derivatives (**4a**) and (**4c**), the *p*-methoxy styrenoid substrate (**4b**) failed to give the corresponding pentacyclic keto ether due to inability of the corresponding benzylic cation (**7**) (Scheme 2) to facilitate the alkoxy migration, thereby resulting in only the dienone (**2b**). The abnormal behaviour of the hydrofluorene analogues (**4d**) and (**4e**) might be due to the strain involved in the intramolecular process of ethoxy transfer (*cf.* Scheme 2) in the relatively flattened hydrofluorene system in comparison with that of the geometrically favourable strain-free hydrophenanthrene systems.

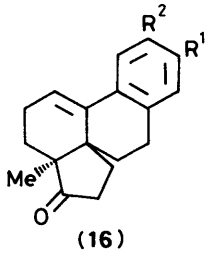
As reported earlier,[2] hydrogenation of the styrenoid cyclopentenone (**2a**) in ethanol in the presence of palladium–charcoal (10%) gave a single saturated cyclopentanone isomer (**14a**). Surprisingly, hydrogenation of the methoxy dienone (**2b**) under identical conditions produced a mixture of four compounds (g.l.c.) containing diastereoisomeric ketones (**14b**) and (**15b**) as well as the enone (**16b**) and possibly another



(**15**)



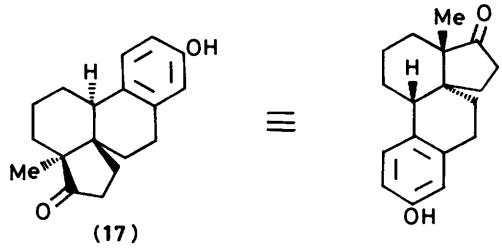
(**14**)



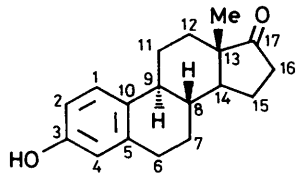
(**16**)

a; $R^1 = R^2 = H$
b; $R^1 = OMe$, $R^2 = H$
c; $R^1 = H$, $R^2 = OMe$

incomplete reduction product. So, in order to have better control over the structure and stereochemistry of the hydrogenation product, the dienone (**2a**) was selectively hydrogenated over palladium–charcoal (10%) in piperidine at atmospheric pressure and temperature to give the styrenoid ketone (**16a**) in 98% yield. Each of the solvents *N*-methylpiperidine, pyridine, γ-picoline, collidine, or pyrrolidine is equally effective. However, hydrogenation in pyridine required a much longer time, as well as giving by-products from concomitant reduction of the solvent. Similarly, chemoselective hydrogenation of the dienones (**2b**) and (**2c**) in piperidine using palladium–charcoal afforded the corresponding styrenoid ketones (**16b**) and (**16c**) in 94 and 90% yield respectively. Catalytic hydrogenation of the enone (**16a**) in the presence of palladium–charcoal (10%) in ethanol gave the known saturated ketone (**14a**)[2] with high stereoselectivity, with the incoming hydrogen at C-4b *anti* to the angularly fused cyclopentanone ring. Under the same conditions reduction of 2-methoxy enone (**16b**) on the other hand produced a mixture of 4bα- and 4bβ-epimer (**14b**) and (**15b**) in the ratio *ca.* 2.5:1 (as determined from g.l.c.) in 97% yield, which was separated by careful fractional crystallisation. While the major epimer (**14b**) exhibits its C-7a methyl singlet at δ_H 1.07 [comparable with that for (**14a**) at δ_H 1.04], the minor epimer (**15b**) shows its at δ_H 0.93. The observed upfield shift of the methyl singlet for (**15b**) can be rationalised as resulting from the ring-current shielding effect.[6] Finally, the demethylation of the major epimer (**14b**) with boron tribromide[7] in methylene dichloride gave the keto phenol (**17**) in 80% yield. This keto phenol represents an interesting 'degenerated' estrone[8] molecule in which fusion at the ring A/B in estrone (**18**) has been shifted from C-10–C-9 and C-7–C-8 to C-10–C-8 and C-7–C-14 respectively.



(**17**)



(**18**)

Certainly the most important aspect of the present work is the improvement of the yield and the extension of the scope of the cyclopentenone annulation by the two-step formylation–cyclisation reaction, reported earlier.[2] Although there exist a large number of methods for cyclopentanone annulation,[9] the simplicity of this new angular cyclopentenone annulation deserves special attention. The chemoselective reduction of the carbonyl-conjugated double bond in the styrenoid cyclopentenones may find further application. In addition to these synthetic aspects, the present investigation provides a better understanding of the mechanism of the complex formylation–cyclisation reactions,[2] particularly the influence of the substituents and the steric factors in the substrates on the nature of the products.

Experimental

The compounds described are all racemates. M.p.s were measured in open capillary tubes and are uncorrected. U.v. spectra were recorded on a Beckman DU spectrophotometer for solutions in 95% ethanol. I.r. spectra of solids (KBr) and liquids (film) were recorded on a Perkin-Elmer model PE 298 instrument. ^1H N.m.r. spectra were recorded at 60 MHz or 200 MHz on Varian Associates T-60A or XL-200 spectrometers respectively for solutions in CCl_4 or $CDCl_3$ with $SiMe_4$ as internal standard. Analytical g.l.c. was performed on a Hewlett Packard model 5730A chromatograph equipped with a flame-ionization detector and employing a UCW-982 column (20 ft × $\frac{1}{8}$ in) using N_2 as carrier gas. Column chromatography was performed on neutral alumina (Brockmann Grade 1, of BDH, India). Light petroleum I and light petroleum II refer to the fractions boiling between 60—80 and 40—60 °C, respectively. Elemental analyses were performed by Mr. P. P. Bhattacharya of this laboratory.

Preparation of Methyl Ketones (**1b**), (**1c**), *and* (**1e**).—*Acetyl-1,2,3,4,9,10-hexahydro-7-methoxy-1-methylphenanthrene* (**1b**). A related procedure was adopted.[1] A solution of diethyl ethoxymagnesiomalonate,[5] prepared from magnesium (1.0 g, 0.04 mol), diethyl malonate (6 ml), and ethanol (4.2 ml), in the presence of a catalytic amount of CCl_4, in ether (50 ml) was added slowly to a stirred solution of the acid chloride made from acid (**10b**) (1.18 g, 4.1 mmol) by treatment with oxalyl chloride (1.4 ml, 16.25 mmol) in the usual way, in ether (50 ml) cooled in a salt–ice bath. The mixture was stirred for 2 h at 0 °C and then for 12 h at room temperature, then added to ice-cold 1M-H_2SO_4 (200 ml); the ether layer was separated, and the aqueous layer was extracted with ether (2 × 50 ml). The combined extracts were washed successively with water, 5% aqueous sodium carbonate, and water, and dried (Na_2SO_4). After evaporation of ether, the crude mixture was refluxed with a mixture of acetic acid (24 ml), conc. sulphuric acid (3 ml), and water (15 ml) for 7 h under nitrogen. The reaction mixture was then diluted to 400 ml with water and extracted with ether (4 × 50 ml). The extract was washed successively with water, 5% aqueous sodium carbonate, and water, and dried (Na_2SO_4). Evaporation of ether left a viscous liquid that on filtration through a short column of neutral alumina (10 g) (light petroleum I) afforded the *ketone* (**1b**) as an oil (2.05 g, 90%), b.p. 190—195 °C/0.1 mmHg (Found: C, 80.05; H, 8.1. $C_{18}H_{22}O_2$ requires C, 79.98; H, 8.20%); $\lambda_{max.}$ 274 nm (log ε 4.1); $\nu_{max.}$ 2 925, 1 690, 1 600, and 1 580 cm^{-1}; δ($CDCl_3$) 1.33 (3 H, s, Me), 1.3—2.8 (10 H, m), 2.03 (3 H, s, COMe), 3.70 (3 H, s, ArOMe), 6.40—6.60 (2 H, m, ArH), and 6.68—7.1 (1 H, m, ArH).

1-*Acetyl-1,2,3,4,9,10-hexahydro-6-methoxy-1-methylphenanthrene* (**1c**). This was obtained in 86% yield from the acid (**10c**), in the same way as above, as an *oil*, b.p. 195—200 °C/0.1 mmHg (Found: C, 80.1; H, 8.2%); $\lambda_{max.}$ 274 nm (log ε 4.22); $\nu_{max.}$ 2 920, 1 700, 1 600, and 1 575 cm^{-1}; δ(CCl_4) 1.23 (3 H, s, Me), 1.65—2.74 (10 H, m), 2.03 (3 H, s, COMe), 3.70 (3 H, s, ArO*Me*), and 6.41—6.94 (3 H, m, ArH).

1-*Acetyl-1,2,3,4-tetrahydro-7-methoxy-1-methylfluorene-* (**1e**). This ketone was obtained in 92% yield, from the acid (**10e**), as an *oil*, b.p. 190—192 °C/0.1 mmHg (Found: C, 80.0; H, 8.2. $C_{17}H_{20}O_2$ requires C, 79.65; H, 7.86%); $\lambda_{max.}$ 274 nm (log ε 4.22); $\nu_{max.}$ 2 925, 1 700, 1 600, and 1 575 cm^{-1}; δ($CDCl_3$) 1.3 (3 H, s, Me), 1.33—2.63 (6 H, m), 2.07 (3 H, s, COMe), 3.17 (2 H, br s, ArCH_2), 3.73 (3 H, s, ArO*Me*), and 6.57—7.13 (3 H, m, ArH).

Preparation of β-*Diethoxyethyl Ketones* (**4a—e**).—1-(3,3-*Diethoxy-1-propyl*)-*1,2,3,4,9,10-hexahydro-1-methylphenanthrene* (**4a**). A related procedure was adopted.[3] A solution of freshly distilled boron trifluoride–diethyl ether (0.92 ml, 7.5 mmol) in methylene dichloride (5 ml) was added dropwise to stirred, freshly distilled triethyl orthoformate (1.05 ml, 6 mmol) at −30 °C under nitrogen. The reaction mixture was then allowed to warm to 0 °C, and the mixture was stirred at this temperature for 15 min. The resulting mixture was then cooled to −78 °C, and a solution of the ketone (**1a**) (720 mg, 3 mmol) in methylene dichloride (5 ml) was added, followed by dropwise addition of *N,N*-di-isopropylethylamine (2.4 ml, 9 mmol) during 10 min. The temperature of the resulting mixture was then allowed to rise up to between −10 and −20 °C, and the mixture was stirred within that temperature range for 2 h, then poured rapidly into saturated aqueous sodium hydrogen carbonate (50 ml). More methylene dichloride was added and the mixture was stirred vigorously for 20 min. The organic phase was separated and washed successively with cold dilute sulphuric acid (2% v/v) followed by water. The organic solution was dried and evaporated to leave compound (**4a**) as a red liquid (950 mg, 92%), $\nu_{max.}$ 1 700 and 1 600 cm^{-1}; δ($CDCl_3$) 0.93—1.33 (6 H, m, OCH$_2$*Me*), 1.26 (3 H, s, Me), 1.36—2.80 (12 H, m), 3.20—3.67 (4 H, m, OCH_2Me), 4.80 [1 H, t, *J* 5 Hz, COCH$_2$C*H*(OEt)$_2$], and 7.0—7.43 (4 H, m, ArH).

(3,3-*Diethoxy-1-oxopropyl*)-*1,2,3,4,9,10-hexahydro-7-methoxy-1-methylphenanthrene* (**4b**). This was obtained as a red liquid in 80% yield from the methyl ketone (**1b**) by the same procedure as above, $\nu_{max.}$ 1 700 and 1 605 cm^{-1}; δ($CDCl_3$) 0.96—1.36 (6 H, m, OCH$_2$*Me*), 1.25 (3 H, s, Me), 1.4—2.8 (12 H, m), 3.23—3.66 (4 H, m, OCH_2Me), 3.70 (3 H, s, ArO*Me*), 4.83 [1 H, t, *J* 5 Hz, COCH$_2$C*H*(OEt)$_2$], 6.40—6.66 (2 H, m, ArH), and 6.90—7.13 (1 H, m, ArH).

1-(3,3-*Diethoxy-1-oxopropyl*)-*1,2,3,4,9,10-hexahydro-6-methoxy-1-methylphenanthrene* (**4c**). This was obtained as a red viscous liquid in 90% yield from the methyl ketone (**1c**), $\nu_{max.}$ 1 700 and 1 605 cm^{-1}; δ($CDCl_3$) 1.00—1.40 (6 H, m, OCH$_2$*Me*), 1.33 (3 H, s, Me), 1.53—2.90 (12 H, m), 3.33—3.70 (4 H, m, OCH_2Me), 3.8 (3 H, s, ArO*Me*), 4.93 [1 H, t, *J* 5 Hz, COCH$_2$C*H*(OEt)$_2$], and 6.46—7.06 (3 H, m, ArH).

1-(3,3-*Diethoxy-1-oxopropyl*)-*1,2,3,4-tetrahydro-1-methylfluorene* (**4d**). This intermediate was obtained as a red liquid in 81% yield starting from the ketone (**1d**), $\nu_{max.}$ 1 700 and 1 600 cm^{-1}; δ($CDCl_3$) 1.20 (6 H, m, OCH$_2$*Me*), 1.37 (3 H, s, Me), 1.57—2.63 (6 H, m), 2.77 [2 H, d, *J* 5 Hz, COCH_2CH(OEt)$_2$], 3.27 (2 H, br s, ArCH_2), 3.37—3.83 (4 H, m, OCH_2Me), 4.97 [1 H, t, *J* 5 Hz, COCH$_2$C*H*(OEt)$_2$], and 7.06—7.45 (4 H, m, ArH).

1-(3,3-*Diethoxy-1-oxopropyl*)-*1,2,3,4-tetrahydro-7-methoxy-1-methylfluorene* (**4e**). This was obtained as a red liquid in 93% yield from the methyl ketone (**1e**), $\nu_{max.}$ 1 695 and 1 605 cm^{-1}; δ($CDCl_3$) 1.17 (6 H, m, OCH$_2$*Me*), 1.33 (3 H, s, Me), 1.50—2.60 (6 H, m), 2.75 [2 H, d, *J* 5 Hz, COCH_2CH(OEt)$_2$], 3.23 (2 H, br s, ArCH_2), 3.37—3.90 (4 H, m, OCH_2Me), 3.80 (3 H, s, ArO*Me*), 4.93 [1 H, t, *J* 5 Hz, COCH$_2$C*H*(OEt)$_2$], and 6.66—7.23 (3 H, m, ArH).

Preparation of Dienones (**2a—d**).—(7aRS,10aSR)-*7,7a,11,12-Hexahydro-7a-methylcyclopenta*[j]*phenanthren-8*(6H)-*one* (**2a**) *by reaction of* β-*diethoxyethyl ketone* (**4a**) *with perchloric acid.* To a stirred solution of the intermediate ketone (**4a**) (500 mg, 1.46 mmol) in benzene (5 ml) at 5 °C under N_2 was added perchloric acid (70%; 0.3 ml). The reaction mixture was stirred at 0 °C for 2 h, then for 1 h at room temperature, and then was poured into 5% aqueous sodium carbonate (50 ml) and extracted with ether (4 × 25 ml). The extracts were washed with brine and dried (Na_2SO_4). Evaporation of the solvent left a gummy mass, which on chromatography through a column of neutral alumina (10 g) and elution with light petroleum I afforded compound (**2a**), m.p. 96 °C (220 mg, 77%), identical (mixed m.p. and i.r.) with a sample prepared earlier.[2]

(7aRS,10aSR)-*7,7a,11,12-Tetrahydro-2-methoxy-7a-methylcyclopenta*[j]*phenanthren-8*(6H)-*one* (**2b**). (A) Reaction of the intermediate ketone (**4b**) (500 mg, 1.34 mmol) with perchloric acid (70%; 0.2 ml) in the same way as above followed by chromatography over alumina [benzene–light petroleum I (1:9)] gave *compound* (**2b**) (210 mg, 56%), m.p. 106 °C (from light petroleum II) (Found: C, 81.7; H, 7.3. $C_{19}H_{20}O_2$ requires C, 81.39; H, 7.19%); $\lambda_{max.}$ 258 nm (log ε 4.36); $\nu_{max.}$ 2 960, 2 920, 2 820, 1 705, 1 605, 1 585, 1 565, 1 490, 1 460, and 1 425 cm^{-1}; δ($CDCl_3$) 1.10 (3 H, s, Me), 1.40—2.36 (6 H, m), 2.70—3.03 (2 H, m), 3.75 (3 H, s, ArO*Me*), 5.96 (1 H, d, *J* 6 Hz, α-keto CH), 6.00 (1 H, t, *J* 4 Hz, ArC=C*H*), 6.47—6.76 (2 H, m, ArH), 7.1—7.33 (1 H, m, ArH), and 7.43 (1 H, d, *J* 6 Hz, β-keto CH).

(B) Reaction of the ketone (**4b**) (250 mg, 0.67 mmol) in benzene (5 ml) with triethyl orthoformate (7 ml) in the presence of perchloric acid (70%; 0.1 ml) under the same conditions as above, followed by chromatography, afforded compound (**2b**), m.p. 106 °C (95 mg, 50%), identical (mixed m.p. and i.r.) with the sample prepared above.

(7aRS,10aSR)-*7,7a,11,12-Tetrahydro-3-methoxy-7a-methyl*

cyclopenta[j]*phenanthren*-8(6H)-*one* (**2c**). This was obtained, in 62% yield from the ketone (**4c**) under identical conditions to procedure A as above, followed by chromatography [benzene–light petroleum I (3:1)], as a solid, m.p. 131—132 °C (from light petroleum I) (Found: C, 81.4; H, 7.1%); $\lambda_{max.}$ 252 (log ε 4.27) and 302 nm (log ε 3.71); $\nu_{max.}$ 2 940, 1 690, 1 601, 1 495, 1 250, and 1 038 cm^{-1}; δ($CDCl_3$) 1.10 (3 H, s, Me), 1.40—2.33 (6 H, m), 2.66—3.0 (2 H, m), 3.76 (3 H, s, ArO*Me*), 6.0 (1 H, d, *J* 6 Hz, α-keto-CH), 6.20 (1 H, t, *J* 4 Hz, ArC=C*H*), 6.60—7.16 (3 H, m, ArH), and 7.50 (1 H, d, *J* 6 Hz, β-keto-CH).

(3aRS, 11aSR)-3a,4,5,11-*Tetrahydro*-3a-*methylcyclopenta*[j]-*fluoren*-3-*one* (**2d**). This was obtained, in 55% yield from the intermediate ketone (**4d**) in the same way as above, followed by chromatography (light petroleum I), as a solid, m.p. 105 °C, identical (mixed m.p. and i.r.) with a sample of (**2d**) reported earlier.[2]

7-*Methoxy*-1-*methylfluorene* (**11**).—Reaction of the intermediate ketone (**4e**) (200 mg, 0.56 mmol) in benzene (5 ml) with perchloric acid (70%; 0.1 ml) under identical conditions as above, followed by chromatography [benzene–light petroleum I (1:9)], afforded the fluorene (**11**) (65 mg, 54%), m.p. 112—114 °C (Found: C, 85.7; H, 6.7. $C_{15}H_{14}O$ requires C, 85.71; H, 6.66%); $\lambda_{max.}$ 209.2 (log ε 5.02) and 273.8 nm (log ε 4.77); δ($CDCl_3$; 200 MHz) 2.40 (3 H, s, ArO*Me*), 3.76 (2 H, s, ArCH_2), 3.88 (3 H, s, ArO*Me*), 6.96 (1 H, d, *J* 8 Hz, ArH), 7.04—7.10 (2 H, m, ArH), 7.30 (1 H, t, *J* 8 Hz, ArH), 7.56 (1 H, d, *J* 8 Hz, ArH), and 7.70 (1 H, d, *J* 8 Hz, ArH).

Preparation of Pentacyclic Keto Ethers (**3a**) *and* (**3c**).—*Compound* (**3a**) *by the reaction of* β-*diethoxyethyl ketone* (**4a**) *with triethyl orthoformate and perchloric acid.* To a stirred solution of the ketone (**4a**) (300 mg, 0.87 mmol) in benzene (5 ml) and freshly distilled triethyl orthoformate (7 ml) at 0—5 °C was added perchloric acid (70%; 0.3 ml) under nitrogen. After being stirred at 0 °C for 2 h, then for 2 h at room temperature, the reaction mixture was worked up in the usual way. Chromatography of the gummy residue over neutral alumina (8 g) and elution with light petroleum I afforded compound (**3a**), m.p. 164—165 °C (210 mg, 80%), identical (mixed m.p. and i.r.) with a sample of (**3a**) reported earlier.[2]

The keto ether (**3c**) was obtained in 69% yield, from the intermediate ketone (**4c**) under identical conditions as above, as a *solid*, m.p. 154 °C (Found: C, 77.4; H, 8.1. $C_{21}H_{26}O_3$ requires C, 77.27; H, 8.03%); $\nu_{max.}$ 2 940, 1 735, 1 610, 1 500, 1 440, and 1 270 cm^{-1}; δ(CCl_4) 0.88 (3 H, s, Me), 1.25 (3 H, d, *J* 6 Hz, OCH*Me*), 1.46—2.40 (11 H, m), 2.70—2.96 (2 H, m), 3.70 (1 H, m, *J* 6 Hz, OC*H*Me), 3.75 (3 H, s, ArO*Me*), and 6.50—6.97 (3 H, m, ArH).

(7aRS,10aSR)-9-*Ethylidene*-7,7a,9,10,11,12-*hexahydro*-7a-*methylcyclopenta*[j]*phenanthren*-8(6H)-*one* (**12**).—A solution of the keto ether (**3a**) (400 mg, 1.35 mmol) in dry benzene (50 ml) was refluxed in the presence of PTSA (400 mg) for 6 h under nitrogen. The reaction mixture was then cooled, washed with water, dried (Na_2SO_4), evaporated, and purified by filtration through a short column of alumina (5 g) (light petroleum I) to leave compound (**12**) as an *oil* (355 mg, 94.5%) (Found: C, 86.2; H, 7.9. $C_{20}H_{22}O$ requires C, 86.28; H, 7.97%); $\lambda_{max.}$ 246 nm (log ε 4.2); $\nu_{max.}$ 2 930, 2 845, 1 718, 1 650, 1 485, and 1 375 cm^{-1}; δ(CCl_4) 1.00 (3 H, s, Me), 1.67 (3 H, d, *J* 7 Hz, olefinic Me), 1.20—3.10 (10 H, m), 6.10 (1 H, t, *J* 4 Hz, ArC=C*H*), 6.60 (1 H, q, with fine allylic coupling, *J* 7 Hz, β-keto-CH), and 7.0—7.46 (4 H, m, ArH).

(4bRS,7aRS,10aSR)-9-*Ethyl*-5,6,7,7a,9,10,11,12-*octahydro*-7a-*methylcyclopenta*[j]*phenanthren*-8(4bH)-*one* (**13**).—The ketone (**12**) (100 mg, 0.36 mmol), dissolved in ethanol (10 ml), was hydrogenated over palladium–charcoal (10%; 40 mg) at room temperature and atmospheric pressure for 2 h. The catalyst was then filtered off, and the filtrate was evaporated to leave the *title compound* (**13**) as an oil (98 mg, 99%) (Found: C, 85.2; H, 9.2. $C_{20}H_{26}O$ requires C, 85.05; H, 9.28%); $\nu_{max.}$ 2 932, 2 865, 1 730, 1 490, 1 450, and 1 378 cm^{-1}; δ(CCl_4) 0.97 (3 H, t, *J* 3 Hz, Me), 1.0 (3 H, s, tertiary Me), 1.25—2.98 (16 H, m), and 6.93—7.21 (4 H, m, ArH).

Chemoselective Reduction of Dienones (**2a**—**c**).—(7aRS,10aSR)-7,7a,9,10,11,12-*Hexahydro*-7a-*methylcyclopenta*[j]*phenanthren*-8(6H)-*one* (**16a**).—The dienone (**2a**) (100 mg, 0.4 mmol) was hydrogenated in dry piperidine (5 ml) in the presence of palladium–charcoal (10%; 25 mg) at room temperature and atmospheric pressure for 2 h. The catalyst was filtered off, and the filtrate was diluted with ice-cold 2M-HCl (25 ml) and extracted with ether (3 × 25 ml). The extract was washed with brine and dried (Na_2SO_4). Evaporation of solvent, followed by crystallisation from light petroleum II, afforded the *enone* (**16a**) (98 mg, 98%), m.p. 126 °C (Found: C, 85.6; H, 8.0. $C_{18}H_{20}O$ requires C, 85.67; H, 7.99%); $\lambda_{max.}$ 250 nm (log ε 4.14); $\nu_{max.}$ 2 970, 2 930, 2 840, 1 730, 1 635, 1 480, 1 470, 1 445, 1 430, and 1 400 cm^{-1}; δ($CDCl_3$) 1.00 (3 H, s, Me), 1.13—2.40 (10 H, m), 2.73—3.06 (2 H, m), 6.06 (1 H, t, *J* 4 Hz, ArC=C*H*), and 6.93—7.46 (4 H, m, ArH).

(7aRS,10aSR)-7,7a,9,10,11,12-*Hexahydro*-2-*methoxy*-7a-*methylcyclopenta*[j]*phenanthren*-8(6H)-*one* (**16b**). This was obtained in 94% yield, from the dienone (**2b**) under identical conditions as above, as a *solid*, m.p. 88 °C (Found: C, 80.8; H, 7.8. $C_{19}H_{22}O_2$ requires C, 80.81; H, 7.85%); $\lambda_{max.}$ 258 nm (log ε 4.42); $\nu_{max.}$ 2 970, 2 930, 2 830, 1 730, 1 640, 1 610, 1 500, 1 450, and 1 400 cm^{-1}; δ($CDCl_3$) 1.00 (3 H, s, Me), 1.13—2.40 (10 H, m), 2.70—3.06 (2 H, m), 3.76 (3 H, s, ArO*Me*), 5.96 (1 H, t, *J* 4 Hz, ArC=C*H*), 6.50—6.80 (2 H, m, ArH), and 7.16—7.50 (1 H, m, ArH).

(7aRS,10aSR)-7,7a,9,10,11,12-*Hexahydro*-3-*methoxy*-7a-*methylcyclopenta*[j]*phenanthren*-8(6H)-*one* (**16c**). This was obtained in 90% yield, from the dienone (**2c**) in the same way as above, as an *oil*, b.p. 160—175 °C/0.1 mmHg (Found: C, 81.0; H, 8.2%); $\lambda_{max.}$ 258 nm (log ε 4.43); $\nu_{max.}$ 2 975, 2 925, 2 835, 1 730, 1 635, 1 600, 1 500, 1 480, 1 450, and 1 400 cm^{-1}; δ($CDCl_3$) 1.03 (3 H, s, Me), 1.20—2.40 (10 H, m), 2.73—3.03 (2 H, m), 3.78 (3 H, s, ArO*Me*), 6.13 (1 H, t, *J* 4 Hz, ArC=C*H*), and 6.60—7.30 (3 H, m, ArH).

Catalytic Hydrogenation of the Enones (**16a** *and* **16b**).—(4bRS,7aRS,10aSR)-5,6,7,7a,9,10,11,12-*octahydro*-7a-*methylcyclopenta*[j]*phenanthren*-8(4bH)-*one* (**14a**). The enone (**16a**) (90 mg, 0.34 mmol) was hydrogenated in ethanol (5 ml) in the presence of palladium–charcoal (10%; 25 mg) at room temperature and atmospheric pressure for 1 h. The catalyst was filtered off and the filtrate, after evaporation of solvent followed by recrystallisation of the residue from light petroleum II, furnished compound (**14a**), m.p. 101—102 °C (83 mg, 90%), identical (mixed m.p. and i.r.) with a sample of (**14a**) reported earlier.[2]

(4bRS,7aRS,10aSR)- *and* (4bRS,7aSR,10aRS)-5,6,7,7a,9,10,-11,12-*Octahydro*-2-*methoxy*-7a-*methylcyclopenta*[j]-*phenanthren*-8(4bH)-*one* (**14b**) *and* (**15b**). The enone (**16b**) (150 mg, 0.53 mmol) was hydrogenated under the same conditions as above for 2 h to give a solid ketone (145 mg, 97%) which was found to contain two isomers, as indicated by g.l.c. (R_t 5.5 and 3.85 min) and ^1H n.m.r. spectoscropy in the ratio 2.5:1. Careful crystallisation from methanol afforded first the *ketone* (**14b**) (95 mg, 63%; R_t 5.5 min), m.p. 120—121 °C (Found: C, 80.35; H, 8.65. $C_{19}H_{24}O_2$ requires C, 80.24; H, 8.51%); $\nu_{max.}$ 2 930, 2 860, 1 730, 1 720, 1 610, 1 570, 1 500, 1 405, and 1 375 cm^{-1};

δ($CDCl_3$) 1.07 (3 H, s, Me), 1.16—3.10 (15 H, m), 3.73 (3 H, s, ArO*Me*), 6.47—6.76 (2 H, m, ArH), and 6.93—7.23 (1 H, m, ArH). Slow crystallisation of the mother liquor afforded *ketone* (**15b**) (35 mg, 23%; R_t 3.85 min), m.p. 112—114 °C (Found: C, 80.3; H, 8.7%); $\nu_{max.}$ 2 990, 2 920, 2 840, 1 730, 1 610, 1 575, 1 500, 1 400, and 1 370 cm^{-1}; δ($CDCl_3$) 0.93 (3 H, s, Me), 1.03—3.0 (15 H, m), 3.76 (3 H, s, ArO*Me*), and 6.50—7.27 (3 H, m, ArH).

(4bRS,7aRS,10a,SR)-5,6,7,7a,9,10,11,12-*Octahydro*-2-*hydroxy*-7a-*methylcyclopenta*[j]*phenanthren*-8(4bH)-*one* (**17**).—To a stirred solution of boron tribromide (0.1 ml) in methylene dichloride (2 ml) at 0 °C was added the methoxy ketone (**14b**) (80 mg, 0.28 ml) in methylene dichloride (7 ml), and the mixture was stirred for 12 h at room temperature. The reaction mixture was then diluted with water (20 ml) and extracted with ether (3 × 25 ml). The extract was washed with brine, dried (Na_2SO_4), and evaporated to leave the phenol (**17**) (60 mg, 80%), m.p. 224—225 °C [from ethyl acetate–light petroleum I (1:3)] (Found: C, 79.8; H, 8.5. $C_{18}H_{22}O_2$ requires C, 79.96; H, 8.20%); $\nu_{max.}$ 3 415, 2 920, 1 715, 1 620, 1 580, 1 500, and 1 370 cm^{-1};δ($CDCl_3$; 200 MHz) 1.08 (3 H, s, Me), 1.16—2.98 (15 H, m), 4.80 (1 H, s, ArO*H*), 6.60—6.74 (2 H, m, ArH), and 7.16 (1 H, d, *J* 8 Hz, ArH).

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