Synthesis and Thermal Racemization of the Predominant Arene Oxide Metabolite of Chrysene, (+)-(3*S*,4*R*)-Chrysene 3,4-Oxide

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(−)-*trans*-4-Bromo-3-hydroxy-1,2,3,4-tetrahydrochrysene has been obtained from the chromatographic separation and cleavage of the corresponding menthyloxyacetyl (MOA) diastereoisomer. The (−)-enantiomer of this bromohydrin has been assigned (3*R*,4*R*) absolute stereochemistry and used in the synthesis of (+)-(3*S*,4*R*)-chrysene 3,4-oxide. Thermal racemization studies on this arene oxide gave a barrier to racemization (E_a) of 25.15 kcal mol^{-1} and an activation entropy ($\Delta S^{\ddagger}$) of 0.7 cal mol^{-1} K^{-1}, in accord with PMO predictions.

Arene oxides are now generally recognized as the initially formed products of metabolism of mono- and poly-cyclic aromatic ring systems in plants, animals, and micro-organisms.[1] The concept of stereoselectivity in the enzymatic epoxidation of polycyclic aromatic hydrocarbons (PAHs) became more important with the chemical synthesis of an arene oxide (naphthalene 1,2-oxide) in optically active form.[2,3] Stereoselectivity has recently been confirmed by the asymmetric synthesis of arene oxides in high optical yield from hepatic mono-oxygenase-catalysed oxidation of the carcinogenic PAHs benzo[*a*]pyrene [4] and benz[*a*]anthracene.[5]

The rapid spontaneous equilibration of benzene oxide (and substituted derivatives) with the corresponding oxepin tautomers [6] has to date precluded the synthesis of optically active arene oxides in the monocyclic benzenoid series. All attempts to synthesise optically pure phenanthrene 1,2- and 3,4-oxides [7,8] have also been thwarted by their rapid spontaneous racemization. These observations prompted a PMO study [7,9] of molecular structural effects on the arene oxide–oxepin tautomerisation process. Based upon the PMO calculations, it was predicted that the previously unknown arene oxide, chrysene 3,4-oxide (3,4-epoxy-3,4-dihydrochrysene), would be isolable in optically active form but that it would racemize quite readily. The preliminary [10] and the present report deal with the synthesis and thermal racemization of (+)-chrysene 3,4-oxide.

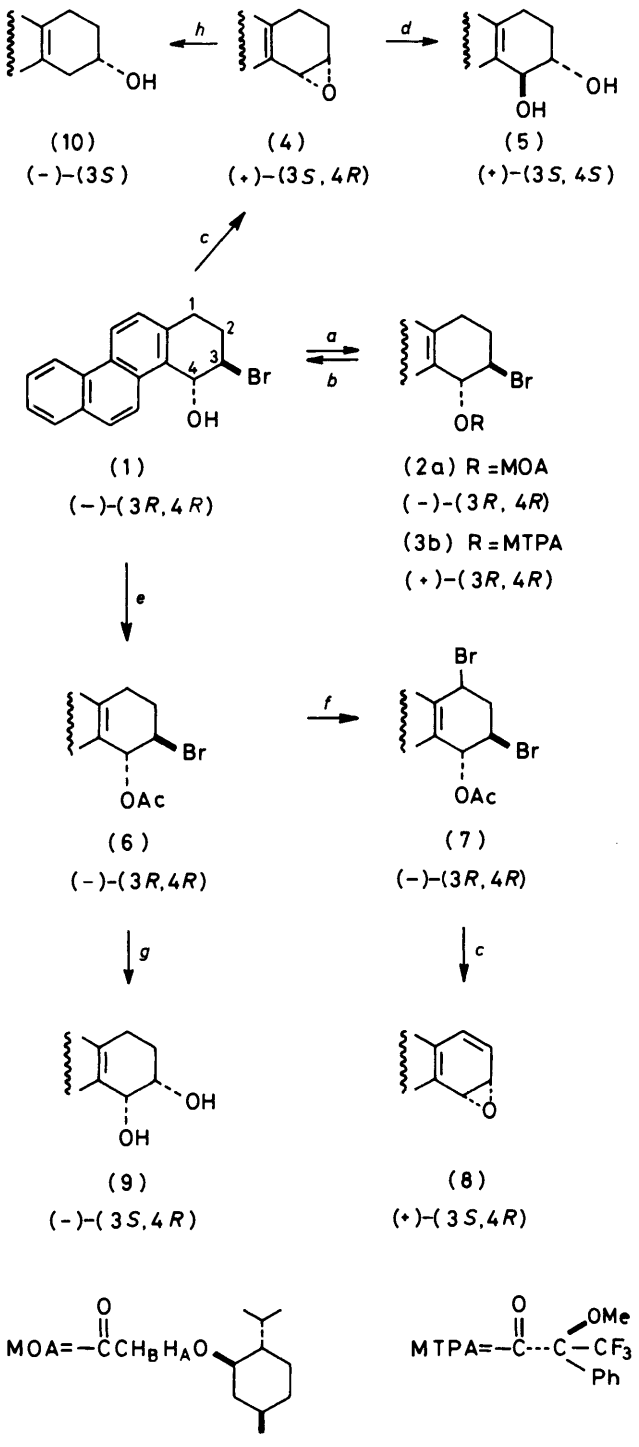
The synthetic pathway used is summarized in Scheme 1 and is similar to those adopted for other chiral arene oxides.[11–16]

1,2-Dihydrochrysene was prepared by a six-step synthesis (30% overall yield) from commercially available 9,10-dihydrophenanthrene using essentially the literature methods.[17,18] Treatment of 1,2-dihydrochrysene with *N*-bromoacetamide yielded bromohydrin (1) which was resolved by h.p.l.c. separation of the diastereoisomeric bromo-menthyloxyacetyl (-MOA) (2a)/(2b) or bromo-2-methoxy-2-phenyl-2-trifluoromethylacetyl (bromo-MTPA) (3a)/(3b) esters. Both the bromo-MOA (2a)/(2b) and bromo-MTPA (3a)/(3b) esters were found to decompose slowly at room temperature and this made purification difficult. Thus, while complete separation by rapid h.p.l.c. of (2a) from (2b) [or (3a) from (3b)] was achieved (≥98% diastereoisomeric purity), samples were frequently used for further reaction directly after chromatography without further purification by recrystallization. The $[\alpha]_D$ values reported for (2a) and (2b) [or (3a) and (3b)] were thus the maximum observed for each diastereoisomer although not necessarily the maximum possible. While the h.p.l.c. separation of (2a) and (2b) on a Zorbax Sil column using ether–cyclohexane (3 : 97) was satisfactory (α 1.36), a better separation (α 1.78) was achieved with the bromo-MTPA esters (3a) and (3b).

Assignment of absolute stereochemistry to the bromo-esters (2a)/(2b) and (3a)/(3b) was based upon a comparison of chromatographic and n.m.r. spectral characteristics with similar compounds of known configuration. Previous results obtained with bromo-MOA esters in the naphthalene,[11] anthracene,[11] phenanthrene,[7,12] chrysene,[13] benz[*a*]anthracene,[14,15] and benzo[*a*]pyrene series,[16] indicated that isomer (2a) should have a (3*R*,4*R*) configuration; it was found to have a negative $[\alpha]_D$ value and gave a higher R_F than (2b) on silica-gel chromatography and a more marked degree of non-equivalence in the exocyclic protons H_A and H_B which appeared as doublets centred at δ 3.86 and 3.94, respectively. Similarly, by comparison with other bromo-MTPA esters of the PAH series [19] the (3*R*,4*R*) configuration was assigned to the isomer (3a); it had a downfield chemical shift for 2-H (δ 4.65) relative to the diastereoisomer (3b), and a smaller negative δ value for the ^{19}F signal (−8.51). The (3*R*,4*R*) configuration was found to be common to both (2a) and (3b) by the base-catalysed cyclization reaction to yield in each case the (+)-(3*S*,4*R*) epoxide (4).

Treatment of (−)-compound (2a) with diborane followed by hydrolysis gave (−)-(3*R*,4*R*)-*trans*-4-bromo-3-hydroxy-1,2,3,4-tetrahydrochrysene (1). This bromohydrin was a key synthetic intermediate which yielded (+)-(3*S*,4*R*)-3,4-epoxy-1,2,3,4-tetrahydrochrysene (4) upon base-catalysed cyclization. When (+)-compound (4) was stirred at room temperature in phosphate-buffered solution (pH 4), hydration occurred to give the (+)-*trans*-diol (5), which has recently been resolved by an independent route and assigned (3*S*,4*S*) stereochemistry by the exciton chirality method.[20,21] This configurational assignment is in total agreement with the present report since a stereochemical correlation can be drawn between (−)-compound (2a) and the (+)-diol (5) (Scheme 1).

A clear stereochemical relationship exists between the (−)-(3*R*,4*R*) enantiomer of (1) and the chiral alcohols (−)-(3*S*)-3-hydroxy-1,2,3,4-tetrahydrochrysene (10) and (−)-(3*S*,4*R*)-*cis*-3,4-dihydroxy-1,2,3,4-tetrahydrochrysene (9) (Scheme 1). The reaction mechanism and stereochemistry in each case is known from earlier reports on similar systems.[11,13] The same enantiomer [(−)-(3*R*,4*R*)] of bromohydrin (1) was also converted into the monobromo-acetate (−)-(6) and dibromo-acetate (−)-(8) which were intermediates in the synthesis of (+)-(3*S*,4*R*)-chrysene 3,4-oxide (8) (Scheme 1). The maximum observed $[\alpha]_D$ value for (+)-compound (8) (224°) appeared to be comparable in magnitude to those observed for arene oxides in the naphthalene 1,2- (149°),[11] anthracene 1,2- (214°),[11] benz[*a*]anthracene 8,9- (115°),[14] and 10,11- (383°),[15] and benzo[*a*]pyrene 7,8-oxide (175°) [16] series. However, while the latter $[\alpha]_D$ values remained unchanged during 12 h at ambient temperature, the optical rotation of (+)-(8) ($[\alpha]_D$ +224°) (recorded immediately after work-up and



Scheme 1. *Reagents*: a, (−)-menthyloxyacetyl chloride–pyridine R = MOA) or (−)-2-methoxy-2-phenyl-2-trifluoromethylacetyl chloride–pyridine (R = MTPA); b, diborane–THF (R = MOA); c, NaOMe; d, H_2O (pH 4); e, acetic anhydride–pyridine; f, *N*-bromosuccinimide; g, AgOAc–HOAc–H_2O, KOH; h, $LiAlH_4$

rapid recrystallization at −70 °C) showed a marked degree of racemization under similar conditions ($t_{\frac{1}{2}}$ 55 h at 19 °C).

A combination of their instability due to ring strain and the unavailability of a convenient general route to optically active epoxides may account for the paucity of literature reports of their racemization. The process of racemization (or epimerization) of the oxiran ring system found in arene oxides may however be commonly encountered *in vivo*. Thus, by analogy with the stereoselective mono-oxygenase-catalysed epoxidation of benzo[*a*]pyrene [4] and benz[*a*]anthracene,[5] it might reasonably be expected that the arene oxides of phenylalanine and its derivatives (proposed as intermediates during the biosynthesis of tyrosine and of the fungal metabolites gliotoxin and aranotin [22]) would be formed initially with an excess of one stereoisomer *in vivo*. Inversion of configuration at the chiral oxiran ring carbon atoms *via* the oxepin tautomer would clearly be an extremely rapid process in such arene oxides.

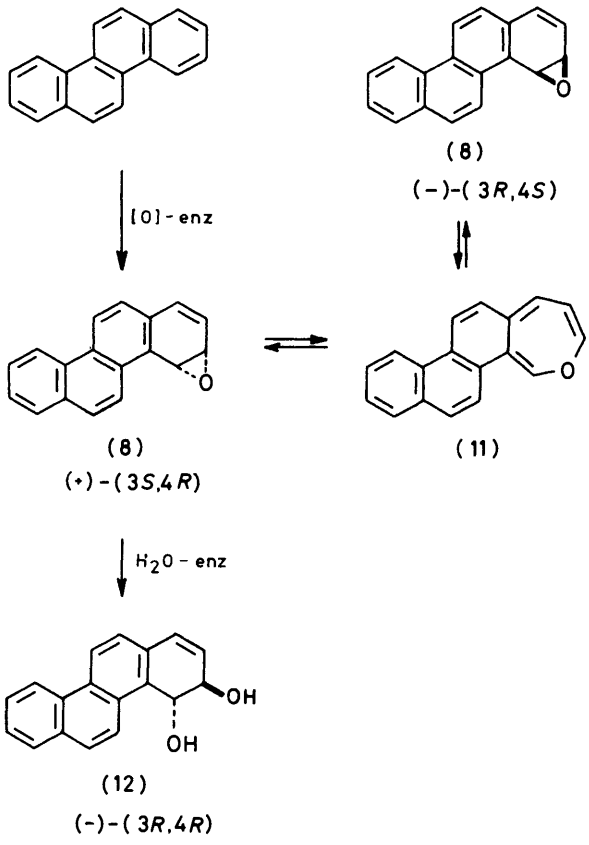
The thermal racemization of (+)-(2*S*,3*R*)-*cis*-2-phenyl-3-*p*-tolyloxiran and (−)-(2*S*,3*S*)-*trans*-2-phenyl-3-*p*-tolyloxiran has been studied over the temperature ranges 225—247 and 180—207 °C, respectively.[23] The results have been rationalized in terms of an orbital-symmetry-allowed conrotatory mode of opening of the 4π-electron oxiran ring *via* either a carbonyl ylide or a diradical intermediate. These studies were only possible at elevated temperatures as reflected in the high barriers to racemization (E_a 35.9—41.1 kcal mol^{-1} *). The low value for the activation entropy ($\Delta S^{\ddagger}$ −2 ± 2 cal mol^{-1} K^{-1}) was consistent with the proposed mechanism.

An alternative type of orbital-symmetry-allowed ring opening of an oxiran ring (resulting in racemization) is possible for arene oxides. Thus the benzene oxide–oxepin isomerization process which occurs spontaneously is an example of a thermal disrotatory electrocyclic reaction in a 6π-system. Kinetic studies (n.m.r.) of this valence tautomerization process yielded a $\Delta S^{\ddagger}$ value of +6.6 ± 5.0 cal mol^{-1} K^{-1} as expected since little molecular reorganisation is involved.[6]

In the present work racemization of (+)-compound (8) occurred spontaneously in deuteriochloroform solution and kinetic data were readily obtainable by polarimetry over the temperature range 19—49 °C. N.m.r. analysis of initial and final samples indicated that no appreciable decomposition had occurred. The barrier to racemization (E_a = 25.2 ± 0.2 kcal mol^{-1}) obtained for (+)-(8), taken in conjunction with the value found for chrysene 1,2-oxide [13] (E_a = 24.8 ± 0.35 kcal mol^{-1}), provides the only reliable data on the racemization of arene oxides. The conclusion that an oxepin intermediate (11) is involved during the racemization of (+)-compound (8) (Scheme 2) is based upon the following factors. (i) The small positive entropy of activation obtained ($\Delta S^{\ddagger}$ = +0.65 ± 0.6 cal mol^{-1} K^{-1}) is in accord with a mechanism involving a small increase in disorder during the arene oxide ⟶ oxepin transition and is similar in magnitude to those found in epoxide racemization [20] or oxepin–benzene oxide tautomerism [6] studies. (ii) It is difficult to envisage any alternative mechanism, apart from the precedented arene oxide–oxepin isomerization process,[6] which could account for the concerted racemization of two chiral centres in (+)-epoxide (8). (iii) The observations are exactly as predicted from PMO calculations which were carried out on the basis of an arene oxide–oxepin interconversion occurring in the arene oxide (8).

Owing to the relative instability of the arene oxide (8) and an insufficient quantity of material, it has not been possible to fully elucidate the factors which influence the racemization process. Based upon an examination of molecular models of (8) and the corresponding oxepin (9), it would appear that steric interactions around the bay region might lead to a slightly higher value of E_a for racemization of the (+)-3,4-epoxide (8) compared with (+)-chrysene 1,2-oxide. In practice, the value of E_a obtained for racemization of (+)-compound (8) agreed within experimental error with that obtained for chrysene 1,2-oxide, as predicted by the PMO method

* 1 Cal is 4.184 J.



Scheme 2.

which did not take steric effects into account. Although solvent-effect studies were not carried out in the present work because of poor solubility no marked change in E_a from that obtained in deuteriochloroform would be expected in hydroxylic solvents if racemization occurs *via* the oxepin intermediate. The racemization of (+)-compound (8) in the more polar conditions which may obtain during its formation by mono-oxygenase-catalysed oxidation of chrysene is thus expected to be roughly comparable in rate to the present studies.

(−)-*trans*-(3*R*,4*R*)-3,4-Dihydroxy-3,4-dihydrochrysene (12) is the dominant enantiomer (95—99%) formed from the metabolism of chrysene by liver microsomes [24] (Scheme 2). By analogy with the carcinogenic PAHs benz[*a*]anthracene [5] and benzo[*a*]pyrene,[4] where dihydro-diols of high optical purity were formed during liver microsomal metabolism, it is probable that the (−)-diol (12) results from the action of epoxide hydrolase enzyme on the (+)-(3*S*,4*R*)-enantiomer of (8) which is formed almost exclusively. While it has now been demonstrated that spontaneous racemization can occur for both chrysene 1,2-oxide ($t_{\frac{1}{2}}$ = 25 min at 37 °C) [13] and chrysene 3,4-oxide ($t_{\frac{1}{2}}$ = 5.4 h at 35 °C) *in vitro*, it would appear that the enzyme-catalysed hydration step is much too fast to allow this process to occur to any significant extent during the metabolism of chrysene. This does not, however, exclude the possibility that the racemization process occurs *in vivo* with arene oxides in the monocyclic series or indeed with those arene oxides in the PAH series where much lower barriers to racemization have been predicted.[9]

Experimental

^{1}H N.m.r. spectra were recorded on Bruker WH90 or WM250 MHz instruments. Deuteriochloroform and tetramethylsilane were used as solvent and reference, respectively, unless stated otherwise. ^{19}F N.m.r. spectra were obtained from a Varian XL-100 instrument (94.2 MHz) using α,α,α-trifluorotoluene as reference.

Optical rotations were measured at the sodium-D line (589 nm) with deuteriochloroform as solvent using a Perkin-Elmer Model 241 polarimeter. Kinetic studies were carried out at 546 nm with the same instrument and solvent (containing a trace of triethylamine) in association with a thermostatically controlled polarimeter cell (±0.1 K) and a Honeywell Electronik 194 chart-recorder. The racemization reactions were found to follow first-order kinetics and a plot of $\log_{10}(\alpha - \alpha_\infty)$ *vs* t gave a slope equal to the rate ($k_{obs.}$). The free energy of activation $\Delta H^\ddagger$ was thus obtained from substitution in the equation $\Delta G^\ddagger_T = 4.57T(10.32 - \log_{10} k/T)$.

Measurement of the racemization rates over a range of temperatures allowed a plot of log k *vs* $^1/T$ to be made. The activation energy E_a was obtained from the slope and the frequency factor (A) from the intercept. A plot of log k/T *vs* $1/T$ gave the enthalpy of activation $\Delta H^\ddagger$ and the entropy of activation $\Delta S^\ddagger$ from the slope and intercept, respectively. Kinetic results and activation parameters for the thermal racemization of (+)-compound (8) are given below.

Temperature (°K)	k_{obs} (× 10^{-6} s^{-1})	$\Delta G^\ddagger$ (kcal mol^{-1})
292.2	3.51	24.39
297.8	7.99	24.39
308.4	35.58	24.36
317.9	120.40	24.36
321.8	186.30	24.39

E_a = 25.2 ± 0.2 kcal mol^{-1}; log A = 13.1 ± 0.1; $\Delta H^\ddagger$ = 24.58 ± 0.2 kcal mol^{-1}; $\Delta S^\ddagger$ = +0.65 ± 0.6 cal mol^{-1} K^{-1}.

The reagents used in the synthesis of compounds (2)—(10) are shown in Scheme 1.

(±)-trans-3-*Bromo*-4-*hydroxy*-1,2,3,4-*tetrahydrochrysene* (1).—1,2-Dihydrochrysene [17] (1.0 g, 4.3 mmol) was dissolved in a mixture of THF (10 ml) and water (75 ml) and stirred at 0 °C with *N*-bromoacetamide (0.75 g, 5.4 mmol) for 0.5 h. The product was poured into ice, filtered, washed with water and recrystallized from benzene to give colourless needles (0.68 g, 48%), m.p. 175—177 °C (decomp.) (Found: C, 66.3; H, 4.8. $C_{18}H_{15}BrO$ requires C, 66.1; H, 4.6%); δ(90 MHz; $CDCl_3$) 2.25—3.43 (4 H, m, 1- and 2-H), 4.68—4.85 (1 H, m, 3-H), 5.64 (1 H, d, $J_{4,3}$ 3.2 Hz, 4-H), 7.08—8.28 (6 H, m, aryl H), and 8.55—8.77 (2 H, m, aryl H).

(−)-(3R,4R)- *and* (+)-(3S,4S)-trans-3-*Bromo*-4-*menthyloxyacetoxy*-1,2,3,4-*tetrahydrochrysene* (2a) *and* (2b).—(−)-Menthyloxyacetyl chloride (1.0 g, 4.3 mmol) was added dropwise at 0 °C to a solution of the bromohydrin (1) (1.0 g, 3.1 mmol) in dry pyridine (10 ml) and the mixture was stirred at room temperature for 4 h. The product was extracted with diethyl ether, which was in turn washed with 1M-hydrochloric acid, 1M-aqueous sodium carbonate, dried and concentrated to yield a viscous yellow oil (1.41 g, 88%) which decomposed slowly at room temperature. A preliminary purification and partial separation of the diastereoisomers by short-column chromatography (Kieselgel G type 60, Merck, eluted with diethyl ether–light petroleum) gave a viscous oil (2a)/(2b) which could not be distilled without decomposition (Found: C, 68.7; H, 6.8. $C_{30}H_{35}BrO_3$ requires C, 68.8; H, 6.7%). A total separation of the diastereoisomers was achieved by semi-preparative h.p.l.c. using a Spectra-Physics 3500B Model instrument equipped with a DuPont Zorbax Sil (9.4 mm × 25

cm) column and cyclohexane–diethyl ether (97 : 3) as solvent systems.

(−)-Compound (2a) was eluted early from the h.p.l.c. column, m.p. 102—103 °C (pentane), $[\alpha]_D$ −121°; δ(C_6D_6; 250 MHz) 3.86 (1 H, d, J_{AB} 16.5 Hz, H_A) and 3.94 (1 H, d, J_{AB} 16.5 Hz, H_B); (+)-compound (2b) was eluted late from the h.p.l.c. column, unstable solid, $[\alpha]_D$ +37°; δ(C_6D_6; 250 MHz) 3.82 (1 H, d, J_{AB} 16.5 Hz, H_A) and 3.95 (1 H, d, J_{AB} 16.5 Hz, H_B).

(+)-(3R,4R)-*and* (−)-(3S,4S)-trans-3-*Bromo*-4-(2-*methoxy* 2-*phenyl*-2-*trifluoromethylacetoxy*)-1,2,3,4-*tetrahydrochrysene* (3a) *and* (3b).—Using a similar procedure to that outlined for compounds (2a) and (2b), bromohydrin (1) and (−)-2-methoxy-2-phenyl-2-trifluoromethylacetyl chloride reacted to form a diastereoisomeric mixture of (3a) and (3b) as a viscous yellow oil (85%) which decomposed slowly at room temperature (Found: C, 61.6; H, 4.1. $C_{28}H_{22}BrF_3O_3$ requires C, 61.9; H, 4.1%).

Separation of the isomers (3a) and (3b) was achieved by preparative t.l.c. (silica gel) eluting with diethyl ether–light petroleum (1 : 9): (+)-compound (3a), high R_F fraction, m.p. 117—125 °C (decomp.), $[\alpha]_D$ +14.0°; δ(90 MHz) 7.06 (1 H, d, $J_{3,4}$ 2.9 Hz, 4-H), 4.65 (1 H, m, 3-H), and 3.39 (3 H, s, OMe); δ(^{19} F) −8.51 (3 F, s, CF_3); (−)-compound (3b), low R_F fraction, m.p. 150—153 °C (benzene), $[\alpha]_D$ −1.3°; δ(90 MHz) 6.97 (1 H, d, $J_{3,4}$ 2.7 Hz, 4-H), 4.84 (1 H, m, 3-H), 3.40 (3 H, s, OMe); δ(^{19} F) −8.81 (3 F, s, CF_3).

(−)-(3R,4R)-trans-3-*Bromo*-4-*hydroxy*-1,2,3,4-*tetrahydrochrysene* (1).—Treatment of (−)-compound (2a) (0.5 g, 9.6 mmol, $[\alpha]_D$ −121°) with an excess of diborane in dry THF (15 ml) at room temperature for four days, followed by addition of water, extraction into chloroform, drying and concentration, yielded (−)-compound (1). Recrystallization from benzene gave needles (0.22 g, 69%), m.p. 183—184 °C, $[\alpha]_D$ −21°, whose spectral characteristics were identical with the racemic sample of the bromohydrin (1).

(+)-(3S,4R)-3,4-*Epoxy*-1,2,3,4-*tetrahydrochrysene* (4).—Sodium methoxide (1.6 g, 30 mmol) was added to a solution of (−)-compound (1) (1.0 g, 3.1 mmol, $[\alpha]_D$ −21° in dry diethyl ether (200 ml) and the mixture stirred at room temperature for 1 h. After water (40 ml) had been added, the product (4) was extracted into diethyl ether, dried and concentrated to yield a brown solid. Recrystallization from diethyl ether–light petroleum (b.p. 40—60 °C) yielded colourless crystals (0.54 g, 71%), m.p. 188—189 °C, $[\alpha]_D$ +109° (Found: *M*, 246.104 09. $C_{18}H_{14}O$ requires *M*, 246.104 46); δ(90 MHz) 1.59—2.11 (2 H, m, 2-H), 2.37—3.30 (2 H, m, 1-H), 3.80—4.00 (1 H, m, 3-H), 4.76 (1 H, d, $J_{3,4}$ 4.3 Hz, 4-H), and 7.31—8.81 (8 H, m, aryl H).

The (+)-(3*S*,4*R*)-enantiomer of the epoxide (4) was also obtained in similar yield from either (−)-compound (2a) or (+)-compound (3a) using identical reaction conditions.

(+)-(3S,4S)-trans-3,4-*Dihydroxy*-1,2,3,4-*tetrahydrochrysene* (5).—A solution of (+)-compound (4) (0.04 g, 0.16 mmol, $[\alpha]_D$ +109°) in dioxan (10 ml) was added dropwise to a solution (pH 4.0) of sodium dihydrogen phosphate (3.5 g in 1 l water) and then stirred at room temperature for 2 h. The product was extracted into chloroform and the solution was dried and concentrated. The *trans*-diol (5) was obtained as colourless needles (0.028 g, 66%) by recrystallization from chloroform, m.p. 181—183 °C, $[\alpha]_D$ +23° (THF) (Found: *M*, 264.115 13. $C_{18}H_{16}O_2$ requires *M*, 264.115 02); δ(250 MHz) 2.02—2.27 (2 H, m, 2-H), 2.96—3.18 (2 H, m, 1-H), 4.29—4.41 (1 H, m, 3-H), 5.31 (1 H, d, $J_{3,4}$ 3.3 Hz, 4-H), and 7.26—8.68 (8 H, m, aryl H).

Traces of the *cis*-diol (9) remained in the mother liquors after recrystallization and were not isolated.

(−)-(3R,4R)-trans-4-*Acetoxy*-3-*bromo*-1,2,3,4-*tetrahydrochrysene* (6).—Bromohydrin (1) (1.0 g, 3.1 mmol) ($[\alpha]_D$ −21°) was stirred for 12 h at room temperature with acetic anhydride (20 ml) in dry pyridine (5 ml). After termination of the reaction by the addition of water, the bromo-acetate (6) was isolated by a similar work-up procedure to that used for the bromo-esters (2) and (3). Recrystallization from chloroform–light petroleum (b.p. 40—60 °C) gave colourless needles of compound (6) (0.83 g, 74%), m.p. 178—180 °C, $[\alpha]_D$ −169° (Found: C, 64.9; H, 4.7. $C_{20}H_{17}BrO_2$ requires C, 65.05; H, 4.6%); δ(90 MHz) 2.08 (3 H, s, OMe), 2.18—2.73 (2 H, m, 2-H), 2.85—3.65 (2 H, m, 1-H), 4.65—4.80 (1 H, m, 3-H), 6.79 (1 H, d, $J_{4,3}$ 2.4 Hz, 4-H), 7.35—8.00 (6 H, m, aryl H), and 8.56—8.78 (2 H, m, aryl H).

(−)-(3R,4R)-4-*Acetoxy*-1,3-*dibromo*-1,2,3,4-*tetrahydrochrysene* (7).—The bromo-acetate (6) (0.068 g, 0.18 mmol) ($[\alpha]_D$ −169°) and *N*-bromosuccinimide (0.035 g, 0.2 mmol) were stirred under nitrogen at 60 °C in carbon tetrachloride (20 ml). A trace of α,α′-azoisobutyronitrile (0.002 g) was added and the solution was irradiated in light petroleum with a Philips 300W IR 300CH lamp. After 40 min the succinimide product was filtered off and the solution was concentrated to yield a crude product (0.08 g, 70%), $[\alpha]_D$ −84°; δ(90 MHz) 2.61 (3 H, s, OMe), 2.78—3.07 (2 H, m, 2-H), 4.44—4.72 (1 H, m, 3-H), 5.59—5.87 (1 H, m, 1-H), 6.67 (1 H, d, $J_{4,3}$ 4.2 Hz, 4-H), 7.39—7.96 (6 H, m, aryl H), and 8.41—8.77 (2 H, m, aryl H).

Decomposition occurred during the attempted purification so (−)-compound (7) was used in the synthesis of the epoxide (8) in this crude form.

(+)-(3S 4R)-(3,4-*Epoxy*-3,4-*dihydrochrysene* (8).—The dibromo-acetate (7) (0.1 g. 0.22 mmol) ($[\alpha]_D$ −84°) was stirred in dry THF (10 ml) at −20 °C in the presence of sodium methoxide (0.06 g, 1.1 mmol) for 40 min. The product was obtained by rapid extraction into ether solution and was washed with aqueous sodium hydroxide (1%) and dried by filtration through anhydrous potassium carbonate. The ether was removed at *ca.* 0 °C under reduced pressure and the product arene oxide (8) was recrystallized at −70 °C from diethyl ether–pentane as pale yellow crystals (0.029 g, 63%), m.p. 115—140 °C (decomp.), $[\alpha]_D$ +224°; δ(90 MHz) 4.31 (1 H, m 3-H), 5.32 (1 H, d, $J_{4,3}$ 4.15, 4-H), 6.56 (1 H, dd, $J_{1,2}$ 9.52, $J_{2,3}$ 3.66 Hz, 2-H), 6.91 (1 H, dd, $J_{1,3}$ 1.71, $J_{1,2}$ 9.52 Hz, 1-H), and 7.56—8.78 (8 H, m, aryl H). Since the arene oxide (8) was found to decompose spontaneously on standing at room temperature it was stored at −70 °C.

(−)-(3S,4R)-cis-3,4-*Dihydroxy*-1,2,3,4-*tetrahydrochrysene* (9).—Silver acetate (0.4 g, 2.3 mmol) in dry acetic acid (10 ml) was stirred at 110 °C for 15 min prior to the addition of water (0.5 ml) and (−)-compound (6) (0.2 g, 0.54 mmol) ($[\alpha]_D$ −169°). Stirring at 110 °C was continued for 24 h and the mixture was then cooled, filtered, and concentrated. Hydrolysis with aqueous potassium hydroxide was followed by extraction into ethyl acetate and the extract was washed with water, dried and concentrated to yield a mixture of *cis* (9) and *trans* (5) diols. Preparative t.l.c. separation on silica gel using methanol–chloroform (8 : 92) as eluant gave the *cis*-diol (9) as the higher R_F component (0.04 g, 28%), m.p. 196—198 °C, $[\alpha]_D$ −43° (THF) (Found: *M*, 264.115 13. $C_{18}H_{16}O_2$ requires *M*, 264.115 02); δ(250 MHz) 2.03—2.28 (2 H, m, 2-H), 3.05—3.12 (2 H, m, 1-H), 4.04 (1 H, m, $J_{3,4}$ 3.7 Hz, $J_{2,3}$ 11.8 Hz, 3-H), 5.44 (1 H, d, $J_{4,3}$ 3.7 Hz, 4-H), and 7.26—8.68 (8 H, m, aryl H). The *trans*-diol was identified as

the major component of the lower R_F band by n.m.r. but was not isolated in pure form.

(−)-(3S)-3-*Hydroxy*-1,2,3,4-*tetrahydrochrysene* (10).—The epoxide (4) (0.1 g, 0.4 mmol) ($[\alpha]_D$ +109°) was reduced to the alcohol (10) by being stirred with $LiAlH_4$ (0.076 g, 0.2 mmol) at room temperature for 2 h in diethyl ether (50 ml). Recrystallization of the product from chloroform–light petroleum (b.p. 40—60 °C) gave compound (10) as colourless plates (0.089 g, 88%), m.p. 173—175 °C, $[\alpha]_D$ −40° (Found: C, 86.9; H, 6.5; $C_{18}H_{16}O$ requires C, 87.1; H, 6.5%); δ(90 MHz) 1.69—2.38 (2 H, m, 2-H), 2.94—3.80 (4 H, m, 1-, 4-H), 4.19—4.43 (1 H, m, 3-H), 7.30—8.02 (6 H, m, aryl H), and 8.37—8.78 (2 H, m, aryl H).

Acknowledgements

We wish to thank Mr. G. Jordan and Mr. B. McKnight for mass spectral and microanalytical data, respectively, and Dr. M. E. Stubbs for helpful discussion.

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Received 13*th July* 1982; *Paper* 2/1187