strument with Me_4Si as an internal standard; chemical shifts are given in δ units: s = singlet; d = doublet; m = multiplet.

Materials. 1-(α-Chlorobenzal)-2-phenylhydrazine (**1a**),[10] methyl chloroglyoxalate phenylhydrazone (**1e**),[11] and phenyl vinyl sulfone (**3**)[12] were prepared according to the reported methods. 1-(α-Chlorobenzal)-2-(p-nitrophenyl)hydrazine (**1b**), 1-(α-chloro-p-tolual)-2-(p-nitrophenyl)hydrazine (**1c**), 1-(α-chloro-2,3,4,5,6-pentadeuteriobenzal)-2-(p-nitrophenyl)hydrazine (**1d**) were prepared according to the method similar to that of **1a**.

1-Deuteriovinyl phenyl sulfone (4) was prepared according to the method reported,[13] except for a modification by an introduction of a deuterium exchange step. The deuterium exchange reaction was carried out as follows: 10 g (54 mmol) of 2-(phenylsulfonyl)ethanol was added to a solution of a few pellets (ca. 5 mmol) of NaOH in 10 mL of deuterium oxide at room temperature with stirring. The heterogeneous mixture was stirred at room temperature overnight and then extracted twice with chloroform (2 × 30 mL). The chloroform layer was dried with sodium sulfate and then evaporated. Distillation in vacuo gave 6.0 g of 2-(phenylsulfonyl)-2,2-dideuterioethanol; bp 130–135 °C (0.1 mmHg).

The Reaction of 1 with 3 or 4 in the Presence of Triethylamine. Triethylamine (5 mmol) was added to a chloroform solution (50 mL) of **1** (5 mmol) and **3** (or **4**) (5 mmol), and the mixture was stirred for 40 h at room temperature. The dark brown mixture was washed with water several times and the chloroform layer was dried over sodium sulfate and evaporated. The crystalline residue was chromatographed on silica gel with chloroform to give 1,3-disubstituted pyrazoles **7** or **8** and 1,2-bis(phenylsulfonyl)ethanes **9**[14] or **10**. α-(Phenylsulfonyl)-p-tolualdehyde p-nitrophenylhydrazone (**11**) was also obtained in the reaction of **1c** with **3** or **4** in 25% and 30% yields, respectively; mp 219–224 °C; ^1H NMR (Me_2SO-d_6) δ 2.4 (s, 3 H), 7.1 (d, 2 H, J = 9 Hz), 7.3 (s, 4 H), 7.55–8.0 (m, 5 H), 8.02 (d, 2 H, J = 9 Hz), 10.55 (s, 1 H, NH). Anal. **7c** (calcd for $C_{16}H_{13}N_3O_2$: C, 68.80; H, 4.69; N, 15.05; and found: C, 68.81; H, 4.57; N, 15.12); **7d** (calcd for $C_{15}H_6D_5N_3O_2$: C, 66.65; H and D, 5.97; N, 15.54; and found: C, 66.91; H and D, 5.89; N, 15.79); **8a** (calcd for $C_{15}H_{11}DN_2$: C, 81.46; H and D, 5.88; N, 12.66; and found: C, 81.49; H and D, 5.91; N, 12.70); **8b** (calcd for $C_{15}H_{10}DN_3O_2$: C, 67.67; H and D, 4.51; N, 15.79; and found: C, 67.47; H and D, 4.30; N, 15.75); **8c** (calcd for $C_{16}H_{12}DN_3O_2$: C, 68.56; H and D, 5.03; N, 14.99; and found: C, 68.70; H and D, 4.96; N, 15.01); **8d** (calcd for $C_{15}H_5D_6N_3O_2$: C, 66.44; H and D, 6.27; N, 15.49; and found: C, 66.43; H and D, 6.29; N, 15.52); **8e** (calcd for $C_{11}H_9DN_2O_2$: C, 65.04; H and D, 5.42; N, 13.79; and found: C, 65.28; H and D, 5.39; N, 13.81); **10** (calcd for $C_{14}H_{13}DO_2S_2$: C, 54.02; H and D, 4.82; and found: C, 54.07; H and D, 4.87); **11** (calcd for $C_{20}H_{17}N_3O_4S$: C, 60.75; H, 4.33; N, 10.63; and found: C, 60.62; H, 4.35; N, 10.59).

Preparation of an Authentic Specimen of 11. A mixture of **1c** (0.01 mol) and sodium benzenesulfinate (0.02 mol) was stirred for 20 h at room temperature in tetrahydrofuran (30 mL) containing a small amount of water (ca. 1–2 mL). The reaction mixture was evaporated and the residue was well mixed with chloroform and water. The organic layer was dried over sodium sulfate and evaporated to give yellow crystals which was recrystallized from ethanol to give **11** in 40% yield; mp 219–222 °C dec. Owing to the polymorphism, the IR and NMR spectra of this authentic specimen are different from those of the compound **11** obtained from **1c** and **3** (or **4**). The identity of these materials was established by the observation that the authentic sample showed the identical NMR spectra with **11** after mixing with a small amount of **11** in Me_2SO-d_6 and standing for a week.

Treatment of 11 with Alcoholic KOH. **11** (1 mmol) was added into stirred ethanol solution (20 mL) containing 6 mmol of KOH and a few drops of water at room temperature. Instantly, the solution became dark purple. After the mixture was stirred for 15 h, the solvent was evaporated and water (30 mL) was added to the residue, which was neutralized with dilute hydrochloric acid. Yellow crystals precipitated and were extracted with chloroform, the organic layer was dried over sodium sulfate and then evaporated to give orange colored crystals (**12**) in 45% yield: mp 319–320 °C. Anal. Calcd for $C_{28}H_{22}N_6O_4$: H, 4.38; C, 66.39; N, 16.59. Found: H, 4.33; C, 66.39; N, 16.57.

Preparation of an Authentic Specimen of 12. **12** is identical with an authentic specimen prepared from the treatment of a chloroform solution (20 mL) of **1c** (1 mmol) with 0.5 mL of triethylamine at 60 °C for 2 h.

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Pseudorotation Barriers in *cis*-4,5-Dimethyl- and *cis*-3,4,5,6-Tetramethyl-9,10-dihydroxy-9,10-dihydrophenanthrene: Measurement of the Buttressing Effect

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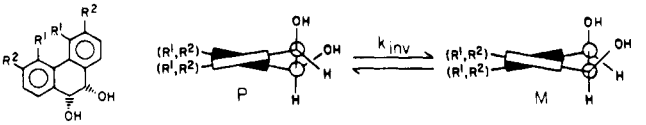
Recent interest[1] in determining the stereoselectivity and conformer specificity of the enzyme UDP-glucuronosyltransferase toward vicinal dihydrodiols of polycyclic aromatic hydrocarbons lead to an investigation[2] of the use of kinetically stable, conformationally locked, dihydrodiols as substrates for the enzyme. For this reason, the kinetic stability of sterically hindered 4,5-dimethyl- and 3,4,5,6-tetramethyl-9,10-dihydroxy-9,10-dihydrophenanthrenes is of considerable interest. The *cis* isomers **1** and **2** exist as slowly interconverting mixtures of two conformational enantiomers **1M** and **1P** and **2M** and **2P**, respectively, which differ in the helicity (M or P) of the biphenyl chromophore (Scheme I). These molecules provide then a convenient means to ascertain the activation barrier for pseudorotation in the hindered biphenyl system and, more interestingly, the magnitude of the buttressing effect[3,4] of the methyl groups at the 3 and 6 positions on this process.

Racemic **1** and **2** are easily prepared by OsO_4 oxidation of 4,5-dimethyl- and 3,4,5,6-tetramethylphenanthrene, respectively. The antipodes **1M** and **1P** can be partially resolved by HPLC at room temperature on a Pirkle type IA column.[5] Isomers **2M** and **2P** are more readily resolved on the same column due, in part, to the increased stability of the conformational antipodes at ambient temperature. In both cases the isomer of P helicity was eluted first. Absolute configurations of the biphenyl systems can be assigned on the basis of the sign of the very intense dis-

Scheme I



1 $R^1 = CH_3, R^2 = H$

2 $R^1 = R^2 = CH_3$

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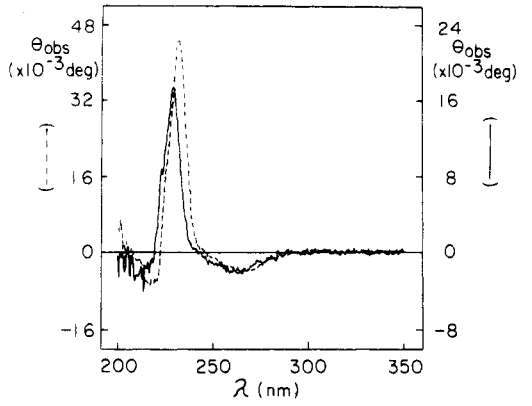

Figure 1. Circular dichroism spectra of 11 μM **1P** (—) of 67% enantiomeric purity and 9.5 μM **2P** (- - -) of >95% enantiomeric purity.

Table I. Barriers to Pseudorotation of 1 and 2[a]

	R^1	R^2	k_{inv}[b]	ΔG^{*}[c]	ΔH^{*}[c]	ΔS^{*}[d]
1	CH_3	H	1.3×10^{-4}	24.0	23.4	−2.1
2	CH_3	CH_3	5.5×10^{-9}	29.4	28.8	−2.0

[a] Correlation coefficients of Arrhenius plots for 1 (20 °C to 50 °C) and 2 (60 °C to 90 °C) were 0.9987 and 0.9999, respectively. [b] In s^{-1} at 25 °C. [c] In kcal/mol. [d] In eu.

symmetry transition in the optical rotatory dispersion[6] or circular dichroism[7] spectra of the biphenyl chromophores. Thus **2P** which was judged of >95% optical purity by HPLC with a chiral stationary phase was found to have a circular dichroic extinction coefficient ($\Delta\epsilon_{233}$ = +143 M^{-1} cm^{-1}), consistent with the P helicity (*S* axial chirality) of the biphenyl chromophore (Figure 1). Similarly, **1P** had $\Delta\epsilon_{229}$ = +48.5 M^{-1} cm^{-1}.[8]

Racemization of **1P** and **2P** was conveniently monitored by the time-dependent loss of the dissymmetry transition at 229 nm or 233 nm, respectively. Activation barriers to pseudorotation shown in Table I were determined from the temperature dependence of k_{inv} obtained from the racemization rate constant $k_{rac} = 2k_{inv}$. As expected, the barrier to pseudorotation in **1** is very close to those previously measured for other 4,5-dimethyl-9,10-dihydrophenanthrenes.[6b,9] To the best of our knowledge, activation parameters for a 3,4,5,6-tetramethyl-9,10-dihydrophenanthrene have not been previously reported. The large difference in the conformational stability of **1** and **2** is clear from comparison of the values of k_{inv} at 25 °C (Table I). In practical terms the racemization half-life of **1** is 45 min at 25 °C as compared to 2.0 years for **2**. Furthermore, comparison of the activation barriers for **1** and **2** provides a direct estimate of the buttressing effect of the methyl groups at the 3 and 6 positions on the 4 and 5 methyl groups of 5.4 ± 0.6 kcal/mol. As expected, the barriers to pseudorotation and the buttressing effect are dominated by the enthalpy of activation.[3] It is interesting to compare the magnitude of the kinetic buttressing effect obtained here to the buttressing effect in the strain energy of the hydrocarbon, 3,4,5,6-tetramethylphenanthrene, of 7.2 ± 1.4 kcal/mol determined by Newman and co-workers.[4] In as much as the near planar hydrocarbon is a reasonable, though not perfect, mimic of a transition state for pseudorotation involving the planar tetramethylbiphenyl moiety, the similar magnitudes of the two effects is not surprising.

Finally, the exceptional conformational stability of the 3,4,5,6-tetramethyl-9,10-dihydroxy-9,10-dihydrophenanthrenes make them excellent molecules for the study of the conformer specificity of enzymes utilizing dihydrodiols as substrates (UDPglucuronosyltransferase,[2] sulfotransferase, and dihydrodiol dehydrogenase) and products (epoxide hydrolase). Work is under way to exploit this potential.

Experimental Section

Racemic **1** and **2** were obtained through oxidation of the respective hydrocarbons[4] with OsO_4 followed by workup with $NaHSO_3$.[10] Isolated yields of **1** and **2** after chromatography on silica gel (1:1 ethyl acetate/benzene) were 80% and 73%, respectively. Both **1** and **2** were judged to be >99% pure by reversed phase HPLC on a Rainin Microsorb C18 column (4.6 mm × 25 cm) eluted at 0.5 mL/min with a linear gradient (1%/min) of 50% to 100% CH_3OH in H_2O. Retention times for **1** and **2** were 23.7 min and 31.4 min, respectively. Spectral data: UV (2-propanol) **1**, λ_{max} 213 nm, ϵ = 39 200, λ_{max} 263 nm, ϵ = 13 600; **2**, λ_{max} 215, ϵ = 40 700, λ_{max} 266 nm, ϵ = 13 500. ^1H NMR (200 MHz, CD_3OD) **1**, δ 2.24 (s, 6 H), 4.52 (d, 1 H, *J* = 2.8 Hz), 4.58 (d, 1 H, *J* = 2.8 Hz), 7.19–7.50 (m, 6 H); **2**, δ 2.32 (s, 6 H), 2.10 (s, 6 H), 4.48 (d, 1 H, *J* = 2.9 Hz), 4.52 (d, 1 H, *J* = 3.0 Hz), 7.16 (d, 2 H, *J* = 7.7 Hz), 7.39 (d, 2 H, *J* = 7.6 Hz). Exact mass for **1** ($C_{16}H_{16}O_2$), *m/e* (calcd) 240.1150, *m/e* (obsd) 240.1153; exact mass for **2** ($C_{18}H_{20}O_2$), *m/e* (calcd) 268.1463, *m/e* (obsd) 268.1450.

Antipodes **1M** and **1P** were partially resolved (α = 1.03) by HPLC with a chiral stationary phase at room temperature on a Pirkle type IA (*N*-(3,5-dinitrobenzoyl)-D-phenylglycinate) column (Regis Chemical Co.) eluted with 5.5% 2-propanol in *n*-hexane.[5] Fractions were stored on ice and pooled, and solvent was removed under vacuum at room temperature. Long term storage was at −90 °C in 2-propanol. Isomers **2M** and **2P** were resolved by using the same HPLC system (α = 1.06). Although this technique is not particularly well suited for preparative resolution of the M and P enantiomers, it is convenient for preparation of spectroscopic quantities used in the racemization studies.

Racemization of **1** and **2** was determined in 2-propanol. First-order decay of the dissymmetry transition of **1P** at 229 nm was followed between 20 °C and 50 °C in a thermostated (±0.03 °C) cell on a JASCO J-500C spectropolarimeter. Racemization of **2P** was monitored between 60 °C and 90 °C by heating (±0.05 °C) samples in a sealed tube, withdrawing and cooling aliquots to room temperature, and determining the loss of the dissymmetry transition at 233 nm by CD spectroscopy. Chemical stability of samples was monitored by reversed phase HPLC.

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