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Concerning the Reaction of *anti*-Benzene Dioxide with Various Nucleophiles

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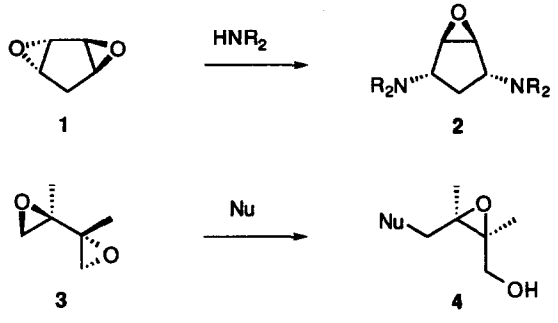
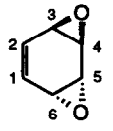
Abstract: *trans*-3,4:5,6-Diepoxycyclohex-1-ene (*anti*-benzene dioxide) (**5**) was brought into reaction with several *S*, *O*, and *C* nucleophiles. *S* and *O* nucleophiles gave the bis-adducts stemming from independent reaction of the two epoxy functions. *C* nucleophiles, on the other hand, led to 1,4-addition products. A deuterium labelling experiment showed that BuLi added to the vinyloxirane part of **5** rather than to the conjugated diepoxide function, yielding the *cis*-adduct. Cuprates gave – as expected – predominatly the *trans*-products.

Introduction. – Whereas the 1,4-addition to conjugated dienes and to vinyloxiranes is well known, 1,2:3,4-diepoxides ("conjugated diepoxides") mainly show independent reaction of the two epoxy functions (see *e. g.* ref.[2]). In 1982, *Kozlov et al.* demonstrated that when *trans*-1,2:3,4-diepoxycyclopentane (**1**)[3] was allowed to react with certain secondary amines, the 1,4-addition product **2** was formed among others.[4] In the course of our investigations of conjugated diepoxides, we recently observed further examples of 1,4-additions, not only to the diepoxycyclopentane **1**,[5] but also to the racemic 1,2:3,4-diepoxy-2,3-dimethylbutane (**3**), leading to products of type **4**.[6]



1 **2** **3** **4**

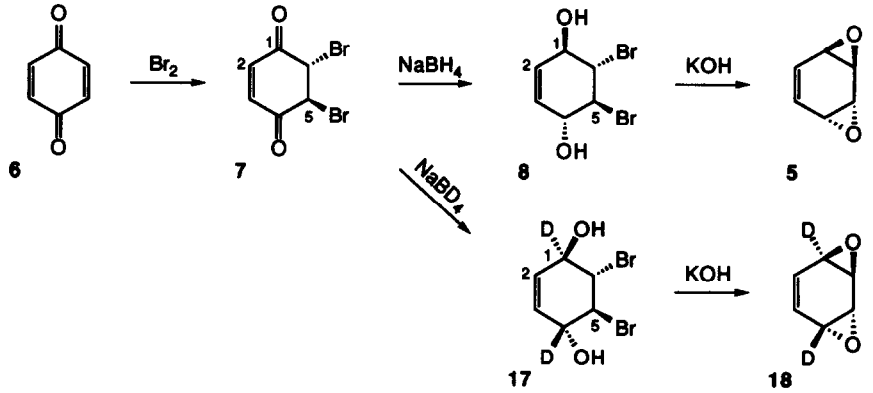


5

For further investigations, *anti*-benzene dioxide (*trans*-3,4:5,6-diepoxycyclohex-1-ene, **5**)[7, 8] seemed to be a suitable candidate. This compound has the two conjugated epoxides arranged in a way which should favor 1,4-additions. Furthermore, it is also a vinyloxirane. Thus, it would be interesting to see whether

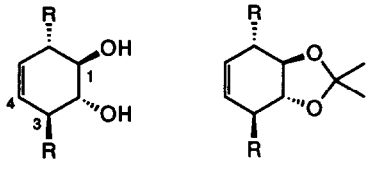
nucleophiles would prefer 1,2- or 1,4-addition and, in this latter case, whether the addition would occur to the diepoxide unit rather than to the vinyloxirane function of the molecule.

Results and Discussion. – The diepoxide **5** was prepared using the procedure of *Vogel* and coworkers[9] with slight modifications. *p*-Benzoquinone (**6**) was brominated and the product **7**[10] subjected to reduction with sodium borohydride to give the bis-bromohydrin **8**; treatment with KOH gave the diepoxide **5**.

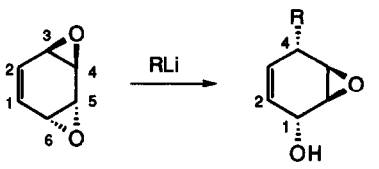


6 **7** **8** **5** **17** **18**

When **5** was allowed to react with *S* and *O* nucleophiles under various conditions, independent opening of the two oxirane rings was observed. Thus, when **5** was brought into reaction with thiophenol in chloroform/methanol/pyridine or with lithium thiophenolate in THF, the symmetrical bis-adduct **9** was isolated in 76 and 25%, respectively. With thiophenol/sodium thiophenolate in DMSO,[11] a 92% yield of **9** was obtained. The constitution of **9** was proved by its transformation to the corresponding acetonide **10**, which could not have been formed, if the OH groups of **9** had been in the 3- and 6-positions. The way of formation of **9** from the *trans*-diepoxide **5** leaves no doubt about the relative configurations in this compound: all substituents are in a mutual *trans*-arrangement.



	R	
9	C_6H_5S-	**10**
11	*t*-BuS-	
12	EtO-	**13**
14	HO-CH_2CH_2-O-	

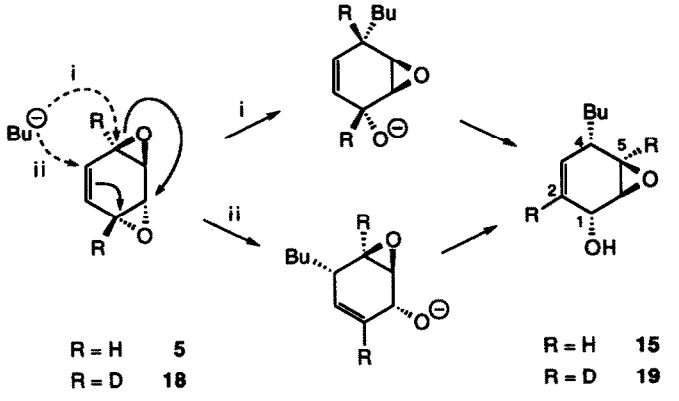


5 R = Bu **15**, R = Me **16**

Similar reaction of **5** with *tert*-butyl mercaptan in chloroform/methanol/pyridine and with sodium ethoxide in ethanol gave in reasonable yields the products **11** and **12**, respectively. Again, **12** was transformed to the corresponding acetonide **13** to corroborate its constitution.

No 1,4-addition either to the diepoxide function of **5** nor to its vinyloxirane part was observed. This is in accord with recent work by *Lehmann* and coworkers, who obtained **14** in good yield from the reaction of the sodium salt of ethylene glycol with **5**.[12]

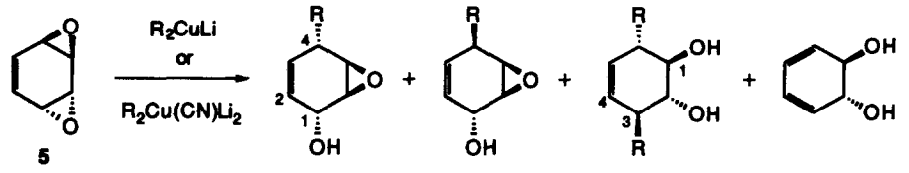
Things were different when *C* nucleophiles were used: the reaction of **5** with butyllithium in THF led in 86% to a compound, which according to its mass spectrum had to be a mono-adduct, and eventually proved to have structure **15** with the butyl and OH groups *cis* to each other (see below). Reaction of **5** with methyllithium gave the analogous product **16** in 77% yield. The adducts **15** and **16** could not just be the products stemming from the simple opening of only one of the two oxirane rings of **5**, but must have been formed in a different way. Several possibilities are conceivable. The nucleophile could have attacked (i) the diepoxide unit or (ii) the vinyloxirane part of **5**; products **15** and **16** would thus be 1,4-addition products. (iii) Compounds **15** and **16** could, however, also stem from 1,2-addition to one of the epoxides with attack of the nucleophile at one of the carbon atoms involved in the inter-epoxide bond and subsequent rearrangement of the allylic alcohol formed. This pathway is unlikely, first because all bis-adducts described above indicated that the nucleophiles would rather attack the "outer", sterically somewhat less hindered carbon atoms of the diepoxide, and second because under the reaction conditions used, an allyl rearrangement would not be favored. The distinction between pathways i and ii could be made with the deuterated diepoxide **18**.

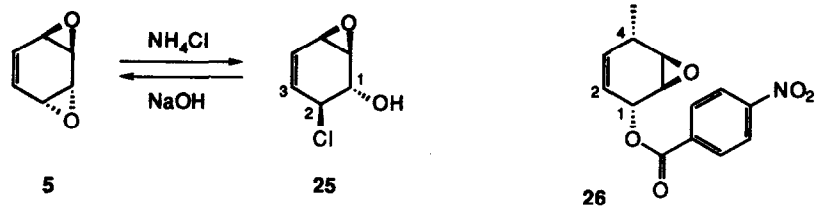


Reduction of the intermediate **7** with $NaBD_4$ rather than with $NaBH_4$ gave **17**, and eventually the deuterated compound **18**; reaction of this with butyllithium led to the adduct **19**. Rigorous assignments of all ^1H- and ^{13}C NMR resonances using H,H and C,H COSY techniques were the basis for the determination of the labelled sites in **19**. Both, the ^1H- and the ^{13}C NMR spectra clearly showed the deuterium labels to be at one of the olefin carbons (C(2)) and at one of the epoxide carbons (C(5)). Thus, butyllithium had added across the vinyloxirane part of **18**.

The reaction of **5** with BuLi and MeLi had given the 1,4-addition products **15** and **16**, respectively. This is in contradiction with earlier observations[13, 14] that MeLi with vinyloxiranes would rather yield the 1,2-adducts together with rearrangement and elimination products. Cuprates, on the other hand, readily give 1,4-addition, but with a predominance of the *trans*-product.[15] We therefore sought to prepare the *trans*-isomers of **15** and **16**, *i.e.* **20** and **21**, respectively; the availability of both, the *cis*- and *trans*-isomers, would certainly facilitate the unambiguous assignment of the relative configurations of these compounds. Thus, when the

diepoxide **5** was brought into reaction with the cuprates Bu_2CuLi or Me_2CuLi, or the cyanocuprate $Me_2Cu(CN)Li_2$, mixtures of products were obtained containing the *cis*- and *trans*-adducts, some bis-adduct (**22** and **23**, respectively), and in some cases the product **24** stemming from base-induced rearrangement[13] and reduction.





In some of the experiments, where aqueous NH_4Cl solution was used in the work-up, the chlorohydrin **25** was isolated. This compound was formed from unconverted starting material **5** with the aqueous NH_4Cl, as could be shown by treating **5** with NH_4Cl: **25** was obtained besides unchanged **5** and some water soluble products, which were not further investigated. This chlorohydrin **25**, when treated with NaOH, was converted back to **5**.

Structure Elucidations. – The constitutions of the reaction products obtained from **5** were readily assigned from the spectral data of the compounds. In some cases, H,H or H,C COSY NMR spectra proved to be necessary to corroborate the assignments made. In addition to the constitution, the relative configurations within the products had to be determined. This was straight-forward for the bis-adducts **9**, **11**, **12**, **22**, and **23**, since it was assumed (i) that no epimerizations occurred during the reactions, and thus the original configurations of C(4) and C(5) of **5** were preserved in the products, and (ii) that the addition to the oxiranes led to *trans*-products. The problem was, however, much more difficult with the 1,4-adducts **15**, **16**, **20**, and **21**. Simple ^1H NMR spectroscopy proved to be of little use. Since the molecules of this type contained two planar sp^2 C atoms and two *quasi*-planar oxirane C atoms, the cyclohexene ring as a whole was more or less planar, too. The consequence is, that the dihedral angles between the protons at C(1) and C(4) and the corresponding vicinal ring protons are all virtually the same, leading to coupling constants of rather similar magnitude. Thus the *Karplus* relationship could not be used for the assignment of the relative configurations. The spectra were further complicated by extensive long-range coupling across the cyclohexene ring. NOE difference spectroscopy[16] gave first hints regarding the configurations of **15** and **20**. When H-C(1) of **15** was irradiated, a weak enhancement for the resonance of H-C(4) was observed and *vice versa*, an indication of the

cis-configuration. The same experiment carried out with **20** did not lead to NOE's, which is in accord with the *trans*-configuration assigned.

Corroboration was sought from an X-ray structure determination. Since the 1,4-adducts were not crystalline, suitable derivatives had to be made. Thus, several esters were prepared from the *cis*-compound **16**:[17] whereas the acetylsalicylate and the α-methoxy-α-(trifluoromethyl)phenylacetate were not solid, the *p*-nitrocinnamate, the *p*-nitrobenzoate and the 3,5-ditnitrobenzoate[18] gave crystals. The *trans*-adduct **21** in turn was esterified[18] with 3,5-dinitrobenzoyl chloride and *p*-bromobenzoyl chloride; both esters were crystalline. Of all these derivatives, only the crystals of the *p*-nitrobenzoate **26** derived from the *cis*-adduct **16** proved to be suitable for an X-ray structure analysis (*Figure 1*). The relative configurations in **16** could in this way be determined unambiguously.

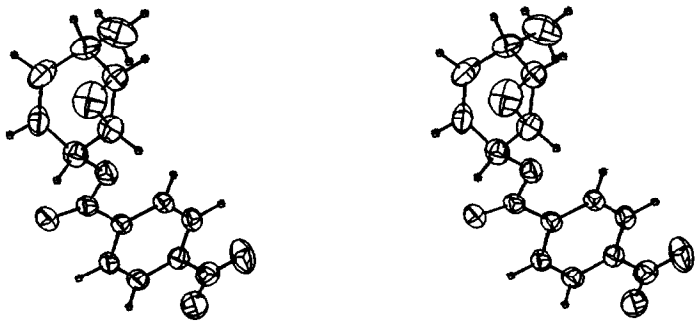


Figure 1. Crystal structure of **26** (stereo view).

The constitution of the chlorohydrin **25** was determined by *in situ* derivatization with trichloroacetyl isocyanate in the NMR tube.[19] The ^{13}C NMR resonance of C(1) was shifted downfield by 3.24 ppm, whereas those of one of the oxirane C atoms and of the chlorinated C atom were shifted upfield by 2.56 and 4.61 ppm, respectively. The resonances of the olefinic C atoms were only displaced by small amounts. This proves that the OH group of **25** is adjacent to the epoxide. The relative configurations of **25** were determined by its conversion back to the diepoxide **5** using NaOH.

Conclusion. – Compound **5**, which represents both, vinyloxiranes and 1,2:3,4-diepoxides, reacts in different ways depending on the nature of the nucleophiles. *S* and *O* nucleophiles gave 1,2-bis-addition, with attack at the less hindered outer carbon atoms of the diepoxide unit. *C* nucleophiles, in contrast, gave 1,4-addition, which was shown to occur at the vinyloxirane function rather than to the conjugated diepoxide. With cuprates, *trans*-adducts were obtained in accord with earlier work.[15] On the other hand, MeLi which is known to give predominantly 1,2-addition to vinyloxiranes[13, 14] surprisingly also gave the 1,4-adduct, but with *cis*-configuration. Finally, it may be noteworthy, that *Rickborn* (see ref.[20]) who investigated the reaction of 1,2:3,4-diepoxycyclohexane with Me_2CuLi, did not observe any 1,4-addition to the conjugated diepoxide either.

EXPERIMENTAL PART

General. All solvents were distilled and dried. The reagents were of reagent grade and used without further purification. Org. extracts were dried (Na_2SO_4) and evaporated below 50°. TLC: silica gel *60 F_{254}* (*Merck*). Column chromatography: silica gel (35-70 μm, *Merck* or *Chemische Fabrik Uetikon*). M. p.: *Kofler* hot stage; corrected. IR: *Perkin-Elmer-781* or *Perkin-Elmer-1310* IR spectrometer. NMR (*K. Aegerter, K. Ulrich;* Dr. *W. Ammann* (*Varian AG*, Zug); *L. Oberer* (*Sandoz AG*, Basel)): *Bruker WH-90* (^1H, 90 MHz; ^{13}C, 22.63 MHz), *Bruker AM-360* (^1H, 360 MHz), *Varian-Gemini-300* (^1H, 300 MHz; ^{13}C, 75 MHz), and *Varian VXR-400* (^1H, 400 MHz; ^{13}C, 101 MHz); multiplicities in ^{13}C NMR spectra where listed were determined by gated decoupling, off-resonance decoupling, or DEPT, otherwise APT experiments were performed; chemical shifts in ppm rel. to internal TMS; where necessary, assignments were corroborated by $^1H,^1H$- or $^1H,^{13}C$ COSY; assignments with asterisks may be interchanged. MS (Dr. *H. Nadig*): *VG-70-250* spectrometer. GC/MS: *Hewlett-Packard 5790A/5970A*.

(5RS,6RS)-5,6-Dibromocyclohex-2-ene-1,4-dione (**7**). To a soln. of *p*-benzoquinone (510 g, 4.718 mol) in 3 l of CH_2Cl_2, Br_2 (250 ml, 4.8 mol, in 1.5 l of CH_2Cl_2) was added at -5° during 3.5 h. After additional 2.5 h, the reaction mixture was concentrated to 1.5 l at 10°. The solution was washed with $NaHCO_3$ soln. and H_2O, dried, and evaporated until crystals separated. The yellow needles were collected and the mother liquor concentrated further to give additional portions of **7**. The last mother liquor was chromatographed (silica gel, pentane/Et_2O 1:2), yielding besides **7**, 210 mg of *2,5-dibromo-1,4-benzoquinone*.[21] Total yield of **7**: 980 g (76%).

Data of **7**: M. p.: 82-84° (Lit.:[10] 85.5-86°). IR (KBr): 3050, 3000, 2980, 1745, 1690, 1600, 1370, 1285, 1235, 1215, 1110, 1010, 850, 640. ^1H NMR (300 MHz, $CDCl_3$): 6.73 (*s*, H-C(2), H-C(3)); 4.81 (*s*, H-C(5), H-C(6)). ^{13}C NMR (75 MHz, $CDCl_3$): 187.9 (C(1), C(4)); 137.0 (C(2), C(3)); 45.1 (C(5), C(6)).

Data of 2,5-dibromo-1,4-benzoquinone: M. p.: 192-194° (Lit.:[22] 189°). IR (KBr): 3060, 1665, 1665, 1585, 1560, 1310, 1190, 990, 900, 790. ^1H NMR (300 MHz, $CDCl_3$): 7.49 (*s*, H-C(3), H-C(6)). ^{13}C NMR (101 MHz, $CDCl_3$): 177.6 (C(1), C(4)); 138.3 (C(2), C(5)); 137.6 (C(3), C(6)). EI-MS: 268 (26), 266 (54), 264 (27, M^+), 240 (6), 238 (14), 236 (6), 187 (8), 185 (8), 159 (39), 157 (40), 134 (22), 132 (23), 106 (18), 104 (18), 53 (100), 50 (19), 49 (11).

(1RS,4RS,5SR,6SR)-5,6-Dibromocyclohex-2-ene-1,4-diol (**8**). In analogy to the published procedure,[9] **7** (53.6 g, 0.2 mol) was dissolved in 900 ml of Et_2O and cooled to 2°. Under vigorous stirring, $NaBH_4$ (19.0 g, 0.5 mol, in 300 ml of H_2O) was added. The reaction mixture lost its yellow color. After 2.5 h, the Et_2O phase was separated. The aqueous layer was washed 10 times with 100 ml of Et_2O, and the combined org. phases were dried and evaporated. The crystalline residue was recrystallized from acetone/pentane 3:1 and dried: 47.0 g (86%) of **8**.

M. p.: 148-152° (Lit.:[9] 149°). IR (KBr): 3320 (br., OH), 2940, 2920, 2880, 1460, 1380, 1330, 1105, 1055, 960, 840, 720. ^1H NMR (400 MHz, $(CD_3)_2CO$): 5.73 (*s*, H-C(2), H-C(3)); 4.85 (*d*, *J*=6.5, 2H, OH, exchangeable with D_2O); 4.50 (*m*, H-C(1), H-C(4)); 4.21 (*m*, H-C(5), H-C(6)). ^1H NMR (400 MHz, $CDCl_3$): 5.84 (*s*, H-C(2), H-C(3)); 4.55 (*m*, H-C(1), H-C(4)); 4.21 (*m*, H-C(5), H-C(6)); 2.60 (br., *s*, 2H, OH). ^{13}C NMR (101 MHz, $(CD_3)_2CO$): 131.1 (C(2), C(3)); 73.9 (C(1), C(4)); 61.9 (C(5), C(6)). EI-MS: 193 (15), 191 (16, [*M*-Br]$^+$), 175 (64), 173 (65), 111 (100), 94 (34), 83 (54), 65 (82), 55 (57). Anal. calc. for $C_6H_8Br_2O_2$ (271.94): C 26.50, H 2.97; found: C 26.63, H 2.82.

(3RS,4RS,5RS,6RS)-3,4:5,6-Diepoxycyclohex-1-ene (**5**). Bis-bromohydrin **8** (5.02 g, 18.4 mmol) was dissolved under Ar in 80 ml of abs. THF containing 6.05 g of activated molecular sieves (4 Å). During 4 h, 6.82 g (0.12 mol) of powdered KOH were added in small portions; the reaction mixture turned green. After a total of 8 h, the solution was filtered and the filtrate evaporated. The residue was chromatographed (silica gel, Et_2O): 1.24 g (61%) **5** as colorless needles.

M. p.: 56.0-57.5° (Lit.:[9] 58-59°). IR(KBr): 3020, 1470 1410, 1240, 1080, 970, 950, 825, 800, 750, 610. ^1H NMR (300 MHz, $CDCl_3$): 6.06 (*m*, H-C(1), H-C(2)); 3.74 (*m*, H-C(4), H-C(5)); 3.07 (*m*, H-C(3), H-C(6)). ^{13}C NMR (75 MHz, $CDCl_3$): 129.7 (C(1), C(2)); 53.8 (C(4), C(5)); 46.6 (C(3), C(6)). EI-MS: 110 (11, M^+), 81 (100), 53 (45), 39 (17). Anal. calc. for $C_6H_6O_2$ (110.11): C 65.44, H 5.49; found: C 65.16, H 5.32.

(1RS,2RS,3RS,6RS)-3,6-Di(phenylthio)cyclohex-4-ene-1,2-diol (**9**). To a solution of **5** (80.0 mg, 0.7 mmol) in 5 ml of DMSO, sodium thiophenolate (370 mg, 2.8 mmol) and thiophenol (0.19 ml, 1.8 mmol) dissolved in 10 ml of DMSO was added in drops. After stirring for 3 h at r.t., the mixture was poured into 60 ml of sat. NH_4Cl soln. and extracted with 100 ml of Et_2O. The combined org. phases were dried, evaporated, and the residue recrystallized from pentane/CH_2Cl_2: 221 mg (92%) of **9**.

Colorless crystals, m. p. 122-123°. IR (KBr): 3340 (br., OH), 3060, 2900, 1580, 1480, 1440, 1365, 1100, 1060, 1025, 840, 770, 740, 690. ^1H NMR (360 MHz, $CDCl_3$): 7.45 (*m*, 4H, arom. H); 7.28 (*m*, 6H, arom. H); 5.67 (*s*, H-C(4), H-C(5)); 3.62* (*m*, H-C(1), H-C(2)); 3.52* (*m*, H-C(3), H-C(6)); 3.02 (*m*, 2H, OH). ^{13}C NMR (22.63 MHz, $CDCl_3$): 133.7 (*d*, phenyl *o*-C); 132.5 (*s*, phenyl *ipso*-C); 129.0 (*d*, phenyl *m* C); 128.6* (*d*, phenyl *p*-C); 128.0* (*d*, C(4), C(5)); 74.10 (*d*, C(1), C(5)); 52.01 (*d*, C(3), C(6)). EI-MS: 330 (2, M^+), 220 (100, $[M-C_6H_5SH]^+$), 203 (29), 175 (22), 111(85), 83 (90), 65 (45), 55 (26), 39 (29). CI-MS (NH_3): 348 (60, $[M+NH_4]^+$), 295 (4), 240 (6), 221 (100), 203 (55), 187 (9), 126 (12), 110 (14), 94 (9). HR-MS: 330.0753±0.0025 ($C_{18}H_{18}O_2S_2$, calc. 330.0748).

(1RS,2RS,3RS,6RS)-1,2-O-Isopropylidene-3,6-bis(phenylthio)cyclohex-4-ene-1,2-diol (**10**). Compound **9** (100 mg, 0.3 mmol) and *p*-toluenesulfonic acid (2.6 mg, 0.02 mmol) were dissolved in 3 ml of 2,2-dimethoxypropane and stirred for 5 h. The mixture was taken up in 10 ml of Et_2O, washed with 2 x 1 ml of 1N Na_2CO_3 soln., dried and evaporated: 130 mg of 91% pure **10**.

IR (KBr): 3060, 2980, 1580, 1480, 1440, 1370, 1230, 1120, 840, 740. ^1H NMR (400 MHz, $CDCl_3$): 7.47 (*m*, 4H, arom. H); 7.27 (*m*, 6H, arom. H); 5.62 (*s*, H-C(4), H-C(5)); 3.72 (*m*, H-C(1), H-C(2)); 3.50 (*m*, H-C(6), H-C(3)); 1.49 (s, $C(Me)_2$). ^{13}C NMR (101 MHz, $CDCl_3$): 133.6 (phenyl *o*-C); 132.1 (phenyl *ipso*-C); 129.2 phenyl *m*-C); 128.9* (phenyl *p*-C); 127.9* (C(4), C(5)); 110.7 ($C(CH_3)_2$); 79.0 (C(1), C(2)); 48.1 (C(3), C(6)); 27.0 ($C(CH_3)_2$). EI-MS: 370 (2, M^+), 218 (99), 203 (8), 175 (11), 154 (10), 109 (100), 77 (10), 65 (35), 51 (11), 39 (19).

(1RS,2RS,3RS,6RS)-3,6-Bis(tert-butylthio)cyclohex-4-ene-1,2-diol (**11**). To a solution of **5** (0.45 g, 4.1 mmol) in 15 ml of chloroform/methanol 1:1, 2-methylpropane-2-thiol (0.3 ml, 8.3 mmol) and pyridine (0.67 ml, 8.3 mmol) were added under vigorous stirring at 0°. After 4 h at 0°, the precipitate that had formed was collected by filtration, dried under high vacuum and recrystallized from hexane/CH_2Cl_2 4:1: 0.85 g (72%) of **11** as colorless prisms. M. p. 168-170° (sealed tube; the compound sublimes).

IR (KBr): 3480 (br., OH), 3040, 2960, 2930, 2900, 1460, 1370, 1170, 1110, 1060, 840, 760. ^1H NMR (400 MHz, $CDCl_3$): 5.58 (*s*, H-C(4), H-C(5)); 3.56 (*m*, H-C(3), H-C(6)); 3.28 (*m*, H-C(1), H-C(2)); 2.99 (br. *s*, 2H, OH); 1.38 (*s*, 18H, $C(CH_3)_3$). ^1H NMR (400 MHz, $(CD_3)_2SO$): 5.46 (*s*, 2H, OH); 4.93 (*m*, H-C(4), H-C(5)); 3.25 (*m*, H-C(3), H-C(6)); 3.15 (*m*, H-C(1), H-C(2)); 1.29 (*s*, 18H, $C(CH_3)_3$). ^{13}C NMR (22.63 MHz, $CDCl_3$): 129.4 (*d*, C(4), C(5)); 75.0 (*d*, C(1), C(2)); 46.6 (*d*, C(3), C(6)); 44.2 (*s*, $C(CH_3)_3$); 31.5 (*q*, $C(CH_3)_3$). EI-MS: 200 (19), 144 (53), 127 (12), 115 (7), 99 (19), 57 (100, $C(CH_3)_3$), 41 (32). CI-MS (NH_3): 308 (3, $[M+NH_4]^+$), 291 (18, $[M+H]^+$), 273 (4, $[M-OH]^+$), 252 (4), 235 (28), 201 (100, $[M-(CH_3)_3CS]^+$), 144 (25), 127 (5), 99 (99), 57 (5, $C(CH_3)_3$).

(1RS,2RS,3RS,6RS)-3,6-Diethoxycyclohex-4-ene-1,2-diol (**12**). Sodium (28.0 mg, 1.2 mmol) was dissolved under Ar in 10 ml of abs. EtOH, the solution cooled to 0°, and a solution of **5** (132 mg, 1.2 mmol) 8 ml abs. EtOH added in drops. The mixture was allowed to reach r.t. and stirred for 6 h. After the addition of further 70.0 mg (3.0 mmol) of sodium in 10 ml of abs. EtOH, stirring was continued for another 18 h. The solution was poured into 20 ml of sat. NH_4Cl soln. and extracted with 4 x 50 ml of Et_2O. The combined extracts were dried and evaporated. The crude product was chromatographed (20 g of silica gel, Et_2O/CH_2Cl_2 2:1): 153.2 mg (62%) of **12** as a waxy solid, which was recrystallized from pentane to give hygroscopic crystals which were dried unter high vacuum over P_2O_5.

M. p.: 54-56°. IR (KBr): 3420 (br., OH), 3040, 2980, 2880, 1650 (C=C), 1390, 1190, 980, 890, 790. ^1H NMR (400 MHz, $CDCl_3$): 5.74 (*s*, H-C(4), H-C(5)); 3.91 (*m*, H-C(3), H-C(6)); 3.68 (*m*, 6H, H-C(1), H-C(2), OCH_2); 3.29 (br. *s*, 2H, OH); 1.24 (*t*, J =7 Hz, 6H, CH_3). ^{13}C NMR (101 MHz, $CDCl_3$): 127.4 (C(4), C(5)); 79.4 (C(3), C(6)); 74.3 (C(1), C(2)); 62.3 (OCH_2); 15.6 (CH_3). EI-MS: 156 (1, $[M-C_2H_5OH]^+$), 142 (100), 127 (45), 114 (71), 99 (17), 85 (47), 57 (32), 43 (16). CI-MS (NH_3): 220 (8, $[M+NH_4]^+$), 203 (10, $[M+H]^+$), 185 (6, $[M-OH]^+$), 157 (43), 142 (100), 127 (48), 114 (55), 99 (8), 83 (8). Anal. calc. for $C_{10}H_{18}O_4$ (202.25): C 59.39, H 8.97; found: C 59.15, H 9.43.

(1RS,2RS,3SR,6SR)-3,6-Diethoxy-1,2-O-isopropylidenecyclohex-4-ene-1,2-diol (**13**). The diol **12** (10.0 mg, 0.05 mmol) and *p*-toluenesulfonic acid (2.0 mg, 1.10 mmol) were dissolved in 1 ml of 2,2-

dimethoxypropane and stirred for 18 h. The reaction mixture was then poured into 1 ml of sat. K_2CO_3 soln. and extracted with 2 x 1 ml of Et_2O. The org. extracts were combined, dried and evaporated: 11.1 mg (92%) of **13** as a viscous oil, which solidified in the cold.

IR (KBr): 3040, 2980, 2940, 2880, 1380, 1230, 1095, 850, 800. ^1H NMR (400 MHz, $CDCl_3$): 5.71 (*s*, H-C(4), H-C(5)); 4.11 (*m*, H-C(3), H-C(6)); 3.77 (*m*, 2H, OCH_2); 3.65 (*m*, 2H, OCH_2); 3.55 (*m*, H-C(1), H-C(2)); 1.45 (*s*, $C(CH_3)_2$); 1.24 (*t*, *J*=7 Hz, 6H, OCH_2CH_3). ^{13}C NMR (101 MHz, $CDCl_3$): 128.8 (*d*, C(4), C(5)); 110.8 (*s*, $C(CH_3)_2$); 80.0 (*d*, C(3), C(6)); 77.6 (*d*, C(1), C(2)); 65.2 (*t*, OCH_2); 27.1 (*q*, $C(CH_3)_2$); 15.5 (*q*, OCH_2CH_3). EI-MS: 227 (0.2, $[M-CH_3]^+$), 167 (5), 155 (100), 142 (62), 129 (14), 99 (16), 87 (16), 59 (14), 43 (31). CI-MS (NH_3): 243 (100, $[M+H]^+$), 185 (3), 155 (11), 139 (35), 103 (10).

[1,4-$^2H_2$](1RS,4RS,5SR,6SR)-5,6-Dibromocyclohex-2-ene-1,4-diol (**17**). The dibromoquinone **7** (2.57 g, 9.6 mmol) was dissolved in 60 ml of Et_2O and cooled to 0°. A solution of 1.00 g (24 mmol) of $NaBD_4$ (*Fluka*) in 20 ml of H_2O was added under vigorous stirring, keeping the temperature below 10°. After 4 h, the mixture was allowed to reach r.t. and was stirred for another 1 h. The two phases were then separated and the aqueous phase washed with 3 x 50 ml of Et_2O. The combined org. phases were washed with sat. NaCl soln., dried and evaporated: 4.21 g of crude product, of which 1.90 g were subjected to recrystallization from $CHCl_3$: 1.30 g of crystalline **17**. M. p. 152-154°.

IR (KBr): 3340 (br., OH), 2930, 2860, 1380, 1235, 1100, 970, 835, 720. ^1H NMR (90 MHz, $(CD_3)_2CO$): 5.72 (*s*, H-C(2), H-C(3)); 4.84 (*s*, 2H, OH); 4.20 (*s*, H-C(5), H-C(6)). ^{13}C NMR (22.63 MHz, $(CD_3)_2CO$): 131.1 (*d*, C(2), C(3)); 73.6 (3*s*, $^1J_{C,D}$=22.5, C(1), C(4)); 61.7 (*d*, C(5), C(6)). EI-MS: 195 (17), 193 (18, $[M-Br]^+$), 177 (97), 175 (100), 149 (13), 147 (12), 135 (8), 133 (8), 113 (93), 96 (26), 88 (46), 67 (70), 58 (54), 40 (40).

[3,6-$^2H_2$](3RS,4RS,5RS,6RS)-3,4:5,6-Diepoxycyclohex-1-ene (**18**). To a solution of the crude diol **17** (2.31 g, 8.4 mmol) in 100 ml of Et_2O, a mixture of powdered KOH (6.00 g) and $MgSO_4$ (6.00 g) was added in portions at 0° under vigorous stirring. After 4 h, the mixtrue was allowed to reach r.t. The inorganic salts were filtered off and washed with Et_2O. After evaporation of the filtrate, the crude product was recrystallized from Et_2O/pentane 2:1: 0.56 g (60%) of **18** as colorless needles.

M. p. 52.5-54°. IR (KBr): 3020 (C=CH), 1440, 1400, 1290, 1140, 995, 940, 770. ^1H NMR (90 MHz, $CDCl_3$): 6.06 (*s*, H-C(2), H-C(1)); 3.73 (*s*, H-C(4), H-C(5)). ^{13}C NMR (22.63 MHz, $CDCl_3$): 129.7 (*d*, C(1), C(2)); 53.8 (*d*, C(4), C(5)); 46.3 (3*s*, $^1J_{C,D}$=27.5, C(3), C(6)). EI-MS: 112 (11.34, M^+), 110 (1.70), 83 (100), 82 (59), 55 (92), 40 (42).

Deuterium content: 87%, as calculated from the ratio of the MS peaks at *m/z* 112 (M^+ of the deuterated compound, relative intensity 11.34) and *m/z* 110 (M^+ of the non-deuterated compound, 1.70).

(1RS,4SR,5RS,6SR)-4-Butyl-5,6-epoxycyclohex-2-en-1-ol (**15**). To a solution of **5** (50.0 mg, 0.45 mmol) in 6 ml of abs. THF, BuLi in hexane (0.28 ml of a 1.6 M solution, 0.045 mmol) was added under Ar at -78°. After stirring for 5 h, the mixture was poured into 20 ml of sat. NH_4Cl soln. This was then extracted with 3 x 20 ml of Et_2O. The Et_2O portions were combined, washed with a little sat. NaCl soln., dried and evaporated. The crude product was chromatographed (15 g of silica gel, $CHCl_3$/AcOEt 97:3): 65.0 mg (86%) of **15** as colorless oil.

IR (film): 3420 (br., OH), 2960, 2920, 2860, 1470, 1260, 1020, 800. ^1H NMR (400 MHz, $CDCl_3$): 5.64 (*m*, H-C(2)); 5.57 (*m*, H-C(3)); 4.44 (br. *s*, H-C(1)); 3.22 (*m*, H-C(6)); 3.10 (*m*, H-C(5)); 2.61 (br. *s*, H-C(4)); 1.72 (br. *s*, OH)); 1.52 (br. *m*, CH_2(1')); 1.34 (br. *m*, CH_2(2'), CH_2(3')); 0.88 (*t*, *J*=7, CH_3(4')). ^{13}C NMR (101 MHz, $CDCl_3$): 130.2 (C(3)); 123.8 (C(2)); 63.2 (C(1)); 54.5 (C(5)); 53.6 (C(6)); 35.1 (C(4)); 33.0 (C(1')); 29.0 (C(2')); 22.9 (C(3')); 14.0 (C (4')). EI-MS: 168 (4, M^+), 151 (3), 139 (7), 125 (30), 111 (57, $[M-C_4H_9]^+$), 107 (15), 95 (31), 83 (60), 67 (29), 55 (100), 41 (80). CI-MS (NH_3): 186 (19, $[M+NH_4]^+$), 168 (50, M^+), 151 (100), 123 (9), 107 (3), 91 (4), 81 (3), 58 (3).

[2,5-$^2H_2$](1RS,4SR,5RS,6SR)-4-Butyl-5,6-epoxycyclohex-2-en-1-ol (**19**). To a solution of **18** (0.38 g, 3.4 mmol) in 25 ml of abs THF, BuLi in hexane (2.20 ml of a 1.6 M solution, 3.5 mmol) was added under Ar at -78° and treated as above. After chromatography (40 g of silica gel), 0.37 g (64%) of **19** were obtained as a pale yellow oil.

IR (film): 3420 (br., OH), 2960, 2940, 2860, 2225, 1650, 1470, 1380, 1030, 820, 730. ^1H NMR (90 MHz, $CDCl_3$): 5.60 (*d*, *J*=4, H-C(3)); 4.44 (br. *s*, H-C(1)); 3.22 (*t*, *J*=1.3, H-C(6)); 2.57 (br. *s*, H-C(4), OH); 1.42 (br. *m*, CH_2(1'), CH_2(2'), CH_2(3')); 0.92 (*t*, *J*=6.2, CH_3(4')). ^{13}C NMR (22.63 MHz, $CDCl_3$): 129.9 (*d*, C(3)); 123.6 (3*s*, $^1J_{C,D}$=24.6, C(2)); 63.0 (*d*, C(1)); 54.1 (3*s*, $^1J_{C,D}$=26.8, C(5)); 53.5 (*d*, C(6)); 34.9 (*d*,

C(4)); 32.8 (*t*, C(1')); 28.9 (*t*, C(2')); 22.7 (*t*, C(3')); 13.7 (*q*, C(4')). EI-MS: 170 (6, M^+), 153 (4), 141 (10), 127 (54, 113 (98, $[M-C_4H_9]^+$), 96 (55), 85 (100), 69 (51), 56 (89), 41(80). CI-MS (NH_3): 188 (16, $[M+NH_4]^+$), 170 (61, M^+), 153 (100), 125 (15), 113 (6), 93 (6), 83 (14).

(1RS,4SR,5RS,6SR)-4-Methyl-5,6-epoxycyclohex-2-en-1-ol (**16**). To a solution of **5** (109 mg, 0.99 mmol) in 15 ml of abs. Et_2O, MeLi (1.6 M in Et_2O, 760 µl, 1.22 mmol) was added at r.t. under Ar with stirring. After 2 h, the reaction was quenched by adding 10 ml of ice-cold H_2O. The aqueous phase was extracted with Et_2O (8 x 5 ml). The org. extracts were combined, dried and evaporated. The crude product (134 mg) was purified by chromatography (8 g of silica gel, CH_2Cl_2/EtOAc 9:1): 91.5 g (77%) of **16** as a slightly yellowish oil.

IR (film): 3400 (br., OH), 3020, 2980, 2890, 1650, 1450, 1410, 1255, 1033, 955, 860, 810, 780. ^1H NMR (400 MHz, $CDCl_3$): 5.63 (*m*, H-C(2), H-C(3)); 4.48 (*m*, H-C(1)); 3.27 (*m*, H-C(6)); 3.13 (*m*, H-C(5)); 2.70 (*m*, H-C(4)); 2.31 (*m*, OH, exchangeable with D_2O); 1.20 (*d*, *J*=7.4, CH_3). ^{13}C NMR (101 MHz, $CDCl_3$): 131.5 (C(3)); 123.2 (C(2)); 63.0 (C(1)); 55.3 (C(5)); 53.6 (C(6)); 30.0 (C(4)); 18.5 (CH_3). CI-MS (NH_3): 144 (41, $[M+NH_4]^+$), 127 (10, $[M+1]^+$), 126 (100, M^+), 109 (36), 108 (15), 81 (5). EI-MS: 126 (3, M^+), 125 (14), 111 (31), 109 (19), 97 (42), 84 (24), 80 (31), 79 (36), 71 (36), 69 (15), 67 (12), 65 (15), 55 (47), 43 (98), 41 (100);, 39 (67). Anal. calc. for $C_7H_{10}O_2$ (126.16): C 66.65, H 7.99; found: C 66.40, H 7.58.

Reaction of **5** *with Bu_2CuLi.* To a suspension of CuI (86.0 mg, 0.45 mmol) in 3 ml of abs. THF under Ar at -78°, BuLi (0.6 ml, 1.6 M soln. in hexane, 0.96 mmol) was added with stirring. The mixture was allowed to warm up to -30° for 10 min, whereupon the suspension turned into a clear solution, which was then again cooled to -78°. A solution of **5** (50.0 mg, 0.45 mmol) in 6 ml of abs. THF was added in drops. After stirring for 5 h, the mixture was poured into 20 ml of sat. NH_4Cl soln., which was extracted with Et_2O (3 x 20 ml). The combined org. phases were washed with sat. NaCl soln., dried, and evaporated. The crude product (103 mg) consisted of **15**, **20**, and **22** in a ratio of 36:55:6 (GC) and was subjected to flash chromatography (15 g of silica gel *Merck* 5-25 µm, CH_2Cl_2/acetone 99:1 → 92:8): 23.4 mg of *(1RS,4SR,5RS,6SR)-4-butyl-5,6-epoxycyclohex-2-en-1-ol* (**15**), 5.5 mg of *(1RS,4RS,5RS,6SR)-4-butyl-5,6-epoxycyclohex-2-en-1-ol* (**20**), and 2.0 mg of *(1RS,2RS,3SR,6SR)-3,6-dibutylcyclohex-4-ene-1,2-diol* (**22**).

Data of **20**: IR (KBr): 3410 (br., OH), 3020, 2960, 2930, 2860, 1470, 1455, 1270, 1255, 1130, 1120, 865, 785. ^1H NMR (400 MHz, $CDCl_3$): 5.68 (*m*, H-C(2)); 5.51 (*m*, H-C(3)); 4.43 (*s*, H-C(1)); 3.30 (*s*, H-C(5), H-C(6)); 2.51 (br. *s*, H-C(4)); 1.70 (br. *m*, OH); 1.48 (*m*, CH_2(1'), CH_2(2')); 1.37 (*m*, CH_2(3')); 0.93 (*t*, *J*=8 Hz, CH_3(4')). ^{13}C NMR (101 MHz, $CDCl_3$): 130.0 (C(4)); 124.0 (C(2)); 63.1 (C(1)); 54.2 (C(5)); 53.8 (C(6)); 34.3 (C(4)); 32.5 (C(1')); 28.9 (C (2')); 22.8 (C(3')); 14.0 (C(4')). EI-MS: 168 (3, M^+), 167 (6), 139 (5), 125 (24), 111 (53, $[M-C_4H_9]^+$), 97 (20), 95 (20), 83 (70), 79 (39), 67 (30), 55 (100), 43 (49, C_3H_7), 41 (82). CI-MS (NH_3): 186 (17, $[M+NH_4]^+$), 168 (64, M^+), 151 (100), 125 (9), 123 (10), 111 (10), 81 (20).

Data of **22**: IR (KBr): 3380 (br., OH), 3020, 2960, 2920, 2860, 1465, 1380, 1070, 720. ^1H NMR (400 MHz, $CDCl_3$): 5.46 (*s*, H-C(4), H-C(5)); 3.35 (*m*, H-C(1), H-C(2)); 2.40 (br. *s*, 2H, OH); 2.12 (br. *s*, H-C(3), H-C(6)); 1.71 (br. *m*, CH_2(1'), CH_2(1")); 1.34 (br. *m*, CH_2(2'), CH_2(2"), CH_2(3'), CH_2(3")); 0.91 (*t*, *J*=7 Hz, CH_3(4'), CH_3(4")). ^{13}C NMR (101 MHz, $CDCl_3$): 128.3 (C(4), C(5)); 76.2 (C(1), C(2)); 43.0 (C(3), C(6)); 31.6 (C(1'), C(1")); 28.4 (C(2'), C(2")); 23.1 (C(3'), C(3")); 14,1 (C(4'), C(4")). EI-MS: 226 (14, M^+), 166 (42), 151 (30), 129 (100), 111 (37), 95 (26), 81 (37), 67 (72), 57 (61), 55 (53), 41 (71). CI-MS (NH_3): 244 (100, $[M+NH_4]^+$), 226 (6), 209 (11), 191 (3), 166 (3), 151 (3).

Reaction of **5** *with Me_2CuLi.* To a suspension of CuI (3.42 g, 18.2 mmol) in 100 ml of abs. THF under Ar at -78°, MeLi (24 ml, 1.6 M soln. in Et_2O, 38 mmol) was added with stirring. The mixture was allowed to warm up briefly to -20°. The yellow solution obtained was cooled to -30°, and a solution of **5** (2.12 g, 19.3 mmol) in 200 ml of abs. THF was added in drops over a period of 1 h. The temperature rose to -24° and stirring was continued at this temperature for 3 h. The reaction mixture was poured into 100 ml of H_2O and the aqueous phase extracted with Et_2O (3 x 100 ml). The combined org. phases were washed with 50 ml of sat. NaCl soln., dired and evaporated. The crude product (2.36 g) consisted of **16**, **21**, **23**, and **24** and was chromatographed (250 g of silica gel, CH_2Cl_2/Et_2O 2:1): 890 mg (32%) of *(1RS,4RS,5RS,6SR)-4-methyl-5,6-epoxycyclohex-2-en-1-ol* (**21**, contaminated with **16**, **21**:**16**≈7:1, separation could not be achieved), 300 mg (19%) of *(1RS,2RS,3SR,6SR)-3,6-dimethylcyclohex-4-ene-1,2-diol* (**23**), and 150 mg (12%) of *(1RS,2RS)-cyclohexa-3,5-diene-1,2-diol* (**24**, Ref.[23]).

Data of **21**: slightly yellow oil. IR (film): 3400, 3030, 2980, 2880, 1650, 1455, 1370, 1250, 1025, 960, 855, 800. ^1H NMR (400 MHz, $CDCl_3$):[24] 5.62 (*m*, H-C(2)); 5.42 (*m*, H-C(3)); 4.41 (br. *s*, H-C(1)); 3.30* (*m*,

H-C(6)); 3.24* (*m*, H-C(5)); 2.65 (br. *m*, H-C(4)); 2.47 (br. *s*, OH); 1.18 (*d*, *J*=7.3, CH_3). ^{13}C NMR (101 MHz, $CDCl_3$):[24] 130.7 (C(3)); 123.6 (C(2)); 62.5 (C(1)); 55.0* (C(5)); 54.5* (C(6)); 29.2 (C(4)); 17.6 (CH_3). EI-MS: 126 (2, M^+), 125 (12), 111 (35), 109 (30), 97 (53), 84 (24), 80 (37), 79 (38), 71 (50), 69 (25), 65 (14), 55 (49), 51 (15), 43 (62), 41 (100), 39 (66). CI-MS (NH_3): 144 (26, $[M+18]^+$), 126 (81, M^+), 111 (16), 109 (100), 97 (15), 81 (46), 80 (28), 69 (5), 65 (4), 55 (8).

Data of **23**: colorless needles (recryst. from pentane/Et_2O) m. p. 101-102°. IR (KBr): 3360, 3260, 3020, 2960, 2880, 1665, 1450, 1370, 1270, 1090, 1050, 1000, 880, 720. ^1H NMR (400 MHz, $CDCl_3$): 5.30 (*s*, H-C(4), H-C(5)); 4.12 (*s*, 2H, OH); 3.23 (*d*, *J*=7.8, H-C(1), H-C(2)); 2.19 (*m*, H-C(3), H-C(6)); 1.12 (*d*, *J*=7, CH_3-C(3), CH_3-C(6)). ^{13}C NMR (101 MHz, $CDCl_3$): 129.8 (C(4), C(5)); 78.1 (C(1), C(2)); 38.3 (C(3), C(6)); 18.4 (CH_3-C(3), CH_3-C(6)). EI-MS: 142 (20, M^+), 125 (5), 124 (6), 111 (10), 109 (17), 95 (10), 87 (99), 84 (100), 82 (97), 79 (8), 71 (14), 67 (79), 60 (32), 55 (43), 43 (41), 41 (55), 39 (33). CI-MS (NH_3): 161 (9), 160 (100, $[M+NH_4]^+$), 142 (12, M^+), 125 (19), 107 (8), 95 (7), 82 (30), 67 (5). Anal. calc. for $C_8H_{14}O_2$ (142.20): C 67.57, H 9.92; found: C 67.41, H 10.23.

Data of **24**: Colorless prisms from pentane/CH_2Cl_2, m. p. 58-62° (contaminated with ca 10% of a regioisomer of **23**). IR (KBr, *cf.* Ref.[23]): 3400, 3040, 2850, 1385, 1345, 1290, 1258, 1070, 1018, 840, 690. ^1H NMR (400 MHz, $CDCl_3$): 5.88 (*s*, H-C(3), H-C(4), H-C(5), H-C(6)); 4.51 (*s*, H-C(1), H-C(2)); 4.08 (br. *s*, 2H, OH). ^{13}C NMR (101 MHz, $CDCl_3$): 130.9 (C(3), C(6)); 124.1 (C(4), C(5)); 74.7 (C(1), C(2)).

Reaction of **5** *with* $Me_2Cu(CN)Li_2$. To a suspension of dry CuCN (823 mg, 9.1 mmol) in 9 ml of abs. THF under Ar at -78°, MeLi (10.1 ml, 1.6 M soln. in Et_2O, 18.3 mmol) was added with stirring. The mixture was allowed to warm up briefly to -24°. The yellow solution obtained was cooled to -78°, and a solution of **5** (930 mg, 8.5 mmol) in 40 ml of abs. THF was added in drops over a period of 45 min. The temperature rose to -61°, and stirring of the orange suspension obtained was continued at -78° for 3 h. The reaction mixture was poured into 50 ml of sat. NH_4Cl soln. at 0° and the aqueous phase successively extracted with 80 ml of CH_2Cl_2 and Et_2O (2 x 80 ml). The combined org. phases were washed with 30 ml of sat. NaCl soln., dried and evaporated. The crude product (1.45 g) consisted of **16**, **21**, and **24** and was chromatographed (120 g of silica gel, CH_2Cl_2/AcOEt 4:1→1:8): 480 mg (45%) of *(1RS,4RS,5RS,6SR)-4-methyl-5,6-epoxycyclohex-2-en-1-ol* (**21**, contaminated with **16**, **21**:**16**≈7:1, separation could not be achieved) and 330 mg (35%) of *(1RS,2RS)-cyclohexa-3,5-diene-1,2-diol* (**24**).

(1RS,2RS,5SR,6RS)-2-Chloro-5,6-epoxycyclohex-3-en-1-ol (**25**). To a solution of **5** (748 mg, 6.8 mmol) in 10 ml of abs. THF, 10 ml of 14% NH_4Cl soln. and 1 ml of 6.8 N NaOH were added. After stirring for 1 h at r.t., the mixture was extracted with Et_2O, the organic phases combined, dried, and evaporated: 310 mg of crude product, which was chromatographed (31 g of silica gel, CH_2Cl_2/AcOEt 9:1) to give 100 mg (13%) of starting material **5** and 180 mg (18%) of **25**.

Colorless prisms (recryst. from pentane/CH_2Cl_2), m.p. 42-48°. IR (KBr): 3400, 3000, 2900, 1630, 1400, 1270, 1040, 1000, 840, 820. ^1H NMR (400 MHz, $CDCl_3$): 6.24 (*dd*, *J*=3.7, 9.9, H-C(3)); 6.00 (*m*, H-C(4)); 4.42 (*m*, H-C(1), H-C(2)); 3.62 (*m*, H-C(6)); 3.40 (*m*, H-C(5)); 3.0 (*d*, *J*=6.3, OH). ^{13}C NMR (101 MHz, $CDCl_3$): 130.9* (C(4)); 127.6 (C(3)); 69.6 (C(1)); 56.8 (C(6)); 54.2 (C(2)); 46.0 (C(5). EI-MS: 119 (6), 117 (20), 111 (25, $[M-Cl]^+$), 102 (20), 100 (21), 87 (19), 83 (40), 81 (100), 68 (32), 65 (39), 60 (17), 55 (38), 53 (56), 51 (51), 43 (26), 39 (53). CI-MS (NH_3): 166 (26), 164 (83, $[M+NH_4]^+$), 146 (6, M^+), 129 (7), 111 (68, $[M-Cl]^+$), 102 (13), 81 (100), 68 (22), 65 (19), 53 (16).

(1RS,4SR,5RS,6SR)-4-Methyl-5,6-epoxycyclohex-2-en-1-yl 4-nitrobenzoate (**26**). To a solution of **16** (251 mg, 1.99 mmol) in 2 ml of dry pyridine, 4-nitrobenzoyl chloride (378 mg, 2.04 mmol, in 3 ml of pyridine) was added in drops at 0°. After keeping the mixture at 55° for 4 h and then cooling it to 0°, 10 ml of ice-cold H_2O and 10 ml of Et_2O were added. The aqueous phase was extracted with 5 x 5 ml of Et_2O. The combined org. phases were combined, dried, and evaporated. Remaining traces of pyridine were removed azeotropically with toluene. The crude product (598 mg) was chromatographed (40 g of silica gel, pentane/THF 5:1) and recrystallized from Et_2O/pentane 5:1: 499 mg (91%) of **26**.

M. p.: 75-76.5°. IR (KBr): 3120, 2960, 2930, 2870, 1715, 1610, 1530 (NO_2), 1345, 1325, 1285, 1270, 1120, 1100, 935, 715. ^1H NMR (300 MHz, $CDCl_3$): 8.32 (*d*, *J*=8.7, aryl H-C(3), H-C(5)); 8.23 (*d*, *J*=8.7, aryl H-C(2), H-C(6)); 5.84 (*m*, H-C(1), H-C(2)); 5.70 (*m*, H-C(3)); 3.39 (*m*, H-C(6)); 3.21 (*d*, *J*=2, H-C(5)); 2.81 (*m*, H-C(4)); 1.27 (*d*, *J*=7.3, Me). ^{13}C NMR (75 MHz, $CDCl_3$): 164.7 (C=O); 151.2 (aryl C(4)); 135.8 (aryl C(1)); 135.1 (C(3)); 131.3 (aryl C(2), C(6)); 124.1 (aryl C(3), C(5)); 119.3 (C(2)); 67.2 (C(1)); 54.9 (C(5)); 51.1 (C(6)); 30.2 (C(4)); 18.3 (Me)). EI-MS: 167 (3), 151 (13), 150 (100), 134 (3), 125 (4), 120 (5), 108 (15),

104 (19), 92 (7), 81 (10), 79 (10), 76 (13), 65 (6), 53 (6), 50 (7), 41 (11). CI-MS (NH_3): 277 (16), 276 ([*M*+H]$^+$, 100), 260 (1), 246 (7), 155 (12), 137 (6), 120 (11) 109 (6). Anal. calc. for $C_{14}H_{13}NO_5$ (275.26): C 61.09, H 4.76, N 5.09; found: C 61.29, H 4.87, N 5.20.

X-Ray structure analysis of **26**.[25] The X-ray structure of **26** is shown in *Figure 1*. For crystal data and parameters of the data collection see below. Unit-cell parameters were determined by accurate centering of 25 strong independent reflections by the least-squares method. Reflection intensities were collected at r.t. on a four-circle diffractometer *Enraf-Nonius CAD4* equipped with a graphite monochromator and using Mo$K\alpha$ radiation. Three standard reflections monitored every h during data collection showed no intensity loss. The usual corrections were applied. Diffraction absorption correction was calculated with DIFABS.[26] The structure was solved by direct-methods strategies using the programs SHELXS-86.[27] Anisotropic least-squares refinement was carried out on all non-H atoms using the program CRYSTALS.[28] Positions of H atoms were calculated with the exception of those attached to the epoxide C atoms. They were refined isotropically restraining the C-H distances to 1.0 Å. Scattering factors were taken from *International Tables of Crystallography Vol. IV*.[29] Fractional coordinates are deposited in the *Cambridge Crystallographic Data Base*.

Molecular formula	$C_{14}H_{13}NO_5$	Abs. coeff. [cm^{-1}]	0.955
Crystal system	monoclinic	Temperature [K]	298
Space group	$P2_1/a$	θ_{max} [°]	28
a [Å]	12.353(6)	Radiation; λ [Å]	Mo$K\alpha$; 0.71069
b [Å]	7.448(1)	Scan type	$\omega/2\theta$
c [Å]	15.041(5)	No. of independent refl.	3141
α [°]	90.0	No. of refl. in refinement	1246
β [°]	96.57(4)	No. of variables	189
γ [°]	90.0	R	6.37
V [Å^3]	1374.7(9)	R_w	5.32
Z	4	Weighting scheme	weight x $[1-(\Delta F/6\sigma F)^2]^2$
Crystal dimensions [mm]	0.18 x 0.25 x 0.29	Weighting parameters	1.23, -8.21, -2.64, -4.03, -2.15

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