Acknowledgment. This study was supported in part by Grants CA-12227 and 12218 awarded by the National Cancer Institute, DHEW, and the Samuel S. Fels Fund.

Registry No.—*p*-chlorobenzenesulfonamide, 98-64-6; *p*-tolylsulfonamide, 70-55-3; benzene sulfonamide, 98-10-2; *p*-nitroaniline, 100-01-6; dimethyl sulfoxide, 67-68-5; oxalyl chloride, 79-37-8.

References and Notes

(1) Iminosulfuranes 18. Paper 17: T. W. Ku and D. Swern, *J. Org. Chem.*, submitted.
(2) Taken from the Ph.D. Thesis of S. L. Huang, Temple University, 1978.
(3) K. Omura and D. Swern, *Tetrahedron*, **34**, 1651 (1978).
(4) A. J. Mancuso, S. L. Huang, and D. Swern, *J. Org. Chem.*, **43**, 2480 (1978).
(5) T. E. Varkey, G. F. Whitfield, and D. Swern, *J. Org. Chem.*, **39**, 3365 (1974).
(6) L. Horner and A. Christmann, *Chem. Ber.*, **96**, 388 (1963).
(7) M. V. Likhorsherstov, *Zh. Obshch. Khim.*, **17**, 1478 (1947).
(8) Starting materials and instrumentation used are described in references 1, 3, 4, and 5. *Caution:* Reaction of Me_2SO with OC is highly exothermic.

Synthesis and Molecular Structure of 1,3-Dihydro-1-hydroxy-3-methyl-1,2,3-benziodoxaphosphole 3-Oxide

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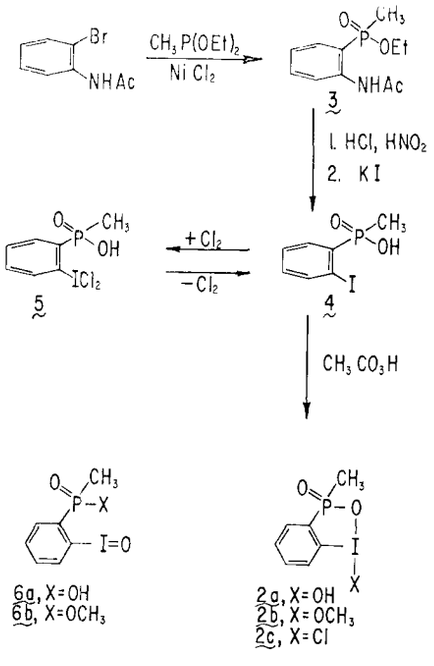
Synthesis of iodosobenzene substituted with phosphorus and sulfur acids in the ortho position has been the subject of several papers[1] since Willgerodt[2] first prepared 2-iodosobenzoic acid (1) in 1893. In all cases, an iodinane (tricoordinate iodine) structure has been proposed based on chemical stability, pK_a measurements, and absorption spectroscopy. This note describes the synthesis and NMR spectra of iodinane **2a.** That **2a** is a tricoordinate iodinane is confirmed by an X-ray structure determination.



The synthesis of iodinane **2a** is outlined below. Arylphosphinate **3** is prepared in 98% yield via a $NiCl_2$-catalyzed Arbuzov reaction of diethyl methylphosphonite and 2-bromoacetanilide. Without purification, **3** is hydrolyzed, diazotized, and converted to the aryl iodide **4.** Much tar is formed in this preparation, making purification by standard methods difficult. Taking advantage of the ease of oxidation of aryl iodides by chlorine[3] renders this purification trivial. Passing chlorine through a $CHCl_3$ solution of the mixture causes crystallization of iododichloride **5.** Heating **5** in boiling $CHCl_3$ induces reductive elimination of chlorine to give **4** on cooling. Oxidation of **4** to **2a** with peracetic acid completes the sequence.

The field desorption mass spectrum of **2a** exhibits, in addition to a molecular ion at *m/e* 298, peaks for $M^{+\cdot} - O$ and $M^{+\cdot} - OH$. Loss of oxygen probably arises from the radical cation of **6a.** The NMR spectrum of **2a** (Me_2SO-d_6) shows a broad D_2O exchangeable absorption at δ 8.61 for the hydroxyl proton and a poorly defined aromatic multiplet. The methyl group on phosphorus appears as a sharp doublet (J_{PH} = 14 Hz) at δ 1.40. No unique absorptions for an open tautomer, **6a,** are observed. No broadening of the doublet is observed at −45 °C (CD_2Cl_2). If an equilibrium exists (**2a** ⇄ **6a**), it is rapid even at this low temperature (assuming no accidental equivalence). The carbon α to iodine appears at δ 121.06 in the ^{13}C NMR spectrum of **2a,** in contrast to a value of δ 98.24 for the same carbon in **4.** This large downfield shift, resulting from oxidation of iodine, has been observed by us for several iodide–iodinane systems.[4]

When **2a** is allowed to react with hot methanol, **2b** is formed quantitatively. The methoxyiodinane reacts with moist air to give **2a,** and no satisfactory elemental analysis has been obtained. That **2b** exists as the iodinane and not **6b** is clearly shown by its NMR spectrum. The OCH_3 group appears as a singlet (no PH coupling, as would be expected for **6b**) at δ 4.25.

No chloroiodinane **2c** is detected on reaction of **5** with triethylamine, sodium acetate, or hot methanol. Reduction to **4** is found in all cases.

Crystal Structure of 2a. Figure 1 shows the pertinent intramolecular bond distances and bond angles for **2a.** The values are the average of the two unique molecules composing the asymmetric unit in the triclinic cell. Iodinane **2a** is best described as a slightly distorted trigonal bipyramid about iodine. Least-squares mean calculations for both molecules in the asymmetric unit show the five- and six-membered rings to be essentially planar (maximum deviation from planarity is 0.1 Å, with the dihedral angles between the five- and six-membered rings averaging 4.01°). Mean plane calculations for each iodine atom and the three atoms bonded to it show the bonding geometry about each iodine to be planar to within ±0.04 Å. For complete tables of mean plane calculations, see the paragraph at the end of this paper regarding supplementary material.

The O–I–O bond angle is 171.3°. Deviations from 180° comparable to this have been observed for **1** as well as for other hypervalent compounds.[5,6] Strain in the heterocyclic ring and repulsion between the lone pairs and bonding electrons have been advanced to explain these deflections from a linear three center four-electron bond.[5,6]

The exocyclic and endocyclic I–O bond distances are respectively shorter (0.04 Å) and longer (0.30 Å) than the sum of 1.99 Å expected[5] for an I–O single bond. While the elongation of the endocyclic bond may result from steric strain, a significant amount of ionic character in this bond is probably the major factor. Bonding schemes[7] for hypervalent molecules predict high electron densities on the apical ligands. The phosphinate group can more readily accommodate the partial negative charge than can the OH group, and hence dissymmetry in the I–O bond lengths. Iodinane **1** also has an elongated[5] ring I–O bond (2.30 Å). The slight shortening of the exocyclic I–O bond could result from crystal forces or an electrostatic attraction concomitant with increased positive charge character on iodine. Vast size differences between 5d and 2p orbitals make π overlap unlikely at best.[3] Remaining

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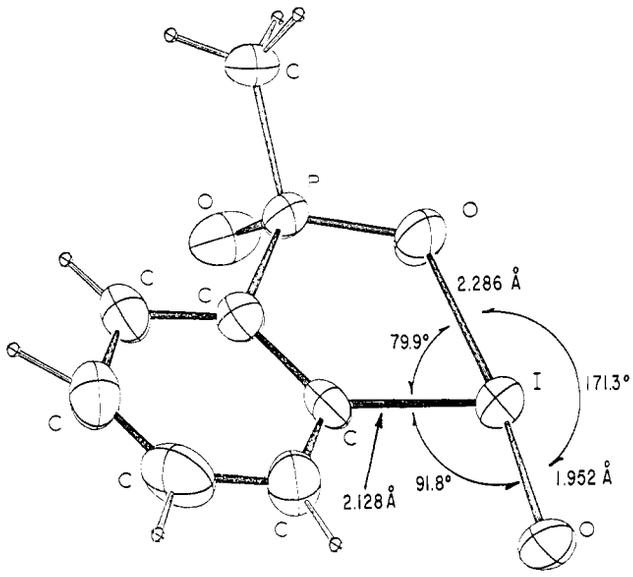

Figure 1. Pertinent bond lengths and angles of **2a.**

bond distances and bond angles within the molecule are not unusual and do not warrant detailed discussion.[8]

Experimental Section

General. Melting points were determined on a Mel-Temp melting point apparatus and are uncorrected. NMR spectra were obtained on Varian T-60 and JEOL FX-100 spectrometers. Chemical shifts are reported on the δ scale, parts per million downfield from a Me_4Si internal standard. Mass spectra were obtained on Varian MAT 311A and MAT CH 7 spectrometers. Elemental analyses were performed by Atlantic Microlabs, Atlanta, Ga.

2-Iodophenylmethylphosphinic Acid (4). To a flask fitted with a distillation head, addition funnel, stirrer, and thermometer was added 2-bromoacetanilide (33.66 g, 157 mmol) and anhydrous $NiCl_2$ (100 mg). The mixture was heated to 170 °C, and diethyl methylphosphonite (22.7 g, 165 mmol) was added at a rate to maintain a pot temperature of 160–190 °C. The ethyl bromide that formed was distilled into a cold trap. Cooling gave 37.2 g (154 mmol, 98.2%) of **3** as a semisolid: ^1H NMR ($CDCl_2$) δ 1.34 (t, 3, J_{HH} = 7.1 Hz, CH_2CH_3), 1.62 (d, 3, J_{PH} = 14.2 Hz, -P-CH_3), 2.19 (s, 3, $COCH_3$), 4.02 (p, 2, J_{PH} = J_{HH} = 7.1 Hz, OCH_2), 6.92–7.69 (m, 5, ArH and NH).

Phosphinate **3** was dissolved in 50% H_2SO_4 and the solution cooled to 0–5 °C. A solution of $NaNO_2$ (10.83 g, 157 mmol) in 30 mL of water was added so the temperature did not exceed 5 °C. After stirring 10 min more, KI (26.06 g, 157 mmol) in 40 mL of water was added slowly (≤5 °C). The mixture was slowly warmed to room temperature (**caution!**) and then heated to 45 °C for 15 min. Sodium hydrosulfite was added and the solution extracted with $CHCl_3$. Chlorine was passed through the $CHCl_3$ solution (4 °C), and a yellow solid (**5**) which formed was collected and dried. This was dissolved in boiling $CHCl_3$, and then hexane was added to induce crystallization of pure **4:** 11.1 g (39.4 mmol, 25.1%); mp 144–147 °C; ^1H NMR δ 1.84 (d, 3, J_{PH} = 16 Hz, P-CH_3), 7.34 (m, 2), 8.02 (m, 2), 12.88 (s, 1, OH); mass spectrum (120 eV), *m/e* 282 ($M^{+\cdot}$), 155 ($M^{+\cdot}$ – I).

Anal. Calcd for $C_7H_8IO_2P$: C, 29.81; H, 2.86; I, 45.00. Found: C, 29.85; H, 2.88; I, 44.82.

Iodinane 2a. Acid **4** (1.5 g, 5.32 mmol) was placed in a flask cooled with ice. Peracetic acid (4.04 g of a 40% solution, 26.6 mmol) was added slowly. The mixture was alternately warmed and cooled to initiate and control the reaction. After 1 h, a homogeneous solution resulted. The reaction mixture was added to acetone (25 mL) and cooled overnight (−29 °C) to give 1.04 g (3.5 mmol, 66.0%) of **2a:** mp 178–185 °C dec; ^1H NMR (Me_2SO-d_6) δ 1.40 (d, J_{PH} = 14 Hz), 1.50 (d, J_{PH} = 14 Hz), 7.78 (m), and see text; mass spectrum (FD, source temperature 70 °C), *m/e* 298 ($M^{+\cdot}$), 282 ($M^{+\cdot}$ – O), 281 ($M^{+\cdot}$ – OH).

Anal. Calcd for $C_7H_8IO_3P$: C, 28.21; H, 2.71; I, 42.58. Found: C, 28.02; H, 2.76; I, 42.40.

NMR Observation of Methoxyiodinane 2b. To methanol (15 mL) was added **2a** (25 mg), and the solution was boiled for 30 min. The solvent was removed in vacuo to give **2b** as the only product: ^1H NMR ($CDCl_3$) δ 1.65 (d, 3, J_{PH} = 15 Hz, P-CH_3), 4.25 (s, 3, OCH_3), 7.49–8.26 (m, 4, ArH).

Table I. Summary of Crystal Data

formula	$C_7H_8IO_3P$
formula wt	298.0
a	10.217 (5) Å
b	10.499 (5) Å
c	9.041 (3) Å
α	98.84 (3) °
β	102.49 (3) °
γ	89.73 (3) °
V	935.2 Å^3
Z	4
density	2.11 g cm^{-3} (cald) 2.10 g cm^{-3} (obsd)
μ	36.0 g cm^{-1}
space group	$P\bar{1}$
crystal shape	approximate cube, 0.3 mm.
temperature	21 ± 2°
radiation	Mo Kα (0.71069 Å) using a graphite crystal monochromator
scan speed	variable scan rates, 3.0–18.0 deg/min
scan range	Mo Kα_1 −1.0°, Mo Kα_2 +1.0°
total background time/scan time	0.5
total data collected	2160 ($2\theta_{MoK\alpha} \leq 43.0°$)
unique data $F_o^2 > 3.0\sigma(F_o^2)$	1805
final residuals	R_1 = 0.044, R_2 = 0.066
error in observation of unit wt	1.15

Iodinane **2b** was converted quantitatively to **2a** on the addition of 1 drop of H_2O.

2-Dichloroiodophenylmethylphosphinic Acid (5). Chlorine gas was passed through a cold (4 °C) $CHCl_3$ solution (20 mL) of **4** (782 mg, 2.77 mmol) for 15 min. The yellow solid which formed was collected and dried (at 1 mm for 15 min) to give 941 mg (2.66 mmol, 96.1%) of dichloride **5,** mp 131–135 °C dec.

Anal. Calcd for $C_7H_8Cl_2IO_2P$: C, 23.75; H, 2.28; Cl, 20.03; I, 35.85. Found: C, 23.60; H, 2.36; Cl, 19.88; I, 35.78.

Stirring samples of **5** in CH_3OH with 1 equiv of triethylamine in CH_3OH with excess sodium acetate or hot CH_3OH gave **4** as the only product by NMR.

Crystallography: Data Collection. The crystal used for data collection, grown by slow solvent evaporation from a CH_3CN solution, was glued to a glass fiber and optically centered on a Syntex $P2_1$ autodiffractometer. Computer programs used for crystal characterization and data collection were those of the Syntex $P2_1$ Fortran data collection system.[9] The crystal class was found to be triclinic with the lattice constants, as determined by least-squares refinement of the diffraction geometry of 25 reflections ($10° \leq 2\theta_{Mo\ K\alpha} \leq 25°$), given in Table I along with other data collection parameters. θ–2θ scan data were collected having $0° \leq 2\theta_{Mo\ K\alpha} \leq 43.0°$ (equivalent to 0.5 Cu sphere data). Intensities for three standard reflections, measured every 150 reflections, showed no decrease in intensity, and the data were reduced to a set of relative F_o values after correction for Lorentz and polarization effects. An empirical absorption correction was applied to all data.

Solution and Structural Refinement.[10] The atomic coordinates for the two independent iodide atoms were derived from a three-dimensional Patterson function. Their positional parameters were refined in two cycles of full-matrix least-squares refinement to give $R_1 = (\Sigma||F_o| - |F_c||)/\Sigma|F_o| = 0.321$ and $R_2 = [\Sigma w(|F_o| - |F_c|)^2/\Sigma|F_o|^2]^{1/2} = 0.376$. The remaining nonhydrogen atoms were located from a single difference Fourier map. The 28 unique nonhydrogen atoms were refined first employing isotropic thermal parameters and then anisotropic thermal parameters to give $R_1 = 0.054$. All hydrogen atoms, excluding the hydrogens bonded to the hydroxyl oxygens, were located from a difference Fourier at this point. The structural model was refined to convergence in three cycles of full-matrix least-squares refinement employing fixed thermal parameters for the hydrogen atoms to final discrepancy indicators of $R_1 = 0.044$ and $R_2 = 0.066$. A final difference Fourier failed to reveal the hydroxyl hydrogen positions. Pertinent bond distances and bond angles are illustrated in Figure 1. See the paragraph at the end of this paper concerning supplementary material for complete tables of positional parameters, thermal parameters, bond distances, and bond angles.

Registry No.—2a, 67673-30-7; **2b,** 67673-31-8; **3,** 67673-32-9; **4,**

67673-33-0; **5**, 67673-34-1; 2-bromoacetanilide, 614-76-6; diethyl methylphosphinite, 15715-41-0.

Supplementary Material Available: Tables of thermal parameters, refined atomic coordinates, bond distances and angles, least-squares mean planes, and crystal data and a stereodrawing of compound **2a** (6 pages). Ordering information is given on any current masthead page.

References and Notes

(1) J. E. Leffler and H. Jaffe, *J. Org. Chem.*, **38**, 2719 (1973); L. D. Freedman and R. P. DeMott, *Phosphorus*, **3**, 277 (1974); H. Jaffe and J. E. Leffler, *J. Org. Chem.*, **40**, 797 (1975).
(2) C. Willgerodt, *Chem. Ber.*, **26**, 357 (1893).
(3) D. F. Banks, *Chem. Rev.*, **66**, 243 (1966).
(4) T. M. Balthazor, unpublished results. The chemical shifts of the carbon α to iodine for C_6H_5I and $C_6H_5I(OAc)_2$ are δ 94.90 and 122.27, respectively.
(5) E. Shefter and W. Wolf, *J. Pharm. Sci.*, **54**, 104 (1965), and references cited therein.
(6) I. C. Paul, J. C. Martin, and E. F. Perozzi, *J. Am. Chem. Soc.*, **94**, 5010 (1972).
(7) M. M. L. Chen and R. Hoffmann, *J. Am. Chem. Soc.*, **98**, 1647 (1976).
(8) The P(2)–O(4) bond is also shorter than the sum of the covalent radii. It has been observed that these distances are usually 10–20% shorter than calculated for tetracoordinate phosphorus compounds; see J. R. Van Wazer, *J. Am. Chem. Soc.*, **78**, 5709 (1956).
(9) Syntex $P2_1$ Fortran diffractometer system: Syntex Analytical Instruments, 10040 Bubb Road, Cupertino, Calif. 95014.
(10) Programs used for the structural solution and the experiment were those of the Syntex XTL structure determination system: Syntex Analytical Instruments, 10040 Bubb Road, Cupertino, Calif. 95014.

Synthesis and Absolute Stereochemistry of *cis*- and *trans*-1,2-Indandiols: Metabolites of Indene and 2-Indanone

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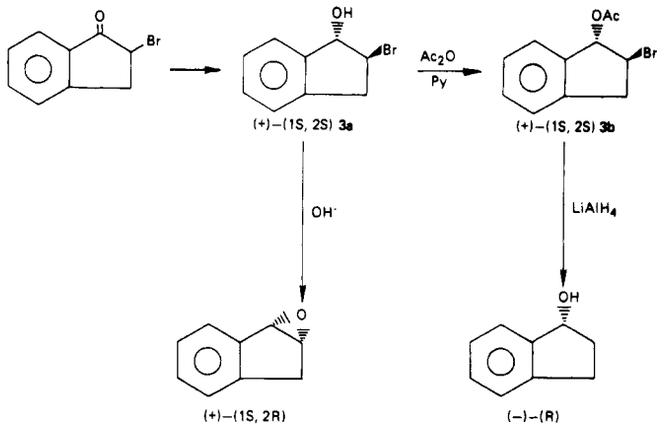
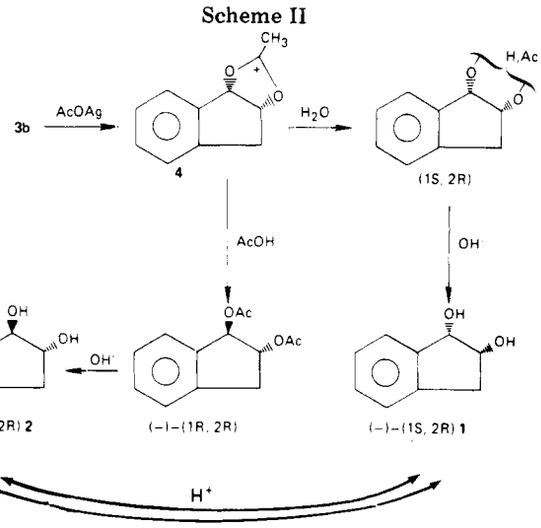
Systematic studies of the mammalian metabolism of aromatic hydrocarbons by Boyland,[1] Jerina,[2] and others[3] have established that these compounds are oxidized to arene oxides, which in turn are enzymatically hydrated to *trans*-dihydrodiols. The reported metabolism by animals of indene[3a] and acenaphthylene[3b] differs from that of other aromatic hydrocarbons in that both *cis*- and *trans*-dihydrodiols are formed. In studying the metabolism of indene, Brooks and Young[3a] introduced the compound into the animals through a stomach tube and isolated from urine the metabolites formed. The small quantities of optically active *cis*- and *trans*-1,2-indandiols obtained in this manner precluded chemical studies. Since the presence of cis and trans diols as animal metabolites is unusual, we wanted to determine which centers (i.e., C-1 or C-2) in these compounds have the same configuration. This information can be used to support or refute proposed biosynthetic schemes for formation of these metabolites. We elected to prepare both compounds by asymmetric synthesis and to determine their absolute stereochemistry.

Although several strategies have been devised to determine the absolute stereochemistry of dihydrodiols, most approaches depend upon a reduction step in which the diol is converted to a β-hydroxy hydroaromatic compound; the latter is synthesized, resolved, and its configuration established.[2a] The absolute stereochemistry of the diol is then logically deduced. Since all approaches that proceed via symmetric 2-indanol are doomed, we chose a synthetic approach utilizing the stereospecific reduction of a 1-indanone derivative. Earlier experiments[4] with *Cryptococcus macerans* demonstrated that this microbe reduces 1-indanone to (1*S*)-indanol. Our projected

Scheme I



Scheme II



synthesis involved preparing a single compound whose absolute stereochemistry could conveniently be determined, and which could be transformed to **1** and **2**, thus circumventing the need to transform **1** and **2** to compounds of known absolute stereochemistry. *trans*-1-Hydroxy-2-bromoindan (**3a**) fulfills these requirements and it was prepared by reduction of 2-bromoindan-1-one by *C. macerans*. The stereochemistry of the bromoindanol was assigned by comparison of its NMR spectrum with that of authentic racemic material. The absolute stereochemistry of (+)-**3a** was established as 1*S*,2*S* by conversion to (1*R*)-indanol of known configuration[5] as shown in Scheme I. The cis diol, (−)-**1**, was prepared from **3b** by treatment with silver acetate in wet acetic acid followed by hydrolyses under basic conditions (see Scheme II). Since Woodward[6a] and Winstein[6b] have shown that these solvolyses proceed by neighboring group participation, as shown for **4**, the absolute stereochemistry of (−)-**1** is 1*S*,2*R*. Although it is possible to convert **3b** to the trans diol diacetate, an assignment of the absolute stereochemistry of the latter compound appeared equivocal. The intermediate **4** could react with acetate at C-1, C-2 or in a non-regioselective manner. In the latter case attack by acetate yields a racemic product. Solvolyses of **3b** in glacial acetic acid in the presence of silver acetate yielded a trans diacetate, which had a large specific rotation ($[\alpha]_D$ −52.4°) demonstrating that the reaction was regioselective. Although the factors that determine the relative ease with which a benzylic vs. a saturated carbon atom of an acyloxonium ion is attacked have not been studied in the detail as they have been in aryloxirans,[7] the acyloxonium's reactivity should parallel that of the aryloxirans. The argument that regioselective attack occurred primarily at C-1 was proved by equilibrating **1** and **2** with dilute acid. This equilibration

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