δ 25.2 (q, CH_3C=N), 45.3 (q, CH_3N), 110.7 (s, C≡N), 141.5 (s, C=N); MS, *m/z* (relative intensity) 82, M^+ (28), 67 (100), 56 (23), 54 (11), 52 (11); high-resolution mass spectrum for $C_4H_6N_2$, calcd 82.0531, found 82.0531.

2-(*N*-Ethylimino)propanenitrile (2b): IR (NaCl) 2220 (C≡N), 1640 cm^{-1} (C=N); ^1H NMR ($CDCl_3$) δ 1.31 (q, 3 H, CH_3CN, ^3J = 7.2 Hz), 2.31 (t, 3 H, CH_3C=N, ^5J = 1.3 Hz), 3.78 (qq, 2 H, CH_2N, ^3J = 7.2 Hz, ^5J = 1.3 Hz); ^{13}C NMR ($CDCl_3$) δ 15.2 (q, CH_3CN), 25.3 (q, CH_3C=N), 53.2 (t, NCH_2), 110.8 (s, C≡N), 139.4 (s, C=N); yield 80%; MS, *m/z* (relative intensity) 96, M^+ (7), 85 (62), 83 (100), 81 (49), 59 (68), 58 (17), 47 (29); high-resolution mass spectrum for $C_5H_8N_2$, calcd 96.0687, found 96.0692.

2-(*N*-Methylimino)butanenitrile (2c): IR (NaCl) 2210 (C≡N), 1638 cm^{-1} (C=N); ^1H NMR ($CDCl_3$) δ 1.23 (q, 3 H, CH_3, ^3J = 7.2 Hz), 2.59 (qq, 2 H, CH_2, ^3J = 7.2 Hz, ^5J = 1.5 Hz), 3.58 (t, 3 H, CH_3N, ^5J = 1.5 Hz); ^{13}C NMR ($CDCl_3$) δ 9.9 (q, CH_3C), 32.1 (t, CH_2), 45.3 (q, NCH_3), 110.4 (s, C≡N), 146.8 (s, C=N); yield 88%; MS, *m/z* (relative intensity) 96, M^+ (20), 95 (15), 67 (100); high-resolution mass spectrum for $C_5H_8N_2$, calcd 96.0687, found 96.0692.

2-(*N*-Ethylimino)butanenitrile (2d): IR (NaCl) 2210 (C≡N), 1640 cm^{-1} (C=N); ^1H NMR δ 1.26 and 1.31 (2 t, 2 × 3 H, 2 CH_3, ^3J = 7.2 Hz), 2.57 (2 q, 2 × 2 H, 2 CH_2, ^3J = 7.2 Hz); ^{13}C NMR ($CDCl_3$) δ 10.0 (q, CH_3C=N), 15.3 (q, $NCCH_3$), 32.1 (t, CH_2C=N), 53.0 (t, NCH_2), 110.4 (s, C≡N), 144.8 (s, C=N); yield 86%; MS, *m/z* (relative intensity) 110, M^+ (8), 95 (100), 85 (12), 83 (17), 81 (34), 68 (21), 29 (72); high-resolution mass spectrum for $C_6H_{10}N_2$, calcd 110.0844, found 110.0840.

Synthesis of Ketene Imines 3a–d. Only analytical samples (0.5 g) of ketene imines **3b–d** were prepared. In a testing experiment, a gram-scale synthesis of ketene imine **3a** was performed. Purity of the crude products was higher than 80% (main impurities: *t*-BuOH and isobutene). The NMR spectra were recorded first at −50 °C and then at the probe temperature while IR spectra were measured at room temperature.

The preparation of compound **3a** is representative of all other preparations of ketene imines **3**.

With the apparatus previously described (Figure 1), the dehydrocyanation of **2a** into **3b** was performed by evaporating 0.063 mol (5.17 g) of imidoyl cyanide from flask A (10^{-3} mmHg, no heating) and passing it over potassium *tert*-butoxide (B) (40 g) in a tube heated at 110 °C. *tert*-Butyl alcohol was captured in the cold trap at −85 °C (G). Ketene imine **3a** was condensed onto a cold finger (liquid-N_2 temperature) (E) and collected in vessel F. The crude product (2.61 g) contains *t*-BuOH (<10%) and isobutene (≃5%). The yield of this reaction is about 61%.

***N*-Methyl ketene imine (ethenylidenemethylamine, 3a)**: yield 65% (NMR); IR (NaCl) 2035 cm^{-1} (C=C=N); ^1H NMR ($CDCl_3$) δ 3.04 (q, 2 H, CH2, ^5J = 2.4 Hz), 3.15 (t, 3 H, NCH_3, ^5J = 2.4 Hz); ^{13}C NMR ($CDCl_3$) δ 33.6 (t, CH_2, $J_{^{13}C-H}$ = 173.4), 39.5 (q, CH_3, $J_{^{13}C-H}$ = 140.3), 188.9 (s, =C=); high-resolution mass spectrum for C_3H_5N, calcd 55.0422, found 55.0427.

***N*-Ethyl ketene imine (ethenylideneethylamine, 3b)**: yield 61% (NMR); IR (NaCl) 2030 cm^{-1} (C=C=N); ^1H NMR ($CDCl_3$) δ 1.31 (q, 3 H, CH_3, ^3J = 7.0 Hz), 3.20 (t, 2 H, CH_2=, ^5J = 2.6 Hz), 3.47 (q, 2 H, CH_2N, ^3J = 7.0 Hz, ^5J = 2.6 Hz); ^{13}C NMR ($CDCl_3$) δ 14.9 (q, CH_3), 35.0 (t, CH_2=), 46.7 (t, NCH_2), 187.7 (s, =C=); high-resolution mass spectrum for C_4H_7N, calcd 69.0578, found 69.0573.

***N*-Methyl methylketene imine (1-propen-1-ylidenemethylamine, 3c)**: yield 60% (NMR); IR (NaCl) 2015 cm^{-1} (C=C=N); ^1H NMR ($CDCl_3$) δ 1.63 (d, 3 H, CH_3CH=, ^3J = 7.0 Hz), 3.16 (d, 3 H, NCH_3, ^5J = 2.2 Hz), 3.50 (m, 1 H, CH=); ^{13}C NMR ($CDCl_3$) δ 8.9 (q, CH_3CH=), 40.5 (q, CH_3N), 45.2 (d, CH=), 193.9 (s, =C=); MS, *m/z* (relative intensity) 69, M^+ (68), 68 (100), 58 (52), 42 (80), 41 (26), 39 (18), 29 (22), 28 (28), 27 (31); high-resolution mass spectrum for C_4H_7N, calcd 69.0578, found 69.0576.

***N*-Ethyl methylketene imine (1-propen-1-ylideneethylamine, 3d)**: yield 65% (NMR); IR (NaCl) 2020 cm^{-1} (C=C=N); ^1H NMR ($CDCl_3$) δ 1.28 (t, 3 H, $NCCH_3$, ^3J = 7.0 Hz), 1.63 (d, 3 H, CH_3CH=, ^3J = 6.0 Hz), 3.40 (qd, 2 H, NCH_2, ^3J = 7.0 Hz, ^5J = 2.4 Hz), 3.55 (qt, 1 H, CH_3CH, ^3J = 6.0 Hz, ^5J = 2.4 Hz); ^{13}C NMR ($CDCl_3$) δ 9.2 (q, CH_3CH=), 15.8 (q, $NCCH_3$), 47.0 (d, CH=), 47.7 (t, NCH_2), 192.1 (s, =C=); MS, *m/z* (relative intensity) 83, M^+ (47), 59 (51), 55 (70), 54 (100), 41 (3); high-resolution mass spectrum for C_5H_9N, calcd 83.0735, found 83.0736.

Registry No. **1a**, 16752-54-8; **1b**, 40651-88-5; **1c**, 106588-24-3; **1d**, 29151-31-3; (*Z*)-**2a**, 106588-25-4; (*E*)-**2a**, 106588-31-2; **2b**, 106588-26-5; **2c**, 106588-27-6; **2d**, 106588-28-7; **3a**, 67533-87-3; **3b**, 106588-29-8; **3c**, 63742-01-8; **3d**, 106588-30-1; MeCHO, 75-07-0; $MeNH_2$·HCl, 593-51-1.

Ruthenium Tetraoxide Phase-Transfer-Promoted Oxidation of Secondary Alcohols to Ketones[1]

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Oxidations of secondary alcohols to ketones constitute an important class of organic reactions, and there are a variety of reagents available for carrying out these conversions. Notable among these reagents are those employing chromium under acidic[2,3] or nonacidic conditions,[4-7] methyl sulfoxide based reagents,[8-11] and ruthenium tetraoxide.[12-16] However, problems are often associated with the use of each of these reagent types. Methyl sulfoxide reagents often give unwanted and difficult to remove side reaction products, particularly the methyl thiomethyl ether of the starting alcohol. The use of pyridinium dichromate and pyridinium chlorochromate on a large scale is made difficult because of the column chromatography required to separate reduced chromium products from the desired ketones. The well-known Jones reagent,[3] an acidic chromium reagent, is limited to those alcohols and/or product ketones not labile to the acidic conditions of the reaction.

Ruthenium tetraoxide, generated in situ from activated ruthenium dioxide[15] and periodate[14] or hypochlorite[15] in a water–chloroform system, has also been used for secondary alcohol to ketone conversions. Such ruthenium tetraoxide systems circumvent the problems associated with the previously mentioned oxidizing agents but poorly

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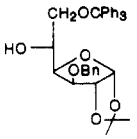
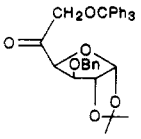
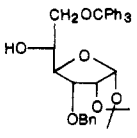
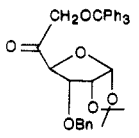
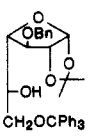
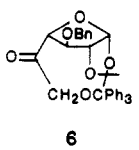
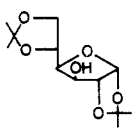
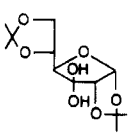
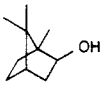
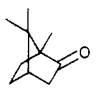
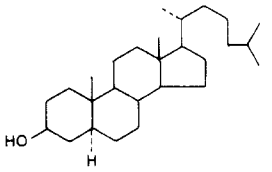
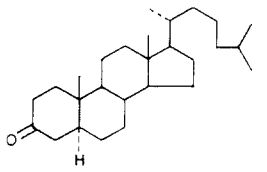
Table I. Oxidation of the Alcohol Precursors to the Corresponding Ketones with BTEAC

substrate	product	time, h	% yield
 1	 4	28	97
 2	 5	48	75
 3	 6	24	94
 7	 8	22	85
 9	 10	40	80
 11	 12	4	78

oxidize alcohols that have low water solubility. The problems associated with all of these standard oxidizing reagents underscores the need for further development of convenient and reliable oxidizing agents.

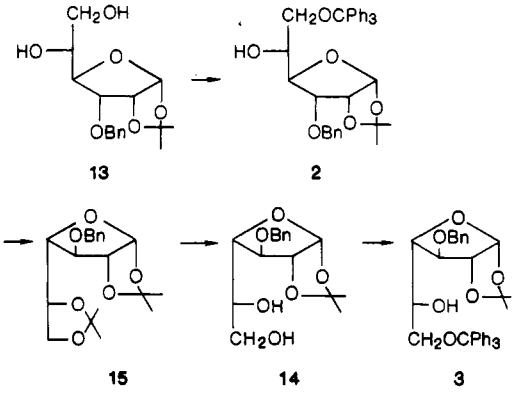
Interest in this laboratory in dicarbonyl sugar chemistry often requires that a second carbonyl function be generated on a monosaccharide through a suitably protected *aldo*-hexose. Of particular recent interest is the oxidation of the C-5 hydroxyl group of the isomeric alcohols **1–3** to the corresponding ketones **4–6**. Because of the afore-mentioned limitations of the chromium and methyl sulfoxide oxidizing systems, attention was given to an in situ generated ruthenium tetraoxide method. When the aqueous chloroform, ruthenium dioxide–periodate system of Baker et al.[13,14] was applied to the oxidation of **1**, 3-*O*-benzyl-1,2-*O*-isopropylidene-6-*O*-(triphenylmethyl)-α-D-glucofuranose, no reaction was observed. When the oxidation of **1** was carried out by using the same system,[14] but with half the amount of ruthenium dioxide and in the presence of 1 mol % of the phase-transfer catalyst, benzyltriethylammonium chloride (BTEAC), the conversion of **1** to **4** was complete at room temperature in 24 h with no observable side products (TLC) and **4** was isolated in crystalline form (97%). The phase-transfer catalyst promoted ruthenium tetraoxide oxidation procedure was then applied to two diastereomers of **1**: 3-*O*-benzyl-1,2-*O*-isopropylidene-6-*O*-(triphenylmethyl)-α-D-allofuranose (**2**) and 3-*O*-benzyl-1,2-*O*-isopropylidene-6-*O*-(triphenylmethyl)-α-D-galactofuranose (**3**). Whereas oxidation of the galacto isomer **3** and the gluco isomer **1** was complete in 24 h, complete oxidation of the allo isomer **2** took 48 h. The exact role of the phase-transfer catalyst in these oxidations has not been determined. However, it may be that the increased concentration of the periodate anion in the chloroform layer, via the phase-transfer catalyst, facilitates reoxidation of RuO_2 to chloroform-soluble RuO_4. The oxidations of **1–3** were carried out on a 3–4-g scale (~6 mmol), required no chromatography for product purification, and did not produce any observable organic side products (cf. Table I). The experimental procedure was quite simple and involved stirring an ethanol-free chloroform solution of the alcohol at room temperature with an equal volume of water-containing activated ruthenium dioxide, sodium or potassium periodate, a small amount of potassium carbonate, and 1 mol % of BTEAC. When reaction was complete (TLC), 2-propanol was added to reduce ruthenium tetraoxide and excess periodate, the mixture was filtered through Celite, and the filtrate was dried and concentrated to give the ketone. In cases where the chloroform layer was still colored after passing through Celite, the color could be easily removed with decolorizing carbon. Both **2** and **3** are newly reported compounds.

The oxidation procedure was also found to be applicable to a large-scale reaction. Using a published procedure[14] for the conversion of **7** (125 g) to 1,2:5,6-di-*O*-isopropylidene-α-D-*ribo*-hexofuranos-3-ulose hydrate (**8**), the oxidation took a minimum of 48 h (78%). When the same oxidation was repeated, but with half the amount of ru-

thenium dioxide and in the presence of 1 mol % BTEAC, reaction was complete in 22 h with an isolated yield for 8 of 85%. A recent Polish patent also describes the use of a phase-transfer catalyst in ruthenium tetraoxide oxidations of carbohydrate alcohols including conversion of 7 to 8.[16] Oxidations were carried out in four different chlorinated hydrocarbon solvents using tetrabutylammonium chloride or tetrabutylphosphonium chloride as the phase-transfer catalyst. The oxidation of 7 to 8 is reported to be complete in less than 20 min by using $RuCl_3/IO_4^-$ in CCl_4 in 96% yield with tetrabutylammonium chloride serving as the phase-transfer catalyst.

Noncarbohydrate secondary alcohols were also conveniently oxidized to the corresponding ketones by using the phase-transfer catalyst promoted reaction. The terpene alcohol isoborneol (9) was converted to camphor (10, 88%) in 28 h and the steroidal alcohol (+)-dihydrocholesterol (11) to cholestan-3-one (12) in only 4 h (78%). Surprisingly, when the oxidation of the steroid 11 was conducted by using the standard phase-transfer catalyst reaction conditions, the reaction medium became warm enough to reflux the chloroform and spill the contents of the reaction flask. *Thus, care should be taken with this system to avoid uncontrolled exothermic oxidations.* It was determined that in the case of 11, slow addition of periodate gave a controlled and efficient oxidation to 12.

For the preparation of the allo derivative 13, the alcohol 7 was oxidized to the ketone 8 as described by using the phase-transfer catalyst promoted system, and 8 was converted to the diol 13 in three steps.[17] Tritylation at the C-6 position of 13 yielded 2 (87%). The D-galactofuranose trityl ether 3 was prepared from the diol 14 by using chlorotriphenylmethane in pyridine (91%). A key step in the synthesis of 3 was selective acid hydrolysis of the 5,6-*O*-isopropylidene group of 15, 3-*O*-benzyl-1,2:5,6-di-*O*-isopropylidene-α-D-galactofuranose. Reports in the literature cite considerable difficulty in attempting to selectively hydrolyze a 5,6-*O*-isopropylidene group from a galactofuranose ring due to the comparable lability of the 1,2-*O*-isopropylidene group.[18,19] However, controlled and monitored hydrolysis of 15 with aqueous acetic acid at room temperature gave 14 after 6 h (91%).



Experimental Section

All reagents and solvents were analytical grade and were used without further purification. Ethanol-free $CHCl_3$ was prepared by shaking with an equal amount of concentrated H_2SO_4, washing with H_2O, distilling from P_2O_5, and storing under N_2 until used. Dry THF was prepared by distilling from sodium metal. Solvents were evaporated under diminished pressure by using a rotary evaporator. Melting points (mp) were determined on a Fisher-Johns melting point apparatus and are reported uncorrected. Thin-layer chromatography (TLC) was performed on precoated 250-μm silica gel GF glass plates from Analtech, Inc. Chromatograms were visualized by spraying with a 0.1 M (2,4-dinitrophenyl)hydrazine solution in 1:1 95% EtOH–H_3PO_4 followed by heating. Infrared (IR) spectra were recorded on a Beckman Acculab spectrometer as Nujol mulls. ^1H NMR spectra were recorded at 300 MHz (Nicolet Fourier Transform Spectrometer) in $CDCl_3$ and are reported downfield from Me_4Si. All reaction mixtures were magnetically stirred unless otherwise stated. Elemental analyses were performed by Atlantic Microlabs, P.O. Box 80569, Atlanta, GA 30366.

1,2:5,6-Di-*O*-isopropylidene-α-D-*ribo*-hexofuranos-3-ulose Hydrate (8). Small-Scale Oxidation. (a) **With Phase-Transfer Catalyst.** 1,2:5,6-Di-*O*-isopropylidene-α-D-glucofuranose (7) (6.5 g, 25 mmol) was dissolved in EtOH-free $CHCl_3$ (50 mL). To the stirred solution was added H_2O (50 mL), activated RuO_2[15] (50 mg), $NaIO_4$ (6.5 g), and 1 mol % $PhCH_2Et_3NCl$ (57.0 mg). After 30 h, TLC (1:1 Et_2O-$PhCH_3$) showed one spot corresponding to the hydrated ketone 8. 2-Propanol (50 mL) was added to the reaction to consume unreacted $NaIO_4$ and RuO_4, and the mixture was stirred for 10 min and then filtered through a bed of Celite. The organic layer was separated, washed with H_2O (2 × 50 mL), dried ($MgSO_4$), and evaporated to give an oil which crystallized on standing overnight (82%). Recrystallization with 1:1 Et_2O–petroleum ether gave an analytical sample of 8 as white crystals: mp 111–112 °C (lit.[14] mp 111–112 °C). (b) **Without Addition of Phase-Transfer Catalyst.** Same conditions, RuO_2 (100 mg); t = 48 h; yield = 80%.

Large-Scale Oxidation. (c) **With Phase-Transfer Catalyst.** 1 (125 g, 0.48 mol); mechanically stirred with EtOH-free $CHCl_3$ (500 mL), activated RuO_2 (1 g), H_2O (500 mL), $NaIO_4$ (165 g), K_2CO_3 (18 g), and 1 mol % $PhCH_2Et_3NCl$ (1.0 g); t = 22 h; yield = 85%. (d) **Without Addition of Phase-Transfer Catalyst.** Same conditions; RuO_2 (2 g); t = 48 h; yield = 78%.

3-*O*-Benzyl-1,2-*O*-isopropylidene-6-*O*-(triphenylmethyl)-α-D-*xylo*-hexofuranos-5-ulose (4). 3-*O*-Benzyl-1,2-*O*-isopropylidene-6-*O*-(triphenylmethyl)-α-D-glucofuranose (1, 5.5 g, 10 mmol), prepared by the method of Gramera et al.,[20] was dissolved in EtOH-free $CHCl_3$ (50 mL) to which H_2O (50 mL), activated RuO_2 (50 mg), $NaIO_4$ (6.5 g), K_2CO_3 (500 mg), and $PhCH_2Et_3NCl$ (23 mg) were added. The reaction was stirred for 32 h at which time TLC (9:1 $PhCH_3$–Et_2O) showed complete conversion of 1 to 4. 2-Propanol (10 mL) was added to consume unreacted $NaIO_4$ and RuO_4 and the mixtured filtered through Celite. The organic layer was separated, washed with H_2O (2 × 50 mL), dried ($MgSO_4$), and removed to give 4 as a white crystalline solid (5.4 g, 97%): mp 169–171 °C (lit.[21] mp 169–171 °C); IR and NMR are consistent with published spectral data.[20]

3-*O*-Benzyl-1,2-*O*-isopropylidene-6-*O*-(triphenylmethyl)-α-D-allofuranose (2). 3-*O*-Benzyl-1,2-*O*-isopropylidene-α-D-allofuranose (13, 3.3 g, 10 mmol) was dissolved in dry pyridine (20 mL) and the solution was stirred with chlorotriphenylmethane (4.0 g, 14 mmol) overnight. TLC (1:1 Et_2O–$PhCH_3$) showed complete conversion of 13 to 2. The reaction mixture was poured onto ice–H_2O (500 mL) and the product collected by vacuum filtration. The gum was dissolved in CH_2Cl_2 (50 mL) and washed with 10% HOAc (2 × 35 mL), 10% $NaHCO_3$ (2 × 35 mL), and H_2O until neutral to litmus. The organic layer was dried ($MgSO_4$) and removed to give 4.8 g (8.7 mmol, 87%) of oily 2. Crystallization with $PhCH_3$–hexane gave 2 as a white crystalline material: mp 100–103 °C; $[\alpha]^{24}_D$ +38.5° (*c* 1.1, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 1.316 and 1.550 (s, 3 H each, CH_3), 2.433 (bs, 1 H, OH), 3.265 (m, 2 H, H-6a, H-6b), 3.847 (dd, 1 H, H-3, $J_{3,4}$ = 8.75), 4.035 (dd, 1 H, H-4, $J_{4,5}$ = 3.25), 4.173 (m, 1 H, H-4), 4.443 (t, 1 H, H-2, $J_{2,3}$ = 4.39), 4.455 (AB quartet, 2 H, CH_2Ph), 5.678 (d, 1 H, H-1, $J_{1,2}$ = 3.68), and 7.1–7.5 (bm, 20 H, Ar). Anal. Calcd for $C_{35}H_{36}O_6$: C, 76.06; H, 6.56. Found: C, 76.12; H, 6.62.

3-*O*-Benzyl-1,2-*O*-isopropylidene-6-*O*-(triphenylmethyl)-α-D-*ribo*-hexofuranos-5-ulose (5). 3-*O*-Benzyl-1,2-*O*-

(17) Reduction of 8 with $NaBH_4$ gave 1,2:5,6-di-*O*-isopropylidene-α-D-allofuranose which was benzylated (NaH, benzyl chloride) and hydrolyzed (HOAc, H_2O) to give 13.

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isopropylidene-6-*O*-(triphenylmethyl)-α-D-allofuranose (**2**, 1.2 g, 2.2 mmol) was dissolved in EtOH-free $CHCl_3$ (10 mL) to which was added activated RuO_2 (20 mg, KIO_4 (1 g), K_2CO_3 (5.0 mg), $PhCH_2Et_3NCl$ (100 mg), and H_2O (10 mL). The solution was stirred for 48 h at which time TLC (9:1 $PhCH_3$–Et_2O) showed complete conversion of **2** to **5**. The unreacted KIO_4 and RuO_4 were consumed with 2-propanol (2 mL), and the mixture was filtered through Celite. The organic layer was separated and dried ($MgSO_4$) and solvent removed to give 1.0 g (83%) of **5** as an oil which was crystallized with $PhCH_3$–hexane to give **5** as white crystals: mp 185 °C; $[\alpha]^{24}_D$ +30.0° (*c* 1.5, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 1.313 and 1.548 (s, 3 H each, CH_3), 3.736 (dd, 1 H, H-3, $J_{3,4}$ = 8.96), 4.020 (q, 2 H, CH_2Ph), 4.449 (t, 1 H, H-2, $J_{2,3}$ = 4.33), 4.537 (d, 1 H, H-4), 4.574 (AB quartet, 2 H, H-6a, H-6b) 5.696 (d, 1 H, H-1, $J_{1,2}$ = 3.48), and 7.15–7.5 (bm, 20 H, Ar); IR 1750 cm^{-1} (C=O). Anal. Calcd for $C_{35}H_{34}O_6$: C, 76.34; H, 6.22. Found: C, 76.24; H, 6.25.

3-*O*-Benzyl-1,2:5,6-di-*O*-isopropylidene-α-D-galactofuranose (15). 1,2:5,6-Di-*O*-isopropylidene-α-D-galactofuranose (**16**, 12.0 g, 46 mmol), prepared by the method of Lemieux and Stick,[22] was dissolved in dry THF (20 mL) and added dropwise under N_2 to a stirred THF solution containing NaH (70 mmol). After the last addition of alcohol, the solution was refluxed for 2 h at 70 °C. The solution was allowed to cool, and benzyl chloride (5.7 mL, 50 mmol) in THF (10 mL) was added and the solution refluxed (70 °C) overnight. The THF was removed, and petroleum ether (200 mL) was added, and the solution was washed with H_2O (2 × 50 mL). The organic layer was dried ($MgSO_4$) and reduced to give 10.1 g (28 mmol, 63%) of **15** as an oil: ^1H NMR ($CDCl_3$) δ 1.544, 1.420, 1.370, and 1.353 (s, 3 H each, CH_3), 3.722 (t, 1 H, H-4, $J_{4,5}$ = 7.26), 3.809 (dd, 1 H, H-3, $J_{3,4}$ = 1.09), 3.907 (m, 1 H, H-5), 4.262 (m, 2 H, H-6a, H-6b), 4.598 (AB quartet, 2 H, CH_2Ph), 4.637 (d, 1 H, H-2, $J_{2,3}$ = 1.27), 5.858 (d, 1 H, H-1, $J_{1,2}$ = 4.01), and 7.341 (m, 5 H, Ar).

3-*O*-Benzyl-1,2-*O*-isopropylidene-α-D-galactofuranose (14). 3-*O*-Benzyl-1,2:5,6-di-*O*-isopropylidene-α-D-galactofuranose (**15**, 4.0 g, 11 mmol) was dissolved in aqueous HOAc (10 mL) and the solution stirred for 6 h at which time TLC (Et_2O) showed complete conversion of **15** to **14**. The solution was neutralized with saturated aqueous K_2CO_3 and extracted with CH_2Cl_2 (2 × 100 mL), and the organic layers were combined, dried ($MgSO_4$), and reduced to give **14** (3.2 g, 10 mmol, 91%) as a wax. Crystallization with MeOH–EtOAc gave **14** as white crystals: mp 95–100 °C; $[\alpha]^{21.5}_D$ −22.6° (*c* 1.2, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 1.337 and 1.521 (*s*, 3 H each, CH_3), 2.570 and 3.061 (bs, 1 H each, OH), 3.622 (m, 2 H, H-6a, H-6b), 3.796 (m, 1 H, H-5, $J_{5,6a}$ = 4.41, $J_{5,6b}$ = 5.06), 4.001 (d, 1 H, H-3, $J_{3,4}$ = 3.23), 4.122 (dd, 1 H, H-4, $J_{4,5}$ = 6.79), 4.600 (AB quartet, 2 H, CH_2Ph), 4.676 (d, 1 H, H-2), 5.908 (d, 1 H, H-1, $J_{1,2}$ = 4.13), and 7.338 (m, 5 H, CH_2Ph). Anal. Calcd for $C_{16}H_{22}O_6$: C, 61.94; H, 7.10. Found: C, 61.85; H, 7.17.

3-*O*-Benzyl-1,2-*O*-isopropylidene-6-*O*-(triphenylmethyl)-α-D-galactofuranose (3). 3-*O*-Benzyl-1,2-*O*-isopropylidene-α-D-galactofuranose (**14**, 3.0 g, 9.7 mmol) was dissolved in dry pyridine (50 mL) and the solution stirred with chlorotriphenylmethane (2.8 g, 10 mmol). TLC (9:1 $PhCH_3$–Et_2O) at 50 h showed complete conversion of **14** to **3**. The reaction mixture was poured onto ice–H_2O (500 mL) and the product collected by vacuum filtration. The gum was dissolved in CH_2Cl_2 (50 mL) and washed with 10% HOAc (2 × 35 mL), 10% $NaHCO_3$ (2 × 35 mL), and H_2O until neutral to litmus. Workup gave 4.9 g (8.8 mmol, 91%) of **3**. Recrystallization with $PhCH_3$–hexane gave an analytical sample of **3** as white crystals: mp 118–120 °C; $[\alpha]^{21.5}_D$ −6.9° (*c* 1.3, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 1.321 and 1.506 (s, 3 H each, CH_3), 2.651 (d, 1 H, 5-OH), 3.254 (d, 2 H, H-6a, H-6b), 3.869 (m, 1 H, H-5, $J_{5,6}$ = 5.28, $J_{5\text{-OH}}$ = 4.54), 4.008 (d, 1 H, H-3, $J_{3,4}$ = 2.8), 4.253 (dd, 1 H, H-4, $J_{4,5}$ = 3.14), 4.444 (AB quartet, 2 H, CH_2Ph), 4.648 (d, 1 H, H-2), 5.894 (d, 1 H, H-1, $J_{1,2}$ = 4.12), 7.254 (m, 15 H, OTr), and 7.449 (m, 5 H, CH_2Ph). Anal. Calcd for $C_{35}H_{36}O_6$: C, 76.08; H, 6.52. Found: C, 76.02; H, 6.59.

3-*O*-Benzyl-1,2-*O*-isopropylidene-6-*O*-(triphenylmethyl)-β-L-*arabino*-hexofuranos-5-ulose (6). 3-*O*-Benzyl-1,2-*O*-isopropylidene-6-*O*-(triphenylmethyl)-α-D-galactofuranose (**3**, 3.6 g, 6.6 mmol) was dissolved in EtOH-free $CHCl_3$ (75 mL). To this solution were added activated RuO_2 (60 mg), $NaIO_4$ (3 g), K_2CO_3 (300 mg), $PhCH_2Et_3NCl$ (15.0 mg), and H_2O (50 mL). The solution was stirred for 24 h at which time TLC (9:1 $PhCH_3$–Et_2O) showed complete conversion of **3** to **6**. 2-Propanol (25 mL) was added to consume unreacted $NaIO_4$ and RuO_4 and the solution was passed through a bed of Celite. The organic layer was separated, dried ($MgSO_4$), and removed to give 3.4 g (94%) of oily **6** which crystallized on standing. Recrystallization with $PhCH_3$–hexane gave an analytical sample: mp 128–130 °C; $[\alpha]^{24}_D$ −1.9° (*c* 1.4, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 1.128 and 1.192 (s, 3 H each, CH_3), 4.230 (AB quartet, CH_2Ph), 4.315 (bs, 1 H, H-4), 4.508 (bs, 1 H, H-3), 4.550 (d, 1 H, H-2), 4.560 (bs, 2 H, CH_2OTr), 5.875 (d, 1 H, H-1, $J_{1,2}$ = 3.83), and 7.15–7.55 (bm, 20 H, Ar); IR 1720 cm^{-1} (C=O). Anal. Calcd for $C_{35}H_{34}O_6$: C, 76.34; H, 6.22. Found: C, 76.44; H, 6.27.

1,7,7-Trimethylbicyclo[2.2.1]heptan-2-one (Camphor, 10). Isoborneol (**9**, 30.8 g, 0.2 mol) was dissolved in EtOH-free $CHCl_3$ (250 mL) and the solution mechanically stirred with activated RuO_2 (500 mg), $NaIO_4$ (43 g), K_2CO_3 (1.0 g), $PhCH_2Et_3NCl$ (450 mg), and H_2O (250 mL). After 40 h TLC (1:1 Et_2O–hexane) showed complete conversion of **9** to **10**. The oxidation was stopped by the addition of 2-propanol (25 mL) and usual workup gave 27.1 g (88%) of **10** as a white crystalline mass: mp 177–180 °C (lit.[23] mp 179–180 °C); IR 1720 cm^{-1} (C=O).

Cholestan-3-one (12). (+)-Dihydrocholesterol (**11**, 7.8 g, 20 mmol) was dissolved in EtOH-free $CHCl_3$ (50 mL) and the solution stirred with activated RuO_2 (50 mg), K_2CO_3 (500 mg), $PhCH_2Et_3NCl$ (50 mg), and H_2O (50 mL). Potassium periodate (4.5 g, 20 mmol) was then added in small portions to prevent heating of the reaction mixture (ca. 30 min). Complete conversion of **11** to **12** required 4 h, TLC (1:1 Et_2O–hexane). 2-Propanol (15 mL) was added to quench the reaction and usual workup gave 5.9 g (15 mmol, 76%) of **12** as a white crystalline solid. Recrystallization with MeOH gave **12**: mp 126–128 °C (authenic material mp 128–130 °C, Aldrich Chemical Co., Milwaukee, WI); IR 1710 cm^{-1} (C=O).

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Analytical Resolution of Secondary Methyl Ethers by Chiral Complexation Gas Chromatography

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One of the challenges in developing enantioselective synthetic methods is the rapid and accurate determination of the efficacy that the process provides.[3] We recently

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