Osmium Tetroxide Oxidation of 23.—Osmylation of 1.0 g of **23** in anhydrous ether with 1 g of OsO_4 for 24 hr, followed by concentration at reduced pressure, dilution with methanol, decomposition with hydrogen sulfide, and work-up in the usual manner, gave a gum. Recrystallization from hexane–ether afforded 0.21 g (19%) of **24**: mp 197–199°; ir 3415 (strong) and 1725 cm^{-1}; nmr (DMSO-d_6) 3.85 (q, J = 5 Hz, H-12, collapses to t on D_2O exchange), 3.58 (methoxyl), 1.16 (C-4 methyl), 0.96 (d, J = 7 Hz, 6 protons, isopropyl), 0.97 ppm (C-10 methyl), and four OH multiplets.

Anal. Calcd for $C_{21}H_{36}O_6$: C, 65.60; H, 9.44; O, 24.97. Found: C, 65.44; H, 9.25; O, 24.92.

Epoxidation of 23.—A solution of 0.5 g of **23** was allowed to stand with 0.35 g of *m*-chloroperbenzoic acid at room temperature overnight and extracted with sodium bicarbonate solution, water, and saturated brine. The dried organic layer was evaporated and the residue was recrystallized from hexane: yield of **25** 0.32 g (61%); mp 156–158°; ir 3325 (strong) and 1724 cm^{-1}; nmr 3.66 (br, H-14, sharpens on addition of D_2O), 3.58 (methoxyl), 3.27 (t br, J = 2 Hz, H-12), 1.17 (C-4 methyl), 1.00 (d) and 0.88 (d, J = 7 Hz, isopropyl), and 0.90 ppm (C-10 methyl).

Anal. Calcd for $C_{21}H_{34}O_5$: C, 68.86; H, 9.35; O, 21.83. Found: C, 69.20; H, 9.39; O, 21.68.

$NaBH_4$ Reduction of 26.—Reduction of 5 g of **26**[23] with $NaBH_4$ in the manner described for **21** gave, in the hot benzene extracts, a gum which was recrystallized from hexane: yield of **27** 2.65 g (52%); mp 143.5–145°; ir 3458 (strong) and 1705 cm^{-1}; nmr 5.18 (H-14), 4.37 (m, H-12, sharpens on addition of D_2O), 3.60 (methoxyl), 1.17 (C-4 methyl), 1.03 d (J = 7 Hz, 6 protons, isopropyl), and 0.80 ppm (C-10 methyl). This material was converted to **28** on standing in chloroform solution.

Anal. Calcd for $C_{21}H_{34}O_4$: C, 71.96; H, 9.78; O, 18.26. Found: C, 72.24; H, 9.71; O, 18.15.

Evaporation of the mother liquors of **27** produced a gum which was homogeneous (tlc) but could not be induced to crystallize and was identified as **28** spectroscopically. Its nmr spectrum exhibited signals at 5.64 (H-14), 5.33 (m, H-7), 4.30 (m, H-12, sharpens on addition of D_2O), 3.59 (methoxyl), 2.60 (m, -OH), 1.27 (C-4 methyl), 1.03 (d, J = 7 Hz, 6 protons, isopropyl), and 0.80 ppm (C-10 methyl).

Osmium Tetroxide Oxidation of 27.—Osmylation of 1 g of **27** with 1 g of OsO_4 in anhydrous ether and work-up as described for **23** gave **29** which was recrystallized from hexane–ether: yield 0.23 g (21%); mp 220–222°; ir 3425 (strong) and 1710 cm^{-1}; nmr (DMSO-d_6) 4.1 (t br, 8, H-12), 3.60 (methoxyl, superimposed on H-14), 1.20 (C-4 methyl), 0.93 (d) and 0.88 (d, J = 7 Hz, isopropyl), 0.85 ppm (C-10 methyl), and four OH multiplets.

Anal. Calcd for $C_{21}H_{36}O_6$: C, 65.60; H, 9.44; O, 24.97. Found: C, 65.72; H, 9.16; O, 25.10.

Epoxidation of 19.—Oxidation of 1 g of **19**[7] with 0.7 g of *m*-chloroperbenzoic acid in chloroform at room temperature for 3 hr and work-up as described for **23** gave, after recrystallization from hexane, 0.55 g (52%) of **30**: mp 145–147°; ir 3478, 1705, and 1164 cm^{-1}; nmr 4.28 (t br, J = 6 Hz, H-12, sharpens on addition of D_2O), 3.66 (methoxyl), 3.02 (H-14), 1.23 (C-4 methyl), 1.04 (d) and 0.98 (d, J = 7 Hz, isopropyl), and 0.88 ppm (C-10 methyl).

Anal. Calcd for $C_{21}H_{34}O_5$: C, 68.82; H, 9.35; O, 21.83. Found: C, 68.68; H, 9.45; O, 22.08.

Reaction of 30 With Acid.—A solution of 0.5 g of **30** in 50 ml of tetrahydrofuran and 50 ml of 20% perchloric acid was stirred at room temperature for 2 days. Since tlc examination revealed that only starting material was present, the solution was refluxed on the steam bath for 3 hr, cooled, poured into water, and extracted with ether. The washed and dried ether extract was evaporated. The residual gum solidified on trituration with hexane, yield 60%, mp 156–158°, identified as methyl 12-hydroxydehydroabietate (**31**) by comparison with an authentic sample.[28] The ether mother liquors yielded an additional 30% of **31**.

Preparation of 32. A.—Oxidation of 0.5 g of **30** with Collins' reagent by the procedure of Ratcliffe and Rodehorst[33] and recrystallization of the crude product from hexane gave 0.32 g (64%) of **32**: mp 83–85°; ir 3478, 1728, 1709, and 1245 cm^{-1}; nmr 3.63 (methoxyl), 3.31 (H-14), 1.18 (C-4 methyl), 1.00 (d) and 0.96 (d, J = 7 Hz, isopropyl), and 0.85 ppm (C-10 methyl).

Anal. Calcd for $C_{21}H_{32}O_5$: C, 69.20; H, 8.85; O, 21.95. Found: C, 68.86; H, 8.86; O, 22.09.

B.—A solution of 1 g of **33**[7] in 50 ml of *p*-xylene was refluxed for 20 hr and evaporated at reduced pressure. The residue was taken up in hot hexane and allowed to cool, whereupon crude **32** precipitated. The mother liquors were evaporated, chromatographed over a short alumina column, and evaporated to furnish additional crude **32**. Recrystallization from hexane afforded 0.71 g (71%) of **32**, mp 83–85°.

Rearrangement reactions were run simultaneously on 0.1 g of **33** in 15 ml of xylene, 15 ml of xylene packed with glass beads, and 15 ml of chlorobenzene, the progress of the reaction being followed by tlc. After 4 hr, conversion of **33** to **32** in chlorobenzene was complete, whereas the xylene runs were just beginning to show a detectable amount of **32**.

A solution of 1 g of **33** in 20 ml of cyclohexylamine was refluxed for 3 hr, poured into dilute phosphoric acid, and extracted with ether. The usual work-up and recrystallization from methanol–water afforded 0.85 g (85%) of pure **34**,[7] mp 241–243°.

Registry No.—**1a,** 79-54-9; **1b,** 3513-69-7; **2b,** 34226-16-9; **3,** 34202-06-7; **4,** 34226-17-0; **5,** 34226-18-1; **7,** 34226-19-2; **8a,** 34217-09-9; **12,** 34217-10-2; **13,** 34217-11-3; **15,** 34217-12-4; **21,** 32111-53-8; **23,** 34217-14-6; **24,** 34217-15-7; **25,** 34217-16-8; **27,** 34217-17-9; **28,** 34217-18-0; **29,** 34217-19-1; **30,** 34217-20-4; **32,** 34217-21-5; potassium permanganate, 7722-64-7; osmium tetroxide, 20816-12-0.

[33] R. Ratcliffe and R. Rodehorst, *J. Org. Chem.*, **35**, 4000 (1970).

Molecular Rotations of Steroids in Relation to Their Structures. The *S* value of a Hydrogen Atom and That of a Hydroxyl Radical

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S values of the hydrogen atom and of the hydroxyl radical vary discontinuously over a range. The particular *S* value selected from a small set of discrete values depends on influences in the remainder of the molecule which can be transmitted through a coplanar zigzag chain.

Though optical rotatory dispersion and optical circular dichroism of steroids have been investigated actively for about two decades,[1,2] many reports of molecular rotations [M]D of steroids measured at the sodium D line date from earlier periods. Therefore, it is necessary to arrange them and to try to explain (or interpret) them in the framework of a physical theory.

In 1959, Brewster applied his idea of a screw pattern

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[1] C. Djerassi, "Optical Rotatory Dispersion, Applications to Organic Chemistry," McGraw-Hill, New York, N. Y., 1960.

[2] For example, see A. I. Scott and A. D. Wrixon, *Tetrahedron*, **27**, 2339 (1971).

TABLE I
$[M]^{20}_{D}$ (IN CHLOROFORM) OF STEROID DERIVATIVES

Compd	Position and orientation of X	$[M]^{20}_{D}$ for X H	F	(OH)	Cl	Br	I	Figure
		5α-Cholestane derivative						
1	2	221.2*	mm	mm	188.6*	173.4*	mm	10
2	2α	435.0*	mm	418.8[a,*]	mm	414.4[a,*]	mm	5
2′	2β	435.0*	mm	165.1[a,*]	mm	−223.5[a]	mm	5
3	2α	164.3	242.8[b,*]	153.0	213.1[c]	190.0	154.8[c]	tt[uu]
3′	2β	164.3	mm	mm	522.2	758.9[d]	mm	11
4	2α	522.2	mm	mm	519.3[e,*]	463.0[e,*]	mm	11
4″	2β	219.0*	mm	mm	551.2*	710.0[e,*]	mm	10
5	2α	338.5	mm	mm	360.4[f,*]	435.7[f,*]	mm	7
6	2α	−30.8	mm	mm	−21.0[f,*]	2.3[f,*]	mm	11
6′	2β	−30.8	mm	mm	410.7[f,*]	533.1[f,*]	mm	10
7	2α	89.4*	mm	72.8[g]	63.5	56.1	mm	5
7″	2β	97.2*	mm	133.5[g]	165.0	205.7	272.7[h]	6
8	2α	56.0	mm	mm	20.9*	−40.8	mm	11
8″	2β	120.6[i]	mm	188.5[j]	297.7[h]	361.8	506.5[h]	4
9′	2β	124.2	mm	224.3	273.8	323.2	mm	5
10′	2β	129.6*	mm	289.9	298.9	413.8	mm	7
11	3α	104.4[k]	125.0[l]	97.2*	124.2	129.6*	161.0[m]	3
11′	3β	104.4[k]	85.9[l]	89.4*	109.9	mm	156.6[n,*]	3
12′	3β	44.5[o]	mm	212.3	405.1[p]	mm	mm	6
13	3α	193.3	mm	mm	673.8	856.6	mm	10
14	3α	130.2	mm	137.6[q]	224.3	289.9	mm	3
15	3α	116.3	mm	145.6	290.7	366.9	512.1[r]	8
15″	3β	−4.3	mm	mm	−130.2[h]	−112.1[h]	−105.8[h]	tt[uu]
16	3α	mm	mm	165.0	273.8	298.9	mm	12
16″	3β	mm	mm	63.5	−28.7	−75.3[s]	mm	12
17	3α	mm	mm	205.7	323.2	413.8	mm	13
17″	3β	mm	mm	56.1	−82.6[s]	−153.8[s]	mm	12
18	3α	244.6[o]	mm	444.7[k]	684.6[t,*]	mm	mm	6
18′	3β	244.6[o]	mm	172.1*	105.3[t,*]	mm	mm	6
19	3α	−200.2	mm	−170.1*	−12.2	−22.5	mm	tt[vv]
19′	3β	−200.2	−176.8[u]	−150.8	−107.4	−98.8	−62.1	5
20′	3β	−468.2	mm	−446.2	−401.1	−387.1	mm	4
21′	3β	mm	mm	−210.5	−190.1	mm	−140.1*	12
22	3α	mm	mm	10.1*	32.4*	46.6	mm	12
22′	3β	mm	mm	−20.1	−4.2*	14.0	41.0	13
23′	3β	31.1	mm	52.6*	61.4	65.5	77.2	5
24	4	338.5	374.5[v]	319.3*	444.2[w]	496.0[w]	mm	3
25	5α	164.3	145.7[x]	165.1	mm	23.3[y]	mm	3
26	5α	mm	mm	13.1*	−123.0	−225.0*	mm	12
27	5α	52.6*	54.9[z]	12.6[pp]	−96.6	−183.8	mm	6
28	5α	mm	mm	−39.5	−123.5	−226.0	mm	13
29	5α	mm	mm	−149.2	−144.9	−233.9*	mm	7
30	5α	mm	mm	−108.6	−126.4	−190.9	mm	7
31	5α	109.9	mm	103.7[aa]	53.9[qq]	16.5*	mm	3
32	5α	114.1	mm	mm	442.2[bb]	307.3[bb]	mm	tt[uu]
33	5α	mm	mm	−179.2[pp,*]	−429.5[cc]	−675.1[cc]	mm	13
34	6α	104.4[k]	mm	136.0*	187.3[dd]	225.8[dd]	mm	4
34′	6β	104.4[k]	mm	mm	8.1[ee]	−72.3[ee]	mm	11
35	6α	338.5	410.7[ff]	325.7*	247.3	245.7	mm	tt[vv]
35′	6β	338.5	40.3[ff]	107.0*	62.9	27.8	mm	13
36′	6β	165.1	277.6[gg]	mm	13.1*	−65.0[y]	mm	11
37′	6β	11.7[hh]	mm	−177.7*	−233.9*	−270.7	mm	13
38′	6β	mm	mm	−129.3	−190.9	−260.2*	mm	13
39′	6β	38.9	mm	mm	−25.4[cc]	−51.4[cc]	mm	10
40	6α	−181.7*	−72.8[ii]	mm	−33.7[ii]	−32.6[ii]	5.1[it]	tt[uu]
40′	6β	−181.7*	−323.7[ii]	mm	139.0[ii]	316.6[ii]	584.3[ii]	8
41	7α	93.2	mm	42.8	−85.5	−90.3	mm	tt[vv]
42	7α	−184.3	mm	−389.1	−764.2	−1233.5	−2024.3	6
43	7α	−73.6	mm	−253.4	−632.9	−1025.4	−1665.0*	6
43′	7β	−73.6	mm	65.9	318.8	113.9[oo]	mm	6
44	7α	−107.4	mm	mm	−725.3*	−1135.0*	mm	11
45′	(3β)′[ss]	417.2	mm	mm	449.4*	mm	401.4*	tt[vv]
46′	(3β)′	263.6	mm	mm	288.5	mm	315.6*	tt[vv]
47′	(3β)′	−184.3	mm	mm	−178.8	−143.1	135.3	11
48′	(6β)′	−237.2*	mm	mm	−235.1*	mm	−209.4*	tt[vv]

TABLE I
(*Continued*)

Compd	Position and orientation of X	$[M]^{20}_D$ for X: H	F	(OH)	Cl	Br	I	Figure
		5β-Cholestane (*i.e.*, coprostane) derivative						
49	3α	96.9	*mm*	120.5	134.4^{jj}	149.0^{jj}	*mm*	5
49′	3β	96.9	*mm*	93.3	91.6*	81.3	*mm*	6
50′	(3β)′	411.3^{kk,*}	*mm*	*mm*	440.4*	*mm*	435.6*	tt^{vv}
		Androstane derivative						
51	2α	238.7*	*mm*	*mm*	352.3	324.2*	375.9	10
52	17α	299.7*	319.5^{l}	206.2^{pp,*}	135.0^{l}	63.2^{l}	*mm*	6
		Pregnane derivative						
53	9α	861.3*	*mm*	*mm*	1101.1*	1131.3*	*mm*	10
54	9α	610.8^{nn,*}	638.0^{ll}	*mm*	610.1*	642.9	769.1*	11
		Spirostane derivative						
55	12α	−223.1	*mm*	*mm*	*mm*	−149.5*	−90.1*	11
		Cholaoic acid derivative						
56	12α	178.8^{rr}	*mm*	396.5^{rr}	634.6	981.7	*mm*	6
57	12α	245.5^{rr}	*mm*	500.2^{rr}	716.2	*mm*	*mm*	8

Compd	Steroid	Compd	Steroid
1	2-X-(5α)cholest-1-en-3-one	2	2α-X-(5α)cholestan-1-one
2′	2β-X-(5α)cholestan-1-one	3	2α-X-(5α)cholestan-3-one
3′	2β-X-(5α)cholestan-3-one	4	2α-X-2β-chloro-(5α)cholestan-3-one
4″	2β-X-2α-chloro-(5α)cholestan-3-one	5	2α-X-(5α)cholest-4-en-3-one
6	2α-X-(5α)cholest-5-en-3-one	6′	2β-X-(5α)cholest-5-en-3-one
7	2α-X-(5α)cholestan-3β-ol	7″	2β-X-(5α)cholestan-3α-ol
8	2α-X-(5α)cholestan-3β-yl acetate	8″	2β-X-(5α)cholestan-3α-yl acetate
9′	2β-X-3α-chloro-(5α)cholestane	10′	2β-X-3α-bromo-(5α)cholestane
11	3α-X-(5α)cholestane	11′	3β-X-(5α)cholestane
12′	3β-X-(5α)cholest-1-ene	13	3α-X-(5α)cholestan-2-one
14	3α-X-(5α)cholestan-2β-ol	15	3α-X-(5α)cholestan-2β-yl acetate
15″	3β-X-(5α)cholestan-2α-yl acetate	16	3α-X-2β-chloro-(5α)cholestane
16″	3β-X-2α-chloro-(5α)cholestane	17	3α-X-2β-bromo-(5α)cholestane
17″	3β-X-2α-bromo-(5α)cholestane	18	3α-X-(5α)cholest-4-ene
18′	3β-X-(5α)cholest-4-ene	19	3α-X-(5α)cholest-5-ene
19′	3β-X-(5α)cholest-5-ene	20′	3β-X-(5α)cholest-5,7-diene
21′	3β-X-24-ethyl-(5α)cholest-5,22-diene	22	3α-X-(5α)cholestan-6-one
22′	3β-X-(5α)cholestan-6-one	23′	3β-X-(5α)cholestan-6β-ol
24	4-X-(5α)cholest-4-en-3-one	25	5-X-(5α)cholestan-3-one
26	5-X-6β-chloro-(5α)cholestan-3-one	27	5-X-(5α)cholestane-3β,6β-diol
28	5-X-6β-chloro-(5α)cholestan-3β-ol	29	5-X-6β-chloro-(5α)cholestan-3β-yl acetate
30	5-X-6β-chloro-(5α)cholestan-3β-yl benzoate	31	5-X-3β-chloro-(5α)cholestane
32	5-X-(5α)cholestan-4-one	33	5-X-(5α)cholestan-6-one
34	6α-X-(5α)cholestane	34′	6β-X-(5α)cholestane
35	6α-X-(5α)cholest-4-en-3-one	35′	6β-X-(5α)cholest-4-en-3-one
36′	6β-X-(5α)cholestan-5-ol-3-one	37′	6β-X-5-bromo-(5α)cholestan-3β-yl acetate
38′	6β-X-5-bromo-(5α)cholestan-3β-yl benzoate	39′	6β-X-(5α)cholestan-5-ol
40	6α-X-(5α)cholestan-7-one	40′	6β-X-(5α)cholestan-7-one
41	7α-X-(5α)cholestane	42	7α-X-cholest-5-en-3β-yl acetate
43	7α-X-cholest-5-en-3β-yl benzoate	43′	7β-X-cholest-5-en-3β-yl benzoate
44	7α-X-3β-chloro-cholest-5-ene	45′	3β-(X-acetoxy)-4,4,14α-trimethyl-(5α)cholest-7,9(11)-diene
46′	3β-(X-acetoxy)-4,4,14α-trimethyl-(5α)cholest-8-ene	47′	3β-(X-acetoxy)cholest-5-ene
48′	6β-(X-acetoxy)-(5α)cholestan-5-ol-3β-yl acetate	49	3α-X-(5β)cholestane
49′	3β-X-(5β)cholestane		
51	2α-X-17β-methoxycarbonyl-(5α)androstan-3-one	50′	3β-(X-acetoxy)-5-methyl-19-nor-(5β)cholest-9-en-6β-yl acetate
53	9α-X-pregn-4-en-17α-ol-3,11,20-trion-21-yl acetate	52	17α-X-androst-4-en-3-one
55	12α-X-(5α,22a)spirostan-11β-ol-3β-yl acetate	54	9α-X-pregn-4-ene-11β,17α-diol-3,20-dion-21-yl acetate
57	methyl ester of 12α-X-3α-acetoxy-(5β)chol-9(11)-en-24-oic acid	56	methyl ester of 12α-X-(5β)chol-9(11)-ene-3α-ol-24-oic acid

Unless noted otherwise, $[M]^{20}_D$ were calculated from $[\alpha]_D$, cited by J. P. Mathieu and A. Petit, in "Tables de Constantes et Données Numériques. 6. Constantes Sélectionnées. Pourvoir Rotatoire Naturel. I. Stéroïdes," Masson et Cie, Paris, 1956. See page 1408 for footnotes.

TABLE I (*Continued*)

[a] H. P. Sigg and C. Tamm, *Helv. Chim. Acta*, **43,** 1402 (1960). [b] G. A. Boswell, Jr., *J. Org. Chem.*, **33,** 3699 (1968). [c] H. R. Nace and B. A. Olsen, *ibid.*, **32,** 3438 (1967). [d] I. Malunowicz, J. Fajkoš, and F. Šorm, *Chem. Listy.*, **52,** 2359 (1958); *Chem. Abstr.*, **53,** 10283*g* (1959). [e] E. W. Warnhoff, *J. Org. Chem.*, **28,** 887 (1963). [f] B. Ellis and V. Petrow, *J. Chem. Soc.*, 1179 (1956). [g] C. W. Shoppee, D. N. Jones, and G. H. R. Summers, *ibid.*, 3100 (1957). [h] D. H. R. Barton and J. F. King, *ibid.*, 4398 (1958). [i] M. Nussim, Y. Mazur, and F. Sondheimer, *J. Org. Chem.*, **29,** 1120 (1964). [j] K. L. Williamson and W. S. Johnson, *ibid.*, **26,** 4563 (1961). [k] C. W. Shoppee, B. D. Agashe, and G. H. R. Summers, *J. Chem. Soc.*, 3107 (1957). [l] H. B. Henbest and W. R. Jackson, *ibid.*, 954 (1962). [m] A. V. Bayless and H. Zimmer, *Tetrahedron Lett.*, No. 35, 3811 (1968). [n] E. J. Corey, M. G. Howell, A. Boston, R. L. Young, and R. A. Sneen, *J. Amer. Chem. Soc.*, **78,** 5036 (1956). [o] R. B. Turner, W. R. Meador, and R. E. Winkler, *ibid.*, **79,** 4122 (1957). [p] H. B. Henbest and R. A. L. Wilson, *J. Chem. Soc.*, 3289 (1956). [q] H. Mori, K. Shibata, K. Tsuneda, and M. Sawai, *Chem. Pharm. Bull.*, **15,** 460 (1967); *Chem. Abstr.*, **67,** 100313*f* (1967). [r] D. G. Hey, G. D. Meakins, and M. W. Pemberton, *J. Chem. Soc. C*, 1331 (1966). [s] G. H. Alt and D. H. R. Barton, *ibid.*, 4284 (1954). [t] W. G. Young, R. E. Ireland, T. I. Wrigley, C. W. Shoppee, B. D. Agashe, and G. H. R. Summers, *J. Amer. Chem. Soc.*, **81,** 1452 (1959). [u] C. W. Shoppee and G. H. R. Summers, *J. Chem. Soc.*, 4813 (1957). [v] S. Nakanishi, R. L. Morgan, and E. V. Jensen, *Chem. Ind. (London)*, 1136 (1960). [w] J. I. Shaw and R. Stevenson, *J. Chem. Soc.*, 3549 (1955). [x] R. Jacquesy and J. Levisalles, *Bull. Soc. Chim. Fr.*, 1884 (1966). [y] J. C. Jacquesy and J. Levisalles, *ibid.*, 1538 (1965). [z] H. B. Henbest and T. I. Wrigley, *J. Chem. Soc.*, 4765 (1957). [aa] C. W. Shoppee, R. J. Bridgwater, D. N. Jones, and G. H. R. Summers, *ibid.*, 2492 (1956). [bb] C. W. Shoppee, M. E. H. Howden, R. W. Killick, and G. H. R. Summers, *ibid.*, 630 (1959). [cc] C. W. Shoppee, R. H. Jenkins, and G. H. R. Summers, *ibid.*, 1657 (1958). [dd] C. W. Shoppee and M. E. H. Howden, *Chem. Ind. (London)*, 414 (1958). [ee] C. W. Shoppee and R. Lack, *J. Chem. Soc.*, 4864 (1960). [ff] S. Nakanishi, K. Morita, and E. V. Jensen, *J. Amer. Chem. Soc.*, **81,** 5259 (1959). [gg] A. Bowers and H. J. Ringold, *Tetrahedron*, **3,** 14 (1958). [hh] S. P. J. Maas and J. G. De Heus, *Recl. Trav. Chim. Pays-Bas*, **77,** 531 (1958). [ii] A. Nickon, M. A. Castle, R. Harada, C. E. Berkoff, and R. O. Williams, *J. Amer. Chem. Soc.*, **85,** 2185 (1963). [jj] J. R. Lewis and C. W. Shoppee, *J. Chem. Soc.*, 1365 (1955). [kk] H. Aebli, C. A. Grob, and E. Schumacher, *Helv. Chim. Acta*, **41,** 774 (1958). [ll] J. Elks, G. H. Phillipps, and W. F. Wall, *J. Chem. Soc.*, 4001 (1958). [mm] Unknown. [nn] In acetone. [oo] In benzene. [pp] In ethanol. [qq] In ether. [rr] In methanol. [ss] $(3\beta)'$ means that the group X is part of a larger group attached to the 3 position of the steroid skeleton in the β orientation, but that it is not itself combined directly with the steroid skeleton, and so on. [tt] No figure. [uu] Refer to footnote 26. [vv] Refer to footnote 19. * This was assumed from the $[M]_D$, which was observed at *ca.* 20°.

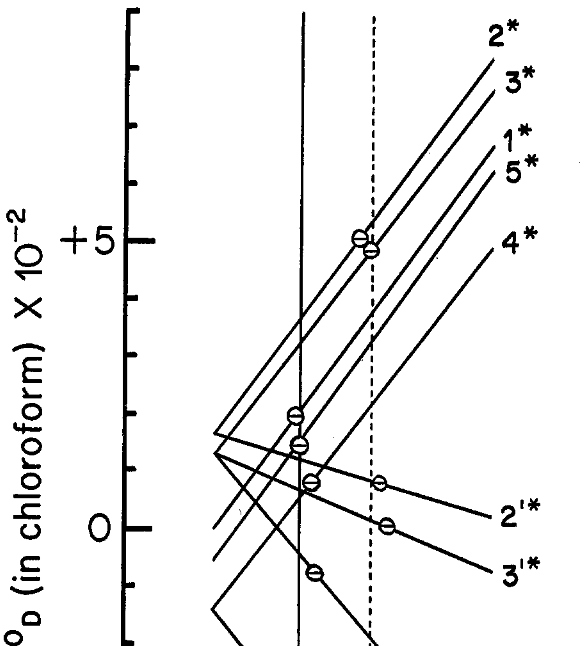

Figure 1.—Estimation of the S value of a radical OH which is attached to the C-1 atom in a pyranose ring;[10,11] ⊖, OH.

of electron polarizability to calculating the $[M]_D$ values of steroids, but some of his calculated values deviate considerably from the observed values.[3]

The present author recently found[4] some empirical rules graphically which govern the molecular rotations $[M]^{20}_D$ (at 20°) of poly-*O*-acetyl (or benzoyl) glycopyranosyl compounds, RX. These rules[5] can be summarized by eq 1 where a and b are constants inherent in

$$[M]^{20}_D \text{ value of a compound, RX} = a + bS \qquad (1)$$

the moiety, R, and S is a new coefficient which is concerned with some optical properties of the atom (or radical) X. It was found that the S value of a halogen atom is equal to its atomic refraction, R_D, but the S value of a hydrogen atom is −1.8.[5] The following method was proposed[6] in order to estimate the S value of an OH radical in a compound, ROH.

First, a straight $[M]^{20}_D$ *vs.* S line is drawn for a series of compounds RX (where X is H, F, Cl, Br, or I).[7] Next, a horizontal line is drawn whose ordinate is $[M]^{20}_D$ of ROH (eq 2).

$$\text{ordinate value} = [M]^{20}_D \text{ value of ROH} \qquad (2)$$

If the OH radical has its own S value, the abscissa at the intersection of these two lines (*i.e.*, the standard line of RX and the horizontal line of ROH) should be the S value of the OH radical which is combined with the R moiety, because $[M]^{20}_D$ of ROH should fall on both of the two lines at this abscissal value.[8]

By using the ITL method[8] in Figure 1 of the previous paper,[6] the S value of the OH radical in poly-*O*-acetylglycopyranosyl compounds was estimated as 1.2. This value has been proved to be applicable not

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(3) J. H. Brewster, *J. Amer. Chem. Soc.*, **81,** 5475, 5483, 5493 (1959).

(4) S. Yamana, *J. Org..Chem.*, **31,** 3698 (1966).

(5) Rule 1. When the molecular rotation of poly-*O*-acetyl- or benzoylglycopyranosyl halides RX, where X is F, Cl, Br, or I, is plotted against the atomic refraction of X, straight lines are obtained, regardless of the configuration at the 1 position. Rule 2. An abscissal value can be found for hydrogen so that the "hydrides," RH, also fall on the lines mentioned in rule 1. Rule 3. The abscissal value of the point for the "hydride" is −1.8 (by the R_D scale for halogen) and is not related to the atomic refraction of hydrogen, 1.028.

(6) S. Yamana, *J. Org. Chem.*, **33,** 185 (1968).

(7) This straight $[M]^{20}_D$ *vs.* S line is called the "Standard Line" of this series of compounds RX.

(8) This method of estimating the S value of an atom or radical in an optically active molecule will be called the "Intersecting Two Lines (or ITL) method," hereafter.

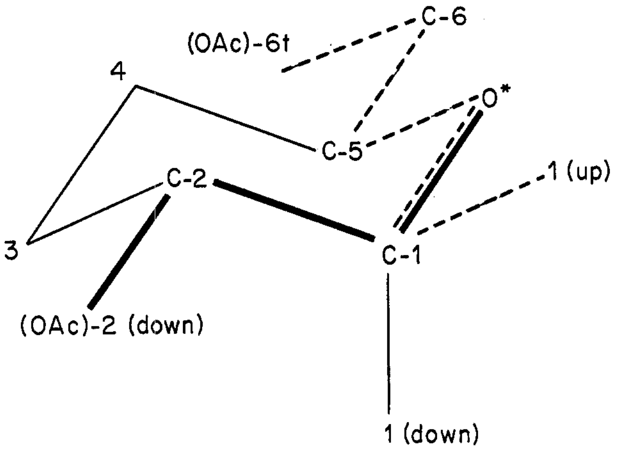

Figure 2.—Two coplanar zigzag chains, containing the C-1 atom of a pyranose ring.

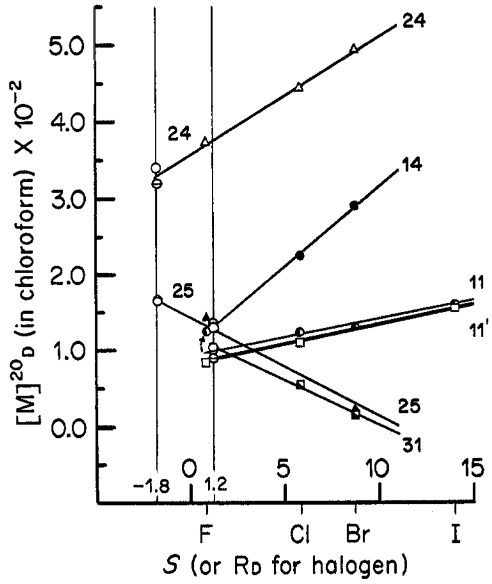

Figure 3.—Estimations of the S value of H and OH in steroid derivatives:[17,20,21] A 1 class (S of H = S of OH = -1.8); B 1 class (S of H = S of OH = 1.2). ○, H; ⊖, OH.

only to all nonsubstituted glycopyranosyl compounds[6] but also to 6-Y-6-deoxy-D-glucopyranose derivatives.[9]

In order to reexamine the S value of the OH radical, the earlier figure is reproduced (with some changes) as Figure 1[10,11] of the present paper.

Figure 1 shows that the abscissal value of the OH radical is *ca.* 1.2 in some compounds (*i.e.*, **1***, **4***, **5***, **6*** and **7***), but in four compounds (*i.e.*, **2***, **3***, **2'***, and **3'***) it is considerably large, *i.e.*, *ca.* 3.7. The larger S values may be explained in terms of the factors illustrated in Figure 2, *i.e.*, (A) the presence of two coplanar zigzag chains,[12] each of which contains the C-1 atom[13] [the first one is C-1–O*–C-5–C-6–(OAc)-6t[14] and the second one is O*–C-1–C-2–(OAc)-2(down)]; (B) the presence of the Ac radical at the end of each of these coplanar zigzag chains.

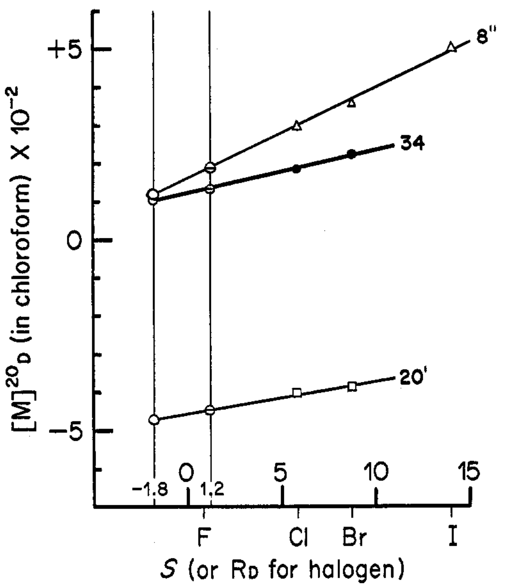

Figure 4.—Estimations of the S value of H and OH in steroid derivatives:[17,20] A 2 class (S of H = -1.8; S of OH = 1.2). ○, H; ⊖, OH.

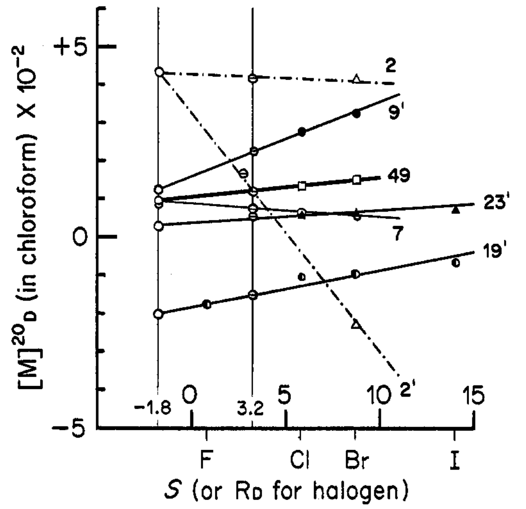

Figure 5.—Estimations of the S value of H and OH in steroid derivatives:[17,20,22] A 3 class (S of H = -1.8; S of OH = 3.2). ○, H; ⊖, OH.

These two conditions are easily seen when one compares the molecular structures of the compounds which have a large S value of OH radical (*i.e.*, **2***, **3***, **2'***, and **3'***) with those of the others (*i.e.*, **1***, **4***, **5***, **6***, and **7***). Moreover, the phenomenon that the S value of the OH radical in **2'*** and **3'*** is slightly larger than that in **2*** and **3*** suggests that the extension of the first coplanar zigzag chain by a new coplanar bond C-1–(OH)-1(up) increases the S value of the OH radical.[15] In other

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[9] S. Yamana, *J. Org. Chem.*, **33**, 1819 (1968).

[10] The oblique lines of Figure 1 are the standard lines.[7] In order to simplify Figure 1, the horizontal lines are omitted. The intersections of the standard lines and the horizontal lines are indicated by ⊖.

[11] Carbohydrates are numbered as follows (the mark * means that we are dealing with a glycopyranosyl compound, RX): **1***, 2,3,4-tri-*O*-acetyl-α-D-xylopyranosyl; **2***, 2,3,4,6-tetra-*O*-acetyl-α-D-galactopyranosyl; **2'***, 2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranosyl; **3***, 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl; **3'***, 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl; **4***, 2,3,4,6-tetra-*O*-acetyl-α-D-mannopyranosyl; **5***, 2,3,4,6-tetra-*O*-acetyl-α-D-talopyranosyl; **6***, 1,3,4,5-tetra-*O*-acetyl-β-D-fructopyranosyl; **7***, 1,3,4,5-tetra-*O*-acetyl-α-L-sorbopyranosyl.

[12] A coplanar chain is a chain composed of some atoms, all of which lie in one plane.

[13] The C-1 atom is the one to which the OH radical is attached. Moreover, these two coplanar zigzag chains contain a common moiety, *i.e.*, the O*–C-1 bond.

[14] O* means the ring oxygen atom and t means the trans position (see Figure 6 of the previous paper[9]).

[15] The increase produced by a coplanar zigzag chain (or a combination of two kinds of coplanar chains) in the S value of an OH radical which is combined (but not coplanar) with this chain (or these chains) is named the "First Coplanar Effect." The increase which is caused by extending a coplanar zigzag chain with the OH radical itself is called the "Second Coplanar Effect."

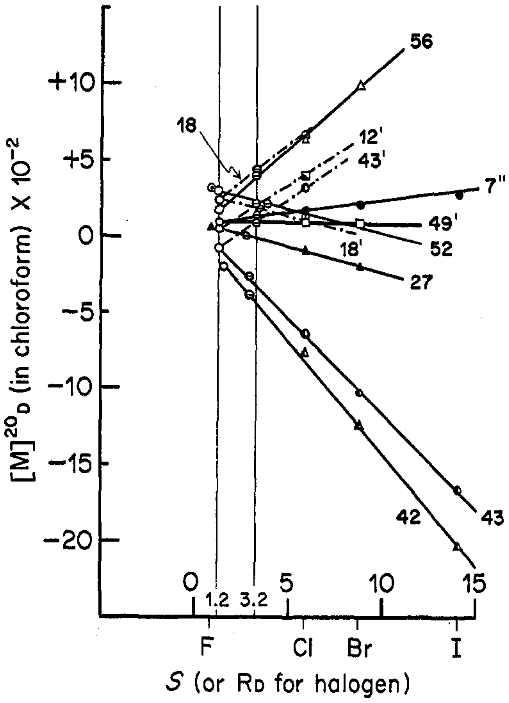

Figure 6.—Estimations of the S value of H and OH in steroid derivatives:[17,20,22] B 2′ class (S of H = 1.2; S of OH = 3.2). ○, H; ⊖, OH.

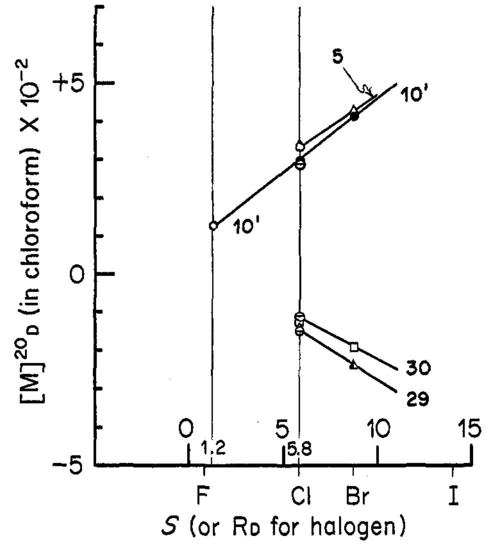

Figure 7.—Estimations of the S value of H and OH in steroid derivatives:[17] B 3 class (S of H = 1.2; S of OH = 5.8) and the case S of H = 5.8. ○, H; ⊖, OH.

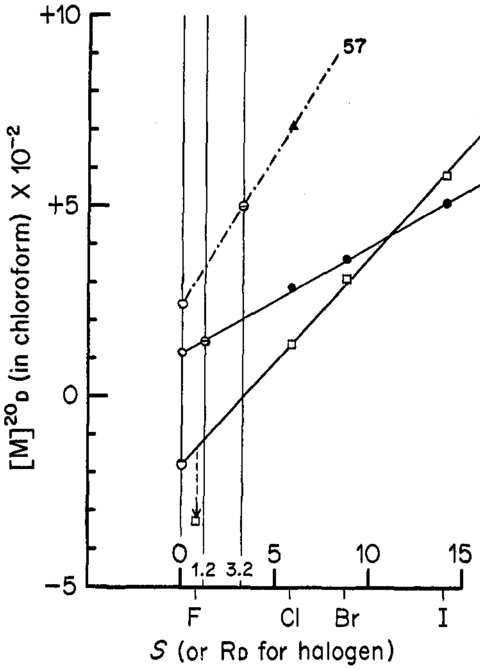

Figure 8.—Estimations of the S value of H and OH in steroid derivatives:[17,21,22,25] C 1′ class (S of H = 0.0; S of OH = 1.2); C 2 class (S of H = 0.0; S of OH = 3.2). ○, H; ⊖, OH.

words, the S value of the OH radical at the 1 position in **2*** and **3*** is much larger than *ca.* 1.2 owing to the first coplanar effect, but the one in **2′*** and **3′*** is additionally increased by the second effect.

Strictly speaking, however, the actual structure of pentopyranosyl compounds is that of an equilibrium between two different conformations related by inversion of the tetrahydropyranyl ring.[16] Therefore, it becomes necessary to examine the applicability of eq 1 and at the same time the variability of the S value of OH in other types of compounds. In this article, the method is applied to steroids because of the rigid carbon skeleton of these substances. The 75 steroid derivatives, RX, discussed in this article and their molecular rotations are given in Table I.

The $[M]^{20}_{D}$ values[17] were plotted against the S (or R_D) value of the halogen atom to get the standard lines of Figures 3–8, but the values of S used are as follows: S of F atom is 0.8; S of Cl atom is 5.8; S of Br atom is 8.7; S of I atom is 14.0.[18] Next, the S values of the H atom and that of the OH radical were estimated. However, in the present instance, not only the S value of the OH radical but also that of the H atom were obtained by using only the ITL method,[8,19] because, as will be noticed later, the S value of the H atom depends on the orientation of the corresponding C–H bond and therefore the method using the intersection of two standard lines of a pair of diastereomers (as shown in Figures 1 and 3 of the previous paper[4] for the case of carbohydrates) is unsuitable.

The intersections formed by the ITL method are shown by the white circles (for the H atom) and the marks ⊖ (for the OH radical) in Figures 3–8.[20-22]

It is apparent from Figures 3–8 that H and OH can

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[16] P. L. Durette and D. Horton, *Carbohyd. Res.*, **18**, 57 (1971).

[17] Refer to Table I.

[18] A. I. Vogel, *J. Chem. Soc.*, 1833 (1948).

[19] Some of the compounds listed in Table I are unsuitable for estimating the S value of the H atom and that of the OH radical, for the following reasons. (a) A standard line may be nearly horizontal, and, accordingly, the abscissal value of the intersection of this standard line *with the horizontal* line (eq 2) cannot be estimated clearly on a figure (for example, **45′**, **46′**, **48′**, and **50′**). (b) A $[M]^{20}_{D}$ *vs.* R_D (for halogen) plot is nearly horizontal and is situated too far from the horizontal line of eq 2, and, therefore, it is impossible to get their intersection at a moderate abscissal value (for example, **19**, **35**, and **41**).

[20] A $[M]^{20}_{D}$ *vs.* R_D (for halogen) plot of a steroid which has only one substituent (*i.e.*, X) is drawn with a somewhat bold line.

[21] The symbol ⟶ means a deviation from the corresponding solid line.

[22] **2** and **2′** have a $[M]^{20}_{D}$ datum of only one kind of halide, and therefore these two compounds do not have any standard lines. If S values for H and for OH are assumed to be −1.8 and 3.2, respectively, $[M]^{20}_{D}$ *vs.* S (or R_D for halogen) plots for these three X's (*i.e.*, H, (OH), and one halogen atom) become straight. Accordingly, **2** and **2′** seem to belong to the A 3 class and they are shown by dotted lines in Figure 5. Similarly, four compounds, **12′**, **18**, **18′**, and **43′**, seem to belong to the B 2′ class and are indicated by the dotted lines in Figure 6. **57**, which is presumed to belong to the C 2 class, is similarly shown in Figure 8.

TABLE II

PAIR OF S VALUE OF H ATOM AND S VALUE OF (OH) RADICAL IN STEROID DERIVATIVES

Figure	Class	S value		Type[a]	Compd
		H	(OH)		
3	A 1	−1.8	−1.8	h	**24, 25**
4	A 2	−1.8	1.2	i	**8″, 20′, 34**
5	A 3	−1.8	3.2	c	**7, 9′, 19′, 23′, 49 (2, 2′)**
3	B 1	1.2	1.2	h	**11, 11′, 14, 31**
6	B 2′	1.2	3.2	i′	**27, 42, 43, 7″, 49′, 52, 56 (12′, 18, 18′, 43′)**
7	B 3	1.2	5.8	c	**10′**
8	C 1′	0.0	1.2		**15**
8	C 2	0.0	3.2	i	**(57)**

[a] See Figure 9.

take several discrete S values and that pairing of the S values of H and OH will lead to a certain classification. Depending on the S value of the H atom (*i.e.*, −1.8, 1.2,[23] or 0.0), the pairs are divided into three main classes (*i.e.*, A, B, and C classes, respectively), each of which is again divided into several subclasses, as shown in Table II.[24]

In order to distinguish visually the various kinds of S value pairs from each other, Figure 9 has been constructed, in which the ordinate corresponds to the S value and the abscissa corresponds to the kind of atom or radical.

It is clear from Figure 9 that there are several kinds of slopes. The main types are named as follows: (a) *horizontal* (or h) type—A 1 class and B 1 class; (b) *gently increasing* (or i′) type—B 2′ class; (c) *increasing* (or i) type—A 2 class; (d) *climbing* (or c) type—A 3 class and B 3 class.

Next, the series of compounds RX, where either the $[M]^{20}_{D}$ value of the hydride (*i.e.*, X = H) or that of the hydroxide (*i.e.*, X = OH) is known, were treated in similar fashion. The results are given in Figures 7, 8, and 10–13 (S of H = −1.8 in Figure 10, S of H = 0.0 in Figure 8, S of H = 1.2 in Figure 11, S of H = 5.8 in Figure 7, S of (OH) = −1.8 or 1.2 in Figure 12, and S of (OH) = 2.2 or 3.2 in Figure 13).[25]

The S values of H and those of OH obtained from Figures 7, 8, and 10–13 are listed in Table III.[26]

From Figures 3–8 and 10–13 and Tables II and III, the following empirical rules are obtained for the steroids.

Rule 1.—$[M]^{20}_{D}$ *of a compound RX (where X is H, OH, F, Cl, Br, or I) = a + bS, but here a and b are constants which are inherent in the moiety R, and S is one which is concerned with some optical property of X.*

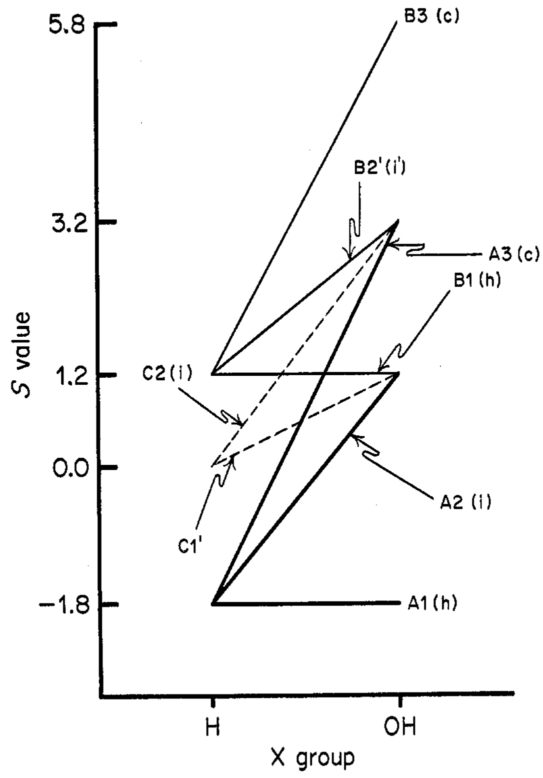

Figure 9.—Types of line slopes which corresponds to a pair of S values (*i.e.*, S value of H atom and S value of OH radical: h, *horizontal;* i, *increasing;* i′, *gently increasing;* c, *climbing*).

TABLE III

S VALUE OF H ATOM OR S VALUE OF (OH) RADICAL IN STEROID DERIVATIVES

Figure	S of H	Compd
10	−1.8	**1, 4″, 6′, 13, 39′, 51, 53**
8	0.0	**40′**
11	1.2	**3′, 4, 6, 8, 34′, 36′, 44, 47′, 54, 55**
7	5.8	**5**
Figure	S of (OH)	Compd
12	−1.8	**16**
12	1.2	**16″, 17″, 21′, 22, 26**
13	2.2	**17, 35′, 37′**
13	3.2	**22′, 28, 33, 38′**
7	5.8	**29, 30**

Rule 2.—*The value of S is equal to the value of atomic refraction,* R_D *only for halogen.*

Rule 3.—*A hydrogen atom (or a hydroxyl radical) assumes discontinuous definite S values, which are as follows:*[27] *H atom (−1.8, 0.0, 1.2, etc.);*[26] *OH radical (−1.8, 1.2, 2.2, 3.2, 5.8, etc.).*

Rule 4.—*In the same series of compounds, S value of H atom* $\leqslant$ *S value of OH radical.*

Moreover, in terms of molecular structures, the following rules can be deduced.

Rule 5.—*The S value of the H atom or OH radical depends on the orientation of the corresponding C–H (or C–O) bond.*

For example, the S value of the H atom is −1.8 in some compounds (*i.e.*, **6′**, **34**, and **49**), but it is 1.2 in their diastereomers (*i.e.*, **6**, **34′**, and **49′**). Similarly, the S value of the OH radical is 1.2 in **22**, but it is 3.2 in **22′**.

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[23] The S value of H, 1.2, is approximately, but not exactly, equal to the R_D value of the H atom in CH_2 (1.028).[18]

[24] The A 2 class was already encountered in the carbohydrates.[4,6,9]

[25] In the case of **51** (Figure 10), the standard line was drawn by using the $[M]^{20}_{D}$ value of the bromide and the iodide. This line was useful to get the S value of H atom, −1.8. The $[M]^{20}_{D}$ value of the chloride does not fall, however, on this standard line at the abscissal value of 5.8 (R_D of Cl atom[18]). Moreover, in three cases (*i.e.*, **35′** (in Figure 13), **36′** (in Figure 11) and **40′** (in Figure 8)), the $[M]^{20}_{D}$ values of their fluorides do not fall on their respective standard lines (all of which are drawn without using the $[M]^{20}_{D}$ values of fluorides) at the abscissal value of 0.8 (R_D of F atom[18]). The study of the reasons for these abnormalities of fluorides is left for the future.

[26] The S value of the H atom is, in some cases, somewhat large (either positive or negative in sign). For example, S of H = *ca.* −7 in **35′**, **37′**, and **40** or *ca.* 14 in **3**, **15″**, and **32**. These S values are somewhat imprecise and are not included in any figures or tables of this article. (Refer to footnote 31.)

[27] Only those S values which are ascertained in more than three cases in this article are given here.

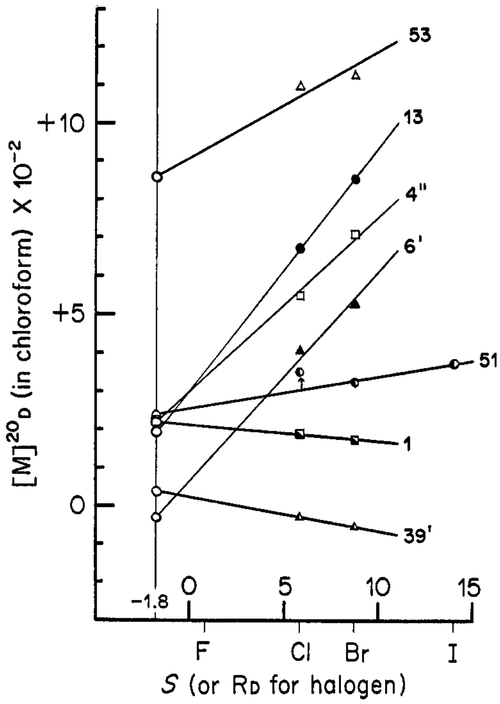

Figure 10.—Estimation of the S value of H in steroid derivatives[17,21,25] (S of H = −1.8); O, H.

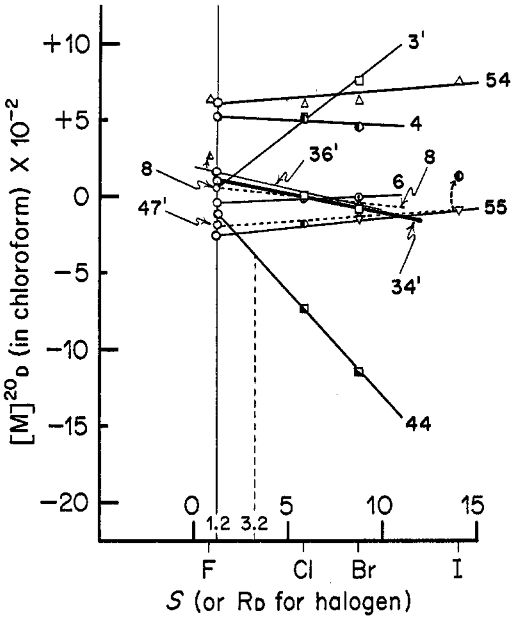

Figure 11.—Estimation of the S value of H in steroid derivatives[17,20,21,25] (S of H = 1.2); O, H.

Rule 6.—*When the X group is located more or less in the plane of symmetry with regard to the arrangement of the atoms which surround it, the compound belongs to the horizontal type class.*

For example, **24** and **25** (A 1 class); **11**, **11′**, **14**, **31** (B 1 class).

Rule 7.—*When there is a double bond at the α position (with respect to the X group) and in the same ring of the steroid skeleton, the compound belongs to the B 2′ class (i.e., S of H = 1.2; S of (OH) = 3.2).*

The examples are **12′**, **18**, **18′**, **42**, **43**, **43′**, and **56**. The only exception is **57**, which belongs to the C 2 class (S of H = 0.0; S of (OH) = 3.2). Referring to Table III, the S value of the H atom is 1.2 in **44**, but, as [M]^{20}D of the corresponding hydroxide is unknown in Table I, the S value of the OH radical cannot be estimated in **44**. However, **44** (*i.e.*, 7α-X-3β-chlorocholest-5-ene) has a double bond between C-5 and C-6 which is located at the α position with respect to the X-7 group; hence, according to rule 7, it is presumed that **44** belongs to the B 2′ class and the S value of OH radical which is attached to the 7 position in α orientation may be 3.2. This value is used in Figure 11 to estimate the [M]^{20}D value of the hydroxide of **44** (in which X is OH radical) at *ca.* −400.

Rule 8.—*If the X group and some other group Y lie on the same coplanar zigzag chain,[12] the influence of the Y group can be easily transmitted to the X group.*

In order to illustrate rule 8, Table IV is given here.[28]

TABLE IV

INFLUENCE OF Y-6 GROUP ON THE S VALUE OF THE OH RADICAL AT THE 3 POSITION

		S of X-3α				S of X-3β	
Compd	Y-6	H	(OH)	Compd	Y-6	H	(OH)
11	Two H's	1.2	1.2	**11′**	Two H's	1.2	1.2
22[b]	O (in CO)	[a]	1.2	**22′**[c]	O (in CO)	[a]	3.2

[a] Unknown. [b] This has a noncoplanar structure, (CO)-6–C-5–C-4–C-3–(OH)-3α. [c] This has a coplanar zigzag chain, (CO)-6–C-5–C-4–C-3–(OH)-3β.

Table IV shows that the replacement of two hydrogen atoms by an O atom to make a carbonyl group at the 6 position changes the S value of the OH at C-3 from 1.2 to 3.2 only when this OH radical is in the β orientation which is coplanar with the carbonyl radical.[29]

Another example illustrating rule 8 is given in Table V.[28]

TABLE V

INFLUENCE OF Y-3α GROUP ON THE KIND OF CLASS

			S of X-2β	
Compd[a]	Y-3α	Class	H	(OH)
9′	Cl	A 3 (c)	−1.8	3.2
10′	Br	B 3 (c)	1.2	5.8

[a] This has a coplanar zigzag chain, Y-3α-C-3-C-2-X-2β.

As shown in Table V, the kind of group at the 3α position determines the class to which **9′** or **10′** belong, although, interestingly enough, both classes are of the same, *i.e.*, *climbing*, type. In other words, the change from Cl to Br (both of which are halogen) does not cause any change in class type but produces a parallel displacement of the line of the class type in Figure 9. In order to examine whether this phenomenon also exists in the corresponding noncoplanar structures (Y-3β-C-3-C-2-X-2α),[29] the [M]^{20}D values of some other compounds (*i.e.*, 2α-X-3β-chloro-(5α)cholestane and 2α-X-3β-bromo-(5α)cholestane) are necessary. Unfortunately, these are not available, but, in order to show the correctness of rule 8, some other examples will be given later in this article.

Interpretation from the Standpoint of Electronic Theory.—As regards the electron density on a hydrogen atom which is combined with a carbon atom in a steroid skeleton, the following situation may be probable. A hydrogen atom has a smaller electronegativity than a carbon atom, and therefore a partially ionized bond

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(28) Refer to Tables II and III.

(29) See Figure 14.

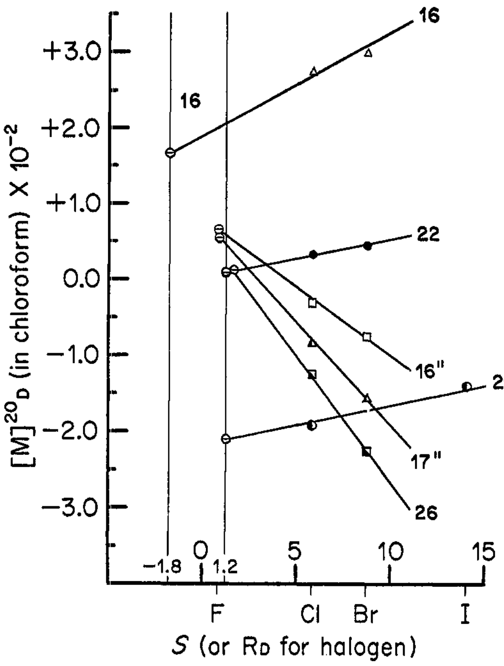

Figure 12.—Estimation of the S value of OH in steroid derivatives[17] (S of OH = −1.8 or 1.2); ⊖, OH.

$C^{\delta-}$–$H^{\delta+}$ is more stable than a perfectly electroneutral covalent bond C–H. However, if an atom or radical Y in the remainder of the molecule repulses an electron toward this $C^{\delta-}$–$H^{\delta+}$ bond, from the opposite side of $H^{\delta+}$, $H^{\delta+}$ will be forced to receive a part of an electron and to become electroneutral H. Then, depending on the magnitude of the electron-repulsing (or -attracting) force of the Y group, roughly speaking, a carbon–hydrogen bond may exist in the two states, C–H or $C^{\delta-}$–$H^{\delta+}$.

On the other hand, it has been reported that the R_D value of an H atom (in CH_2) is positive in sign, 1.028,[18] but a proton H^+ has a negative refractivity.[30] On this basis, the several discrete S values of H atom given in rule 3 can be interpreted as follows: the S value of H in C–H is 1.2 and the S value of H in $C^{\delta-}$–$H^{\delta+}$ is −1.8. The case where the S value of H is equal to 0.0 may be a mixture of the two states of a carbon–hydrogen bond.[31] One way of showing the correctness of this interpretation is to compare **3′** with **4″**.[28] The S value of the H-2β atom is 1.2 in **3′** which does not have any halogen atom attached to the C-2 atom of the steroid skeleton, but it is −1.8 in **4″** in which the Cl-2α atom is supposed to attract an electron from the H-2β atom through the coplanar chain, Cl-2α–C-2–H-2β.

In order to examine the correctness of rule 8 and the author's interpretation of the reasons for the variability in the S value of H, some examples are shown in Table VI.[28]

Table VI shows that the Y-3α group in the second column attracts an electron more strongly than that in the fifth column of the same line. This influence of the Y-3α group is transmitted to the H-2β group through the coplanar zigzag chain, Y-3α–C-3–C-2–H-2β.[29]

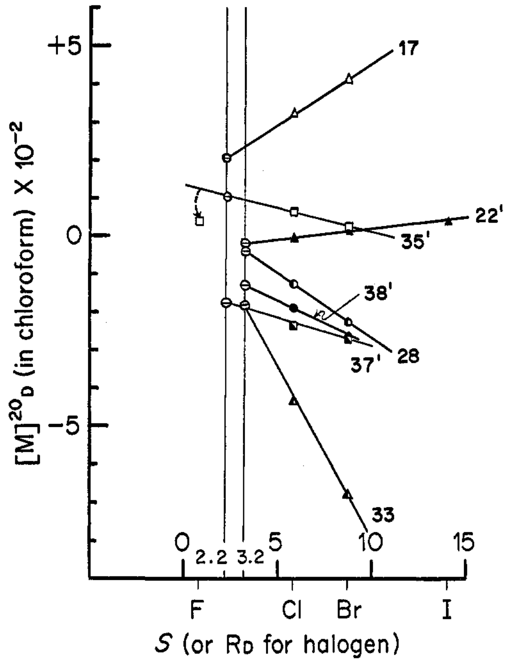

Figure 13.—Estimation of the S value of OH in steroid derivatives[17,21,25] (S of OH = 2.2 or 3.2); ⊖, OH.

Table VI

Influence of Y-3α Group on the S Value of H-2β and the Kind of Class-Type

Compd[a]	Y-3α	S of H-2β	Compd[a]	Y-3α	S of H-2β	Type[b]
25[c]	O (in CO)	−1.8	**11**	H	1.2	h
8″	OAc	−1.8	**7″**	OH	1.2	i or i′
9′[d]	Cl	−1.8	**10′**	Br	1.2	*c*

[a] This has a coplanar zigzag chain, Y-3α–C-3–C-2–H-2β. [b] See Figure 9. [c] Strictly speaking, the O–C-3 bond is not coplanar with the C-2–H-2β bond. [d] **9′** and **10′** have already been included in Table V, with the S values of their OH radicals.

The other coplanar zigzag chain, Y-2β–C-2–C-3–X-3α, and its corresponding noncoplanar structure, Y-2α–C-2–C-3–X-3β, are treated in Tables VII and VIII, respectively.[28,29]

Table VII

Influence of Y-2β Group on the S Value of X-3α Group

Compd[b]	Y-2β	S of X-3α H	S of X-3α (OH)
11	H	1.2	1.2
14	OH	1.2	1.2
15	OAc	0.0	1.2
13	CO[c]	−1.8	*a*
16	Cl	*a*	−1.8
17	Br	*a*	2.2

[a] Unknown. [b] This has a coplanar zigzag chain, Y-2β–C-2–C-3–X-3α. [c] Strictly speaking, the O–C-2 bond is not coplanar with the C-3–X-3α bond.

Table VIII

Influence of Y-2α Group on the S Value of X-3β Group

Compd[b]	Y-2α	S of X-3β H	S of X-3β (OH)
11′	H	1.2	1.2
16″	Cl	*a*	1.2
17″	Br	*a*	1.2

[a] Unknown. [b] This has a noncoplanar structure, Y-2α–C-2–C-3–X-3β.

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(30) R. J. W. Le Fèvre in "Advances in Physical Organic Chemistry," Vol. 3, V. Gold, Ed., Academic Press, London, 1965, p 1.

(31) In some instances, the S value of the H atom is somewhat larger in magnitude,[26] but, when one examines the molecular structures giving rise to these values, one finds that in some of those compounds the H atom is situated at the α position with regard to a CO radical (*i.e.*, in **3**, **32**, and **40**) or to some other functional group which is conjugated with a CO radical (*i.e.*, in **35′**). This suggests that, in these compounds, some kind of constitutional change is involved (for example, keto–enol tautomerism, etc.). The study of these cases is, however, left for the future.

Table VII, which lists compounds containing a coplanar zigzag chain, shows that the *S* value of the OH-3α radical is not constant but depends on the kind of Y-2β group. On the other hand, Table VIII, which lists compounds containing a noncoplanar chain, shows that the *S* value of the OH-3β radical is constant and independent of the kind of Y-2α group. One concludes that, although the direct distance between the Y-2 group and the OH-3 radical is much larger in the coplanar zigzag chain, *i.e.*, in the trans conformation, than in the noncoplanar structure, *i.e.*, in the gauche conformation, the influence of the Y-2 group is easily transmitted to the OH-3 radical only through a coplanar zigzag chain.

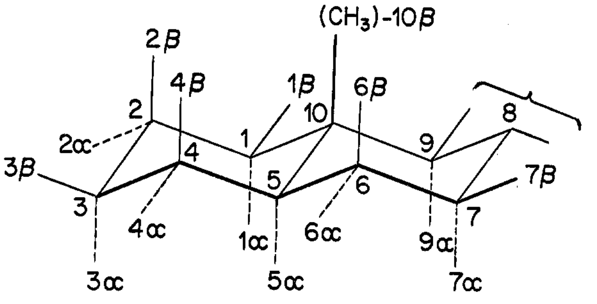

Figure 14.—Steroid skeleton.

Conclusion

Several theories (or calculation methods) have been presented for estimating the optical rotation of an organic compound.[32] Some of these emphasize the role of the atomic refraction, *R*D (or polarizability, α), of an atom (or a radical) in producing the optical rotatory power of a molecule. However, none of them pay any attention to the variability of or the nature of the change in this *R*D (or α) value. Moreover, since the days of van't Hoff,[33] the role apparently played by the presence or absence of a coplanar zigzag chain has never been noticed. It is hoped that the empirical rules 1–8 presented in this article will be of help in constructing a new theory or developing new approaches to the calculation of optical rotatory power.

Addendum.—The fact that a straight $[M]^{20}\text{D}$ *vs.* *S* line changes its slope, according to the change in the kind of a Y atom (or radical) which is coplanar with the X atom (or radical) in the same molecule, means that these two atoms (or radicals) (*i.e.*, X and Y) couple with each other to produce a certain partial molecular rotation, in spite of their existence in one plane (*cf.* **7″**, **9′**, and **10′**; **11**, **14**, **16**, and **17**; **11′**, **16″**, and **17″**, etc.).

[32] J. H. Brewster, in "Topics in Stereochemistry," Vol. 2, N. L. Allinger and E. L. Eliel, Ed., Interscience, New York, N. Y., 1967, p 1.

[33] van't Hoff, *Bull. Soc. Chim. Fr.*, **23**, 298 (1875).

Nonclassical Oxidation of Aromatics. I. Cobaltic Ion Catalyzed Oxidations of *p*-Cymene, *p*-Ethyltoluene, and *sec*-Butyltoluenes[1]

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Co(III) ion catalyzed oxidation of alkyltoluenes with oxygen was studied under mild conditions. It was found that the methyl group was preferentially oxidized in the presence of other groups on the same benzene ring. *p*-Cymene afforded *p*-isopropylbenzoic acid (90%) and *p*-methylacetophenone (10%) as the primary products. *p*-Ethyltoluene gave *p*-ethylbenzoic acid (68%) and *p*-methylacetophenone (25%) as major products. Prolonged oxidation converted *p*-methylacetophenone into *p*-acetobenzoic acid and eventually into terephthalic acid. A mixture of the isomeric *sec*-butyltoluenes was oxidized to the corresponding *sec*-butylbenzoic acids (89%). The relative ease of oxidation of the alkyl groups follows the sequence methyl > ethyl > isopropyl ~ *sec*-butyl. These results cannot be rationalized on the basis of the classical free-radical mechanism, and an electron-transfer mechanism involving the intermediacy of radical cations is proposed.

The literature has numerous references to the oxidation of various alkyltoluenes in which secondary or tertiary hydrogen on alkyl groups is preferentially abstracted. In fact, the oxidation of the methyl group in such instances is difficult. Products are comprised of carboxylic acids, hydroperoxides, and/or cleavage products of the latter. Oxidation of *p*-cymene or *p*-ethyltoluene with 15% nitric acid is reported to produce *p*-toluic acid, whereas *p*-ethylisopropylbenzene affords *p*-ethylbenzoic acid.[2] In the autoxidation of *p*-ethyltoluene[3] or *p*-cymene,[4–7] major products were either *p*-toluic acid, terephthalic acid, *p*-methylacetophenone, or a combination of these. *p*-Acetobenzoic acid, *p*-isopropylbenzoic acid, and *p*-(α-hydroxyisopropyl)-benzoic acid were also formed in varying amounts. The relative ease of oxidation of these alkyl groups follows the sequence isopropyl > ethyl > methyl. In this paper, we report on a study of Co(III) ion catalyzed oxidation of a methyl group in preference to isopropyl, ethyl, or *sec*-butyl in *p*-cymene, *p*-ethyltoluene, and *sec*-butyltoluenes. Results obtained are surprising as the normal order of hydrogen abstraction, tertiary > secondary > primary, is reversed.

Results

Reactants, experimental conditions, and the results obtained are summarized in Table I. Conversion in all experiments was essentially 100%.

Oxidation of *p*-cymene gave *p*-isopropylbenzoic

[1] A preliminary report by A. Onopchenko, J. G. D. Schultz, and R. Seekircher appeared in *Chem. Commun.*, 939 (1971).

[2] L. N. Ferguson and A. I. Wims, *J. Org. Chem.*, **25**, 668 (1960).

[3] A. Kobayashi, K. Sadakata, and S. Akiyoshi, *Kogyo Kagaku Zasshi*, **59**, 654 (1956); *Chem. Abstr.*, **52**, 5334 (1958).

[4] V. B. Fal'kovskii and L. A. Golubko, *Neftekhimiya*, **8** (3), 392 (1968).

[5] U. S. Patent 2,833,816 (1958).

[6] U. S. Patent 3,227,752 (1966).

[7] M. I. Khmura, B. V. Suvorov, and S. R. Rafikov, *Zh. Obshch. Khim.*, **26**, 1418 (1956).