145 (20), 119 (13), 117 (18), 116 (20), 115 (38), 107 (11), 105 (98), 91 (51), 77 (78), 65 (11), 51 (18), *m/z* calcd for $C_{16}H_{14}O$ 222.1045, obsd 222.1051.

1-Phenyl-3-*o*-tolyl-1-propanol. A slurry of 5.90 g (155 mmol) of $LiAlH_4$ in 200 mL of ether was added dropwise to a stirred solution of 35.44 g (155 mmol) of 2-methylchalcone in 250 mL of ether. After 3 h at reflux, the solution was quenched with water and then 5% HCl until it was acidic. The brine-washed, dried ($MgSO_4$) ether layer was concentrated and distilled to give 31.0 g (88%) of the alcohol: bp 155 °C (0.25 mmHg); IR (film) 3350 (br, OH), 1605, 1500, 1460, 1050 (C-O), 760, 700 cm^{-1}; ^1H NMR (CCl_4, 60 MHz) δ 7.10 (s, 5, C_6H_5), 6.93 (s, 4, *o*-MeC_6H_4), 4.43 [t, 1, *J* = 6 Hz, CH(OH)], 2.90 (br s, 1, OH), 2.50 [m, 2, CH(OH)CH_2], 1.85 (t, 2, *o*-tolyl CH_2); mass spectrum, *m/z* (rel intensity) 226 (M^+, 8), 209 (11), 208 ($M^+ - H_2O$, 60), 193 (16), 130 (10), 119 (20), 117 (10), 115 (10), 107 (100), 105 (42), 104 (43), 103 (12), 92 (11), 91 (31), 79 (55), 78 (10), 77 (44), 51 (15), 18 (39), 17 (26); *m/z* calcd for $C_{16}H_{18}O$ 226.1358, obsd 226.1351.

1-Acetoxy-1-phenyl-3-*o*-tolylpropane. This acetate was made from the corresponding alcohol by the same method used to make 1-acetoxy-3-phenyl-1-*o*-tolyl-propane. The product was a colorless oil: bp 150 °C (0.20 mmHg); IR (film) 1740 (C=O), 1605, 1500, 1460, 1380 (acetyl CH_3), 1240 (acetyl C-O), 1050 (C-O), 760, 710 cm^{-1}; ^1H NMR (CCl_4, 90 MHz) δ 7.25 (s, 5, C_6H_5), 6.98 (s, 4, MeC_6H_4), 5.68 [t, 1, *J* = 6 Hz, CH(OAc)], 2.45 [m, 2, CH(OAc)CH_2], 2.18 (s, 3, Ar CH_3), 2.00 (m, 2, Ar CH_2), 1.90 (s, 3, CH_3CO); mass spectrum, *m/z* (rel intensity) 268 (M^+, <1), 208 (M^+ − HOAc, 26), 193 (12), 131 (12), 121 (15), 119 (11), 118 (12), 117 (52), 116 (23), 115 (11), 105 (25), 104 (100), 103 (11), 92 (17), 91 (63), 90 (12), 79 (11), 78 (11), 77 (14), 65 (14), 59 (15), 51 (12), 43 (46).

***trans*-1-Phenyl-3-*o*-tolylpropene (10t).** The preceding acetate was thermolyzed in essentially the same way used to prepare **9t**, yielding **10t** as a colorless oil: bp 130 °C (0.10 mmHg); IR (film) 1650 (C=C), 1605, 1500, 1460, 970 (*trans*-CH=CH), 750, 700 cm^{-1}; UV max (hexane) 252 nm (ϵ 19 400), 282 (1640), 292 (1020); ^1H NMR ($CDCl_3$, 300 MHz) δ 7.4–7.1 (m, 9, Ar H), 6.3–6.4 (m, 2, AB of ABX_2, δ_A 6.36, δ_B 6.33, J_{AB} = 15.6 Hz, J_{AX} = −1.5 Hz, J_{BX} = 7.1 Hz, CH=CH), 3.53 (m, 2, X of ABX_2, CH=$CHCH_2$); ^{13}C NMR ($CDCl_3$, 20 MHz) δ (multiplicity in off-resonance decoupling) 138.3 (s), 137.7 (s), 136.4 (s), 131.0, 130.3, 129.3, 128.5, 127.0, 126.5, 126.2, 36.9 (t), 19.4 (q); mas spectrum, *m/z* (rel intensity) 209 (20), 208 (M^+, 100), 207 (18), 194 (15), 193 (78), 192 (10), 191 (10), 179 (12), 178 (24), 130 (18), 129 (12), 117 (24), 116 (21), 115 (75), 105 (18), 104 (66), 103 (12), 91 (36), 89 (10), 78 (10), 77 (15), 65 (10); *m/z* calcd for $C_{16}H_{16}$ 208.1252, obsd 208.1256. Anal. Calcd for $C_{16}H_{16}$: C, 92.26; H, 7.74. Found: C, 92.22, 91.90; H, 7.82, 7.75.

Equilibration of Propenes 5–10. The propene (3–20 mg) was placed in a tared Schlenk tube either directly or by concentration of a solution. The argon-purged tube was sealed and transferred to a drybox containing an atmosphere of N_2. A measured amount (10–30 mL) of freshly prepared (from metallic K) *t*-BuOK in *t*-BuOH (0.03–1.1 M) was added to the opened tube, which was resealed, removed from the drybox, purged with argon, and sealed again. The tube was then kept at constant temperature, and during sampling, argon was added to maintain a positive pressure. Aliquots were removed by syringe and analyzed by HPLC or NMR.

Generation and Quenching of Lithio Derivatives of 5–10. The propene (5–21 mg) was placed in a tared 25-mL Schlenk tube that had been washed with D_2O and dried under vacuum at 150 °C. The tube was purged with argon and sealed. Freshly distilled THF (10 mL) was added by syringe, followed by 1.0 mL of 1.55 M (an excess) of *n*-butyllithium in hexane, with the immediate formation of an intense color. The spectrum of the orange-red color obtained with **5t** and **6t** was not determined, but the products from **7t** and **8t** had a maximum at 675 nm, and the product from **9t** and **10t** had a maximum at 470 ± 20 nm. Addition of 1.0 mL of 99.96% D_2O (an excess) discharged the color. the quenched mixture was combined with ether and brine. The ether layer was dried ($CaCl_2$) and concentrated, and the residue was analyzed by HPLC and mass spectral measurements.

In a similar run using 44 mg (0.15 mmol) of **7t**, ^1H NMR ($CDCl_3$, 90 MHz) analysis showed, in addition to peaks characteristic of 28% **8t** and 11% **7t**, the following: δ 8.20 (m, 2), 7.90 (m, 2), 7.55 (m, 4), 7.4–7.1 (m, 6), 6.8–6.3 (m, 2), 3.87 (s, 2). Separation of this mixture by HPLC gave as the main component, for which the structure 9-(3-phenyl-2-propenylidene)-9,10-dihydroanthracene is suggested, a compound with the following UV max (hexane): 248 nm (ϵ 37 000), 343 nm (78 000). Molar absorptivities were estimated from HPLC (256 nm) and NMR comparisons using **8t** as an internal standard.

Registry No. **1**, 83135-65-3; **1**·HCl, 83135-67-5; **2**, 83135-66-4; **3**, 83135-59-5; **4t**, 83135-60-8; **5c**, 83135-56-2; **5t**, 83135-53-9; **5/6** Li, 83135-62-0; **6c**, 83135-72-2; **6t**, 83135-52-8; **7c**, 83135-57-3; **7t**, 5738-43-2; **7/8** Li, 83135-63-1; **8c**, 83135-73-3; **8t**, 83152-05-0; **9c**, 83135-58-4; **9t**, 83135-54-0; **9/10** Li, 83135-64-2; **10c**, 83135-74-4; **10t**, 18916-11-5; **11t**, 83135-61-9; **12**, 83135-55-1; $PhCH_2CH_2Br$, 103-63-9; Ph_3P, 603-35-0; 1-(9-anthryl)-3-phenylpropane, 74387-95-4; 2-acetylpyrrole, 1072-83-9; dimethylammonium chloride, 506-59-2; paraformaldehyde, 30525-89-4; (2-phenylethyl)triphenylphosphonium bromide, 53213-26-6; 1-methyl-2-formylpyrrole, 1192-58-1; 1-(9-anthryl)-3-phenyl-1-propanol, 50688-75-0; 1-acetoxy-3-phenyl-1-*o*-tolylpropane, 83135-68-6; 3-phenyl-1-*o*-tolyl-1-propanol, 83135-69-7; (*E*)-2-methylchalcone, 14182-01-5; acetophenone, 98-86-2; *o*-tolualdehyde, 529-20-4; 1-phenyl-3-*o*-tolyl-1-propanol, 83135-70-0; 1-acetoxy-1-phenyl-3-*o*-tolylpropane, 83135-71-1.

Effects of 57 Substituents on the Stabilities of Carbon–Carbon Double Bonds[1]

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Literature data on equilibria in which *trans*-XCH_2CH=CHY is transformed to *trans*-XCH=$CHCH_2Y$ have been collected to expand a previous correlation of ΔG^{chem} values for reactions of this type. For 11 substituents in an overdetermined set of 30 equilibria the observed data are fitted with a standard deviation of 0.29 kcal/mol. In addition to the double-bond-stabilizing parameters (*D* values) for these substituents, *D* values are listed for 46 substituents that were each involved in only one equilibrium.

A correlation of equilibrium constants for double bond migration reactions of the type shown in eq 1 was described some time ago.[2] A simple correlation could be made in

$$trans\text{-}XCH_2CH{=}CHY \rightleftarrows trans\text{-}XCH{=}CHCH_2Y \qquad (1)$$

terms of eq 2, in which ΔG_{XY}^{chem} is the change in chemical free energy[3] and D_X and D_Y are the double bond stabilizing

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Table I. Equilibria in Reactions of the Type *trans*-$XCH_2CH{=}CHY \rightleftharpoons$ *trans*-$XCH{=}CHCH_2Y$

X	Y	% trans reactant	% trans product	medium	temp, °C	K	ΔG^{chem}, kcal/mol	ref
Ph	H		98[a]	Me_2SO	25	2000[a]	−4.49[a,b]	10
Ph	Me	68[c,d]	98[c,e]	Me_2SO	55	17	−1.83	17
Ph	*i*-Pr	64[c,f]	90[c,e]	MeOH	165	8.3	−1.83	11
Ph	*t*-Bu	90[c,e]	90[c,e]	MeOH	165	10	−2.02	11
Ph	CN	49	91	*t*-BuOH	23	2.74	−0.59	12
Ph	NMe_2	98[c,e]	98[c,e]	*t*-BuOH–Me_2SO	35	0.025	2.3	5
Ph	OBu-*t*	32	93	*t*-BuOH–Me_2SO	25	0.15	1.12	19
Ph	*p*-$Me_2NC_6H_4$	98	99.6	Et_2O–NH_3	25	0.40	0.15	20
Ph	*p*-$MeOC_6H_4$	98	99	Et_2O–NH_3	25	0.60	0.30	20
Ph	*p*-MeC_6H_4	99	99	Et_2O–NH_3	25	0.86	0.09	20
Ph	*p*-*t*-BuC_6H_4	97	96	Et_2O–NH_3	25	0.80	0.13	20
Ph	*p*-FC_6H_4	99	98	Et_2O–NH_3	25	1.13	−0.07	20
Ph	*p*-ClC_6H_4	97	98	Et_2O–NH_3	25	1.05	−0.03	20
Ph	*m*-FC_6H_4	99.5	98	Et_2O–NH_3	25	1.28	−0.15	20
Ph	*o*-MeC_6H_4	96	98	*t*-BuOH	30	2.46	−0.54	1b
Ph	1-naphthyl	96[c,g]	96[c,h]	MeOH	80	2.3	−0.57	21
Ph	1-phenanthryl	96[c,g]	96[c,h]	MeOH	80	2.1	−0.51	21
Ph	9-phenanthryl	96[c,g]	96[c,h]	MeOH	80	2.7	−0.70	21
Ph	2-naphthyl	96[c,h]	96[c,h]	MeOH	80	0.85	0.12	21
Ph	2-phenanthryl	96[c,h]	96[c,h]	MeOH	80	0.77	0.20	21
Ph	3-phenanthryl	96[c,h]	96[c,h]	MeOH	80	0.71	0.22	21
Ph	9-anthryl	56	96	*t*-BuOH	30	2.92	−0.65	1b
Ph	2-furyl	95	98[c,e]	*t*-BuOH	25	0.314	0.69	19
Ph	1-methyl-2-pyrrolyl	86	98	*t*-BuOH	30	0.65	0.26	1b
H	$CH{=}CH_2$			gas	25	6.8×10^{-5}[i]	5.93[i,j]	16
H	$C(OMe){=}CH_2$	99		cyclohexane	25	0.00013[a]	5.31[a,k]	22
H	SMe	42		Me_2SO	20	0.0024	4.16[k]	9
H	SEt	53		Me_2SO	20	0.0019	4.29[k]	9
H	SPr-*i*	60		Me_2SO	20	0.0083	3.43[k]	9
H	SBu-*t*	70		Me_2SO	20	0.022	2.87[k]	9
H	SOMe	95[l]		*t*-BuOH	27	0.26	1.47[k]	23
H	SOMe	95		*t*-BuOH	20	0.29	1.36[k]	9
H	SOEt	94		*t*-BuOH	20	0.146	1.78[k]	9
H	SOPr-*i*	95		*t*-BuOH	20	0.080	2.11[k]	9
H	SOBu-*t*	94		*t*-BuOH	20	0.044	2.45[k]	9
H	SO_2Me	99.6		*t*-BuOH	20	0.418	1.15[k]	9
H	SO_2Et	99.6		*t*-BuOH	20	0.233	1.49[k]	9
H	SO_2Pr-*i*	99.7		*t*-BuOH	20	0.0935	2.02[k]	9
H	SO_2Bu-*t*	99.7		*t*-BuOH	20	0.0236	2.82[b]	9
H	SO_2Ph	97		Me_2SO	25	0.406	1.18[k]	24
H	Cl			gas	25	0.16[m]	1.73[k,m]	7, 8
Me	CHO	95[a]	72[a]	*t*-BuOH	25	0.042[a]	1.9[a]	6
Me	Ac	98[c,e]	70	*t*-BuOH	25	0.213	0.92	5
Me	CO_2Me	96[a]	68[a]	*t*-BuOH	25	0.204[a]	0.94[a]	6
Me	CO_2Bu-*t*	98	73	*t*-BuOH	25	0.196	0.96	6
Me	NO_2	98	65	$CHCl_3$	25	0.082	1.48	25
Me	SO_2Bu-*n*	99.6[c,n]	82	*t*-BuOH	25	40	−2.2	5
CN	OPh	37	83	$(Me_2N)_3PO$	165	0.14	1.7	13
CN	Cl	32	68	MeCN	40	9.0	−1.38	14
Cl	CO_2Et	95	36	MeCN	40	0.13	1.28	14

[a] Calculated from ΔH and ΔS values obtained from data at other temperatures. [b] $K_{chem} = 3K_{obsd}$. [c] Estimated by assuming $\Delta G°$ for cis–trans isomerization is the same as that for a model compound. [d] Model compound was 2-hexene.[18] [e] Model compound was 1-phenylpropene.[10] [f] Model compound was 4-methyl-2-pentene.[18] [g] Model compound was 1-*o*-tolyl-3-phenylpropene.[1b] [h] Model compounds were 3-*o*-tolyl-1-phenylpropene and 3-(9-anthryl)-1-phenylpropene (data averaged).[1b] [i] Data calculated from the thermodynamic functions of *trans*-1,3-pentadiene and 1,4-pentadiene.[16] [j] $K_{chem} = 2K_{obsd}/3$. [k] $K_{chem} = K_{obsd}/3$. [l] Assumed to be the same as in ref 9. [m] Data obtained as described in the text. [n] Model compound was ethyl 1-propenyl sulfone.[9]

constants for X and Y. An improved correlation allowed for polar interactions across the *trans*-vinylene group, as shown in eq 3, where the σ constants are Hammett para

$$\Delta G_{XY}{}^{chem} = D_Y - D_X \qquad (2)$$

substituent constants and τ_v is a proportionality constant that is treated as a disposable parameter. Hydrogen is

$$\Delta G_{XY}{}^{chem} = D_Y - D_X + \tau_v(\sigma_X \sigma_{CH_2Y} - \sigma_Y \sigma_{CH_2X}) \qquad (3)$$

taken as the reference substituent, and D_H is arbitrarily set equal to zero. The compilation of literature data contained equilibrium constants for 37 different reactions; 20 of these involved only substituents that appeared in more than one reaction. These 20 equilibrium constants were treated by a least-squares method using eq 2 and 3 to obtain values of τ_v and D for the 8 substituents involved. Optimally, the data should all have referred to the same temperature and the same reaction medium. Actually, the 20 equilibria were in 5 different media and at temperatures ranging from 20 to 150 °C, although 25 °C was the temperature used when possible.

Subsequently, we have come across relevant earlier work that had been missed in the previous compilation, we have redetermined equilibrium constants that seemed implausible, we have studied interesting substituents for which

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(2) Hine, J.; Flachskam, N. W. *J. Am. Chem. Soc.* **1973**, *95*, 1179–85.

(3) This is the change in standard free energy corrected for symmetry effects.[4]

(4) Benson, S. W. *J. Am. Chem. Soc.* **1958**, *80*, 5151–4.

Table II. Double-Bond-Stabilizing Parameters for Use in Eq 2 and 3

substituent	*D*(eq 2),[a] kcal/mol	*D*(eq 3),[a,b] kcal/mol
NMe_2	6.83	7.46
$CH=CH_2$	5.93	5.89
OBu-*t*	5.65	5.84
$C(OMe)=CH_2$	5.31	5.27
2-furyl	5.22	5.17
p-$Me_2NC_6H_4$	5.07	5.02
OMe	4.87 (0.25)	4.93 (0.18)
p-$MeOC_6H_4$	4.83	4.78
1-methyl-2-pyrrolyl	4.79	4.74
3-phenanthryl	4.75	4.70
2-phenanthryl	4.73	4.68
p-*t*-BuC_6H_4	4.66	4.61
2-naphthyl	4.65	4.60
p-MeC_6H_4	4.62	4.57
Ph	4.53 (0.21)	4.48 (0.16)
p-ClC_6H_4	4.50	4.45
p-FC_6H_4	4.46	4.41
CHO	4.81	4.34
m-FC_6H_4	4.38	4.33
SEt	4.29	4.28
1-phenanthryl	4.02	3.97
o-MeC_6H_4	3.99	3.94
CO_2^-	4.06	3.92[c]
1-naphthyl	3.96	3.91
9-anthryl	3.88	3.83
OPh	5.17	3.78
9-phenanthryl	3.83	3.78
NO_2	4.39 (0.29)	3.42 (0.31)
SPr-*i*	3.43	3.42
Ac	3.83	3.36
F	3.43	3.36
$(CH_2)_4CO_2R$	3.05	3.26
CO_2R	3.36 (0.22)	3.14 (0.17)
SMe	3.02 (0.25)	3.03 (0.19)
n-C_nH_{2n+1}	2.91 (0.15)	3.02 (0.11)
$(CH_2)_3CO_2R$	2.83	2.94
$(CH_2)_2CO_2R$	2.79	2.90
SBu-*t*	2.87	2.86
CN	3.47 (0.23)	2.80 (0.23)
t-Bu	2.51	2.70
i-Pr	2.49 (0.30)	2.67 (0.22)
CH_2OMe	2.66	2.50
CH_2CO_2R	2.19	2.02
$(CH_2)_2OMe$	1.79	2.00
SO_2Bu-*t*	2.82	1.73
SOBu-*t*	2.45	1.72
SOPr-*i*	2.11	1.38
Cl	1.97 (0.26)	1.26 (0.25)
SOEt	1.78	1.05
SO_2Pr-*i*	2.02	0.93
SOMe	1.15 (0.25)	0.66 (0.22)
SO_2Et	1.49	0.40
Br	0.74	0.40
SO_2Ph	1.18	0.12
SO_2Me	1.15	0.06
H	0.00[d]	0.00[d]
SO_2Bu-*n*	0.71	−0.01

[a] Parenthesized figures are estimated standard deviations. [b] For use with a τ_V value of 10.6 (2.5) kcal/mol. [c] Although this substituent participated in several equilibria, it was not used in the least-squares treatment because of the many complications that affect electrically charged substituents. [d] By definition.

no data existed, and other workers have reported equilibrium constants of the appropriate type. Our present data set includes all the equilibrium constants in the previous set[2] except for the following: The equilibrium constant for the butyl butenyl sulfones has been replaced by a considerably different redetermined value.[5] The equilibrium constant for the methyl pentenoates at 117 °C has been replaced by a value at 25 °C.[6] Combination of new data on the equilibration of allyl chloride and the 1-chloropropenes[7] with the older data[8] gives equilibrium constants over the range 150–407 °C that give a curved plot of log *K* vs. $1/T$. We fitted the data by least-squares methods to eq 4, obtaining values of −743.5, −5.622, and

$$\log K = A/T + B \log T + C \qquad (4)$$

17.20 for *A*, *B*, and *C*, respectively. From these the $\Delta G°$ value at 25 °C was calculated. The equilibrium constant for equilibration of the methyl propenyl sulfones at 90 °C has been replaced by a value at 20 °C.[9] The equilibrium constant for the methyl propenyl sulfoxides at 27 °C listed previously has been averaged with a new value at 20 °C.[9] The percent trans composition estimated[2] for 1-phenyl-1-butene has been replaced by a value based on an improved model compound, 1-phenylpropene.[10] The resulting equilibrium constant for the butenylbenzenes at 55 °C was used in preference to a value determined at 165 °C.[11] The preceding replacements of old equilibrium constants are listed in Table I along with the values for new equilibria.

For equilibration of the 4-phenylbutenonitriles the data obtained at 23 °C[12] were used in preference to those obtained at 150 °C[13] (although the latter would fit our correlation much better). For the 4-chlorobutenonitriles, however, we took the data at 40 °C[14] to be more reliable than that at 25 °C,[15] in spite of its 15 °C deviation from our preferred temperature. For the vinyl substituent, the equilibrium constant (for isomerization of *trans*-1,3-pentadiene to 1,4-pentadiene) is not a measured value but was calculated from the thermodynamic functions of the reactant and product.[16] Other details of our treatment of the literature data[17–25] such as the methods of estimating the cis–trans contents of some of the components of the equilibria are indicated by footnotes in Table I.

The expanded set of equilibrium constants adds three new substituents to the list of those for which two or more equilibrium constants are available and ten more reactions[26] to the list of those involving only such substituents.

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Table III. Comparison of Calculated and Observed Values of ΔG^{chem}[a]

X	Y	from eq 2		from eq 3	
		$\Delta G^{\text{chem}}_{\text{calcd}}$	$\Delta G^{\text{chem}}_{\text{obsd}} - \Delta G^{\text{chem}}_{\text{calcd}}$	$\Delta G^{\text{chem}}_{\text{calcd}}$	$\Delta G^{\text{chem}}_{\text{obsd}} - \Delta G^{\text{chem}}_{\text{calcd}}$
H	Me	2.91	0.04	2.81	0.14
H	Et	2.91	−0.04	2.81	0.06
H	*n*-Pr	2.91	0.23	2.81	0.33
H	*n*-Bu	2.91	0.13	2.81	0.23
H	*i*-Pr	2.49	−0.22	2.44	−0.17
H	Ph	4.53	−0.04	4.53	−0.04
H	CN	3.47	−0.16	3.82	−0.51
H	NO_2	4.39	0.01	4.61	−0.21
H	SOMe	1.15	0.28	1.39	0.03
H	Cl	1.97	−0.24	1.59	0.14
Me	*n*-Pr	0.00	−0.04	0.00	−0.04
Me	Ph	1.62	0.21	1.64	0.19
Me	CN	0.56	−0.19	0.54	−0.17
Me	CO_2Me	0.45	0.49	0.69	0.25
n-Bu	CO_2Me	0.45	0.24	0.69	0.00
Me	CO_2Bu-*t*	0.45	0.51	0.69	0.27
Me	NO_2	1.49	−0.01	1.27	0.21
Et	OMe	1.96	−0.75	1.46	−0.25
n-Pr	SMe	0.12	0.06	0.04	0.14
n-C_9H_{19}	SMe	0.12	0.08	0.04	0.16
n-Pr	SOMe	−1.75	−0.14	−1.87	−0.02
n-C_9H_{19}	SOMe	−1.75	−0.14	−1.87	−0.02
Ph	*i*-Pr	−2.05	0.22	−2.00	0.17
Ph	CN	−1.06	0.47	−0.97	0.38
Ph	OMe	0.33	−0.52	0.21	−0.40
CO_2Me	OMe	1.51	0.88	2.10	0.29
CO_2Me	Cl	−1.39	0.11	−1.45	0.17
CN	Cl	−1.50	0.12	−1.07	−0.31
OMe	SMe	−1.84	−0.39	−1.87	−0.36

[a] For equilibria of the type shown in eq 1.

Table IV. Hammett Para Substituent Constants Used in the Correlation

X	σ_X	σ_{CH_2X}
NMe_2	-0.69^{a}	-0.06^{b}
$CH{=}CH_2$	0.03^{c}	-0.09^{c}
OBu-*t*	-0.26^{d}	0.04^{d}
$C(OMe){=}CH_2$	0.03^{c}	-0.09^{c}
OMe	-0.26^{e}	0.04^{b}
Ph	0.03^{e}	-0.09^{e}
CHO	0.44^{f}	0.05^{b}
SR	0.01^{e}	-0.01^{b}
CO_2^-	0.0^{g}	-0.14^{h}
OPh	-0.03^{e}	0.09^{b}
NO_2	0.80^{e}	0.22^{b}
Ac	0.44^{e}	0.05^{b}
F	0.05^{e}	0.15^{b}
$(CH_2)_nCO_2R$	*i*	-0.14^{j}
CO_2R	0.43^{e}	0.05^{b}
n-C_nH_{2n+1}	-0.14^{j}	-0.14^{j}
CN	0.69^{e}	0.18^{e}
t-Bu	-0.20^{j}	-0.15^{b}
i-Pr	-0.15^{j}	-0.14^{b}
CH_2OMe	0.04^{b}	-0.14^{b}
$(CH_2)_2OMe$	-0.14^{b}	-0.14^{b}
SOR	0.49^{e}	0.16^{b}
SO_2R	0.73^{e}	0.17^{e}
Cl	0.22^{e}	0.12^{e}
Br	0.23^{e}	0.14^{e}
SO_2Ph	0.71^{e}	0.18^{b}
H	0.00	-0.14^{b}

[a] van der Graaf, B.; Hoefnagel, A. J.; Wepster, B. M. *J. Org. Chem.* **1981**, *46*, 653–7. [b] Calculated from the correlation equation $\sigma_{CH_2X} = 0.4668\sigma_X{}^{I} - 0.110$ obtained from the σ_{CH_2X} and $\sigma_X{}^{I}$ values of ref 27 by using a least-squares treatment. [c] Taken to be the same as for X = Ph. [d] Taken to be the same as for X = OMe. [e] Reference 27. [f] Humffray, A. A.; Ryan, J. J.; Warren, J. P.; Yung, J. H. *Chem. Connum.* **1965**, 610–1. [g] Hine, J. "Structural Effects on Equilibria in Organic Chemistry"; Wiley-Interscience: New York, 1975, p 66. [h] Taken to be the same as for X = H. [i] For $n = 1$, $\sigma_X = 0.05$; for $n > 1$, the correlation equation[b] gives a value of −0.14. [j] Reference 2.

As in the previous correlation, all primary R groups were treated as a single substituent and all CO_2R groups as a single substituent: this treatment was not extended to SR, SOR, SO_2R, or OR groups. The 30 ΔG^{chem} values were fitted to both eq 2 and 3, with standard deviations of calculated from observed values of 0.39 and 0.29 kcal/mol, respectively. In the latter correlation a τ_v value of 10.6(2.5) kcal/mol was obtained. The *D* values obtained for the 11 substituents involved in these equilibria and their estimated standard deviations are listed in Table II. Also listed, with no assessment of their uncertainty, are the *D* values that may then be calculated for the 46 other substituents involved in only one of the equilibria listed in Table I or previously.[2] Observed and calculated values of ΔG^{chem} for the 30 equilibria that were treated by least-squares methods are in Table III, and the σ values used, which were obtained in a manner similar to that used previously,[2,27] are in Table IV. All the *D* values for aryl and hetaryl groups, except phenyl, were determined by pitting the group in question against phenyl. In most such cases the required σ constants are not available, but plausible estimates give values smaller than 0.01 kcal/mol for the term in eq 3 that allows for polar interactions. For this reason the polar term was neglected in such equilibria.

We will comment here only on a trend in the *D* values that we have not discussed previously.[1b,2,5,6,19] There are now four series of substituents in which increasing steric bulk seems to cause an increase in *D* values, relative to what would otherwise be expected: (1) $SO_2Me < SO_2Et < SO_2$Pr-*i* $< SO_2$Bu-*t*, (2) SOMe < SOEt < SOPr-*i* < SOBu-*t*, (3) 2-naphthyl > 1-naphthyl ≈ 9-anthryl, (4) OMe < OBu-*t*. It is true that the values for SR groups in Table II follow the order SMe < SEt > SPr-*i* > SBu-*t*, but the latter three values are based only on experiments in which

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[26] The equilibration of the methyl propenyl sulfides, which was very one-sided and gave a quite inprecise equilibrium constant, was not included in the least-squares treatment.

[27] Exner, O. *Collect. Czech. Chem. Commun.* **1966**, *31*, 65–89.

the equilibrium concentration of $CH_2{=}CHCH_2SR$ was of about the same magnitude as the estimated uncertainty in measuring the concentrations;[9] furthermore, steric effects should be smaller with SR than with SOR, SO_2R, or OR. In the series $n\text{-}C_nH_{2n+1} > i\text{-Pr} \approx t\text{-Bu}$ it is again not clear that the observed differences are significant, and it is a series in which steric crowding of the CH_2 group in $XCH_2CH{=}CHY$ should be less than with OBu-*t*, SO_2Bu-*t*, etc. groups. Steric hindrance can decrease resonance interactions with the double bond, as in the first part of the series 2-naphthyl > 1-naphthyl ≈ 9-anthryl, but when there is too much hindrance, this resonance effect is counteracted, presumably by crowding the CH_2 group, as in the last part of the series.

Notes

The Periodination Reaction: Fast One-Step Synthesis of C_6I_6 from C_6H_6

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In an attempt to prepare the unknown compound, periodyl benzene ($PhIO_3$), benzene was added dropwise over a period of around 15 min to a 1.0 M solution of H_5IO_6 in concentrated H_2SO_4 in an open beaker at 0-5 °C, whereupon the colorless solution turns green,[1] then red, and finally light yellow, as a yellow-tan precipitate gradually forms, which, after recrystallization from Me_2SO, is insoluble in all common solvents except Me_2SO and MeCN: mp ~260 °C with decomposition, giving off I_2; elemental analysis, 8.5% C and 91.5% I; $M_r \gtrsim 800$ by freezing point depression of camphor; mass spectrum parent peak at 834 ($C_6I_6^{+}\cdot$) and M − 1 at 707 ($C_6I_5^{+}\cdot$); proton NMR, no resonance absorption; burns with an aromatic sooty flame along with dense purple fumes of I_2, from all of which evidence one would rightly conclude that the compound prepared here is C_6I_6,[2] and, on the basis of the quantity of benzene used, the yield is 48% peridobenzene.

Registry No. H_5IO_6, 10450-60-9; C_6I_6, 608-74-2; $PhIO_3$, 82891-66-5; benzene, 71-43-2.

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[1] The green intermediate first formed (presumably $PhIO_3$), and the red one, should be further investigated, as well as the generality of the periodination of aromatics. The authors invite any investigator interested in this unusual reaction, which might be of use in deuterating aromatic compounds, to pursue this research.

[2] The stoichiometric equation used to calculate yield is $2C_6H_6 + 3IO_4^- + 9I^- + 12H_3O^+ \rightarrow 2C_6I_6 + 24H_2O$, the I^- indicating that some of the benzene is oxidized, presumably to CO_2.

Stereoselective Synthesis of (23*S*,25*R*)-23,25,26-Trihydroxyvitamin D_3 and (23*S*,25*R*)-25-Hydroxyvitamin D_3 26,23-Lactol, Presumed Vitamin D_3 Metabolites

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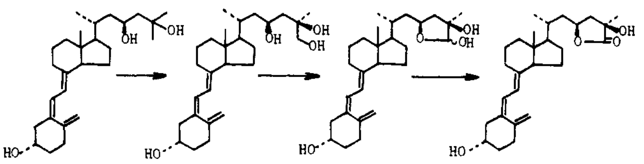
Calcidiol lactone, 25-hydroxyvitamin D_3 26,23-lactone (4),[1] is a unique metabolite of vitamin D_3 which exhibits a weak activity in intestinal calcium transport and bone calcium mobilization but shows the most potent activity[2] toward vitamin D binding protein in blood plasma of all known vitamin D metabolites. These characteristics have suggested that the metabolite may have an important role in other aspects of vitamin D action. As one of our projects on the stereoselective synthesis of vitamin D metabolites using chiral templates,[3] we have synthesized (23*R*,25*S*)-[4] and (23*S*,25*R*)-calcidiol lactones[5] stereoselectively and for the first time determined the stereochemistry of the natural metabolite[5] to be *S* at C-23 and *R* at C-25. Recently a new metabolite, (23*S*)-23,25-dihydroxyvitamin D_3 (1),[6] has been isolated and has been shown to be a biosynthetic precursor of calcidiol lactone (4).[7] It can be assumed that biological transformation of 23,25-dihydroxyvitamin D_3 (1) to the lactone (4) may proceed via 23,25,26-trihydroxyvitamin D_3 (2) through 25-hydroxyvitamin D_3 26,23-lactol (3; Scheme I) and that these postulated biosynthetic intermediates have the same stereochemical configuration at C-23 and C-25 as those of calcidiol lactone (4). So we planned the stereoselective synthesis of these two presumed vitamin D_3 metabolites.

Scheme I. Presumed Metabolic Pathway of (23*S*)-23,25-Dihydroxyvitamin D_3 (1) to Calcidiol Lactone (4)



1 2 3 4

In this paper we report the stereoselective synthesis of (23*S*,25*R*)-23,25,26-trihydroxyvitamin D_3 (2) and (23*S*,25*R*)-25-hydroxyvitamin D_3 26,23-lactol (3). Both compounds have been demonstrated to be converted to

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[1] Wichmann, J. K.; DeLuca, H. F.; Schnoes, H. K.; Horst, R. L.; Shepard, R. M.; Jorgensen, N A. *Biochemistry* **1979**, *18*, 4775.

[2] (a) Tanaka, Y.; Wichmann, J. K.; Paaren, H. E.; Schnoes, H. K.; DeLuca, H. F. *Proc. Natl. Acad. Sci. U.S.A.* **1980**, *77*, 6411. (b) Horst, R. L. *Biochem. Biophys. Res. Commun.* **1979**, *89*, 286.

[3] Takayama, H.; Ohmori, M.; Yamada, S. *Tetrahedron Lett.* **1980**, *21*, 5027.

[4] Yamada, S.; Nakayama, K.; Takayama, H. *Tetrahedron Lett.* **1981**, *22*, 2591.

[5] Yamada, S.; Nakayama, K.; Takayama, H. *Chem. Pharm. Bull.* **1981**, *29*, 2393.

[6] Tanaka, Y.; Wichmann, J. K.; Schnoes, H. K.; DeLuca, H. F. *Biochemistry* **1981**, *20*, 3895.

[7] Tanaka, Y.; DeLuca, H. F.; Schnoes, H. K.; Ikekawa, N.; Eguchi, T. *Proc. Natl. Acad. Sci. U.S.A.* **1981**, *78*, 4805.