Table I. Interfacial Reaction of Water-Insoluble Acid Chlorides with Aqueous D,L-Alanine

	acid chloride A	catalyst	rxn time	% conversion of A	% amide in prod
1	decanoyl	DMAP	1 h[a]	91	52[b]
		none	1 h	52	60[b]
2	*p*-chlorobenzoyl	DMAP	10 min	85	44[c]
		none	10 min	nil[d]	

[a] The catalyzed reaction was essentially complete in 5-10 min. [b] FTIR spectroscopy was used to quantitate percent amide in product. [c] ^{1}H NMR spectroscopy was used to quantitate percent amide in product. [d] No product could be isolated from the control reaction.

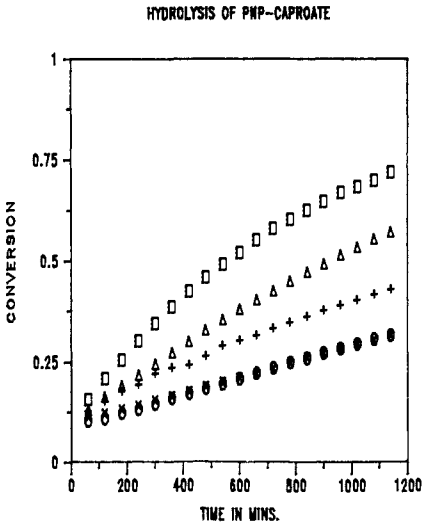

Figure 1. Plots of conversion of **4** vs. time for control (○), PPY (X), and **3** (+) in the excess substrate regime and PPY (△) and **3** (□) in the excess catalyst regime.

DMAP is even more striking for the *p*-chlorobenzoyl chloride. In both cases, competing hydrolysis accounts for conversion of approximately half of the starting material. While no effort has been made to optimize reaction conditions, increasing the concentration of the aqueous reactant should increase both the rate and the yield of the desired reaction.

Further support for inverse phase transfer catalysis (IPTC) was provided by evaluation of relative rates of interfacial hydrolysis of *p*-nitrophenyl caproate (**4**).[8] Figure 1 summarizes hydrolysis kinetics for both PPY and polymer catalyst **3**. Substrate **4** was present as a solution in toluene. Homogeneous hydrolysis of **4** in the absence of toluene (but with all other conditions identical) occurred ca. 10 times faster. This clearly indicates that solubility of **4** is much greater in toluene than in water in this two-phase system and that interfacial transport is the rate-limiting step.

The hydrolysis rate of **4** with PPY in the excess substrate regime was experimentally identical with that of the control. The polymer-catalyzed reaction is clearly faster. In the excess catalyst regime, both PPY and polymer were effective catalysts with the polymer displaying significantly faster conversion.

(8) General procedure for the hydrolysis of *p*-nitrophenyl caproate (**4**). Aqueous 1 N NaOH, 3 mL, was added to a capped glass UV cuvette stirred by a gas-driven magnetic stirrer mounted inside a Perkin-Elmer 320 UV-vis spectrometer.[9] The catalyst was injected as a concentrated solution in methanol. The total amount of methanol injected was the same for PPY and the polymer and was 60 μL in the excess catalyst regime and 3 μL in the excess substrate regime. Control reactions with and without these amounts of methanol were found to have experimentally identical rates. The ratio of substrate to catalyst was 2 in the excess substrate regime and 0.1 in the excess catalyst regime. The substrate (**4**) was injected as a 10-μL dose of a 8.28×10^{-3} g/mL solution in toluene. The contents were momentarily shaken and the toluene droplets rose to the top within minutes. The aqueous phase was stirred at a constant rate without disturbing the organic phase for the duration of the reaction. Absorbance at 400 nm (λ_{max} for *p*-nitrophenoxide ion) was monitored as a function of time.

(9) The stirrer has been described: Vaidya, R. A.; Hermes, R. E.; Mathias, L. J.; Bridges, J. L. *Am. Lab.* (*Fairfield, Conn.*) **1985**, *17*, 84.

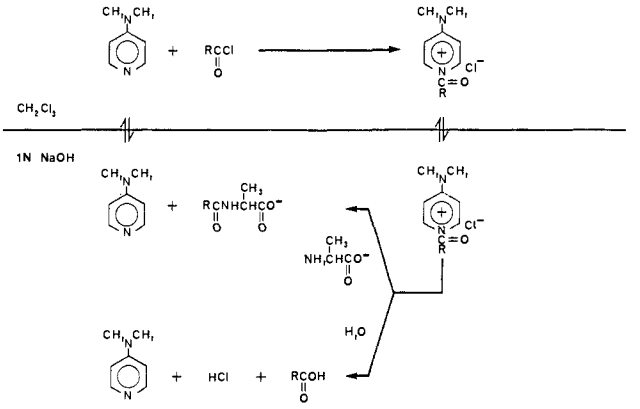

Figure 2. Schematic representation of the IPTC process.

Figure 2 depicts the proposed sequence of steps in the overall inverse phase transfer process. A major difference of this process compared to normal phase transfer catalysis is that the catalyst actually *reacts* with the substrate to generate the charged intermediate which possesses increased solubility in the aqueous phase. This intermediate undergoes phase transport and then reacts with the water-soluble nucleophile or with water to give the two products observed. Regeneration of the neutral supernucleophile and transport back to the organic phase allows true catalytic activity.

Further examination of the proposed mechanism and intermediates is under way along with extension of inverse phase transfer catalysis to additional reactions.

Acknowledgment. We gratefully acknowledge continued financial support for this project from 3M and the donors of the Petroleum Research Fund, administered by the American Chemical Society, and helpful discussions with J. K. Rasmussen, S. M. Heilmann, and C. J. Podsiadly of 3M Central Research Laboratory.

Hyperconjugative Effects of Allylic Substituents Are Not Important in Osmylations

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Received June 4, 1985

Allylic ethers are osmylated with useful selectivity for diastereomer I over II, especially in the case of electron-rich *Z* alkenes.[1,2] This result has been rationalized by Kishi et al.[1] using a reactant-like empirical model, but other explanations based on "perpendicular" transition states have recently appeared.[3] Houk et al. originally suggested that bulky allylic substituents would prefer "anti", "outside", and "inside" positions in that order, σ-acceptors would occupy "inside" or "outside" positions, and the best σ-donor would be "anti" to the electrophile to facilitate olefin HOMO–electrophile LUMO interactions.[3a] Although details were not specified for osmylations, structures **1** and **2** follow as the best transition states for I- or II-selective allylic ether hydroxylations (X = alkoxy, Figure 1). These factors are difficult to evaluate because the mechanism of osmylation is not well defined.[4]

(1) Cha, J. K.; Christ, W. J.; Kishi, Y. *Tetrahedron* **1984**, *40*, 2247.
(2) A different pattern is seen with α,β-unsaturated carbonyl compounds: Stork, G.; Kahn, M. *Tetrahedron Lett.* **1983**, *24*, 3951. Also, ref 1.
(3) (a) Houk, K. N.; Moses, S. R.; Wu, Y.-D.; Rondan, N. G.; Jäger, V.; Schohe, R.; Fronczek, R. *J. Am. Chem. Soc.* **1984**, *106*, 3880. (b) McGarvey, G. J.; Williams, M. J. *Ibid.* **1985**, *107*, 1435.
(4) Schröder, M. *Chem. Rev.* **1980**, *80*, 187. Sharpless, K. B.; Teranishi, A. Y.; Backvall, J.-E. *J. Am. Chem. Soc.* **1977**, *99*, 3120; **1980**, *102*, 4263.

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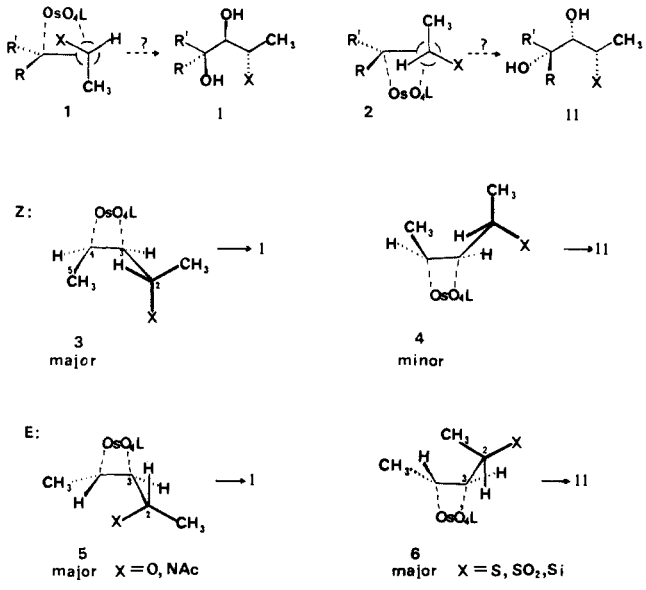

Figure 1.

Table I. Osmylations[a] and Epoxidations[b] of $CH_3CH{=}CHCHXCH_3$

			I:II	
entry	X	isomer	osmylation	epoxidation[c]
1	$PhMe_2Si$	*Z*	78:22	>95:5
2	$PhMe_2Si$	*E*	34:66	61:39
3	$PhSO_2$	*Z*	80:20	95:5
4	$PhSO_2$	*E*	22:78	75:25
5	$MeSO_2$	*Z*	83:17	
6	$MeSO_2$	*E*	18:82	
7	PhS	*Z*	84:16	
8	PhS	*E*	33:67	
9	*t*-$BuMe_2SiO$	*Z*	62:38	40:60
10	*t*-$BuMe_2SiO$	*E*	61:39	36:64
11	CH_3CO_2	*Z*	70:30	1:1
12	CH_3CO_2	*E*	62:38	1:1

[a] OsO_4/NMO except for 7 and 8 (OsO_4/pyridine); ratios by NMR analysis of crude agree with isolated product ratios ±3%. [b] MCPBA. [c] Epoxide products: erythro epoxide corresponds to face selectivity of diol I, threo epoxide to II.

However, **1** should be destabilized in *Z* alkenes (R = alkyl) and higher selectivity for product I would be expected for the *E* isomers (R = H). This is contrary to Kishi's findings.

If σ–π interactions are important, they can be tested by comparing the osmylation of substrates having bulky donor (X = $PhMe_2Si$) vs. bulky acceptor (X = RSO_2) substituents.[5] Both the *E* and *Z* silanes should react via a geometry similar to **3** because the best σ-donor is also the largest substituent.[6] Appropriate type-I face selectivity is seen for the *Z* silane (Table I, entry 1) but the *E* silane reacts with selectivity for product II![7] In the case of sulfones, geometry **2** should be best with donor CH_3 "anti" and bulky acceptor (X = RSO_2) in the "outside" position. Appropriate selectivity for II is seen for *E* sulfones (entries 4 and 6), but again the *Z* isomers show type-I selectivity. It is hard to believe that highly congested **1** should be favored for *Z* sulfones regardless of electronic effects. Thus, one of the two olefin isomers

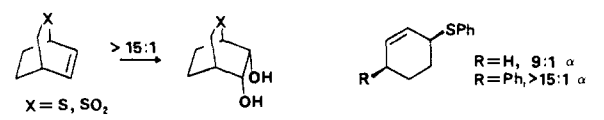

Figure 2.

in each example of sulfone or silane osmylations prefers a different transition state from that predicted by hyperconjugative arguments.

Several other 3-penten-2-yl derivatives are included in Table I for comparison (X = sulfide, ether, and ester). In each case, stereochemistry is assigned by *chemical correlation* with known structures.[8] Most striking is the result that *all* of the *Z* alkenes are osmylated with similar selectivity for type-I diol. We can detect no systematic trend involving σ-donor/acceptor effects. There is less consistency in the *E* alkenes, but the third-row elements all show product II selectivity.

We suggest that osmylation transition states will have the C_2 hydrogen in the most demanding environment and that this depends on olefin geometry. For *E* alkenes, steric requirements of osmium ligands are dominant and **5** or **6** are preferred with C_2 hydrogen near osmium. For *Z* alkenes, ligand interactions can be reduced by distorting the osmium heterocycle toward the unsubstituted olefin side. The sterically dominant effects are now between C_5 and C_2, and C_2 hydrogen is placed "inside" as in **3** (major) or **4** (minor). With X = bulky silyl or sulfone groups, the product-like geometry **3** is clearly favored on steric grounds. For X = sulfide, we suggest that **3** is more stable than **4** because diffuse 3p electron pairs prefer to be away from developing bonds and osmate electron pairs. A similar preference for S away from O is observed in 5-alkoxy-1,3-dithianes and 5-(alkylthio)-1,3-dioxanes.[11] This effect should be smaller for ethers, esters, and amides[12] corresponding to the lower selectivity for **3** in these systems. As summarized by Kishi et al.,[1] there are several examples of conformationally restricted allylic ethers where osmylation occurs preferentially on the olefin face away from oxygen. The effect is not always large, but there are few exceptions. As expected, conformationally restricted sulfides show a greater tendency for osmylation away from the heteroatom and neither sulfides nor sulfones show evidence of chelation effects (Figure2).[13b]

Osmylation selectivities with simple *E* alkenes are generally lower and trends are less clear. Bulky sulfones favor **6** over **5**, the sulfide less so, and the relatively compact ethers prefer **5**. Other geometries are not ruled out, but these models are consistent with the lone pair argument and the behavior of conformationally restricted systems, and **5** explains the increased selectivity observed by Kishi et al. as the size and complexity of C_2–alkyl substituents increases.

Recent findings by Houk et al. on nitrile *N*-oxide cycloadditions likewise favor a steric role for allylic oxygen substituents rather than the electronic effects of the earlier proposal.[14] The original

(5) Preparation of *E* silane: $PhSiMe_2Li$ + (*E*)-allylic chloride (THF), 51%, 9:1 E/Z. *Z* silane: $CH_3C{\equiv}CLi$ + $PhMe_2SiCHICH_3$ (HMPA/THF; yield, 20% propargyl silane); H_2/Pd–$BaSO_4$ gives *Z* silane, 95:5 Z:E. *E* sulfide: E-allylic chloride + PhSNa/EtOH, 70%. *Z*-sulfide: (*Z*)-allylic alcohol + Bu_3P/PhSSPh/CH_3CN, 20 °C, 86% (1:1 Z/E).

(6) Analogous *A* value comparisons: Me_3Si, 2.5 kcal/mol: Kitching, W.; Olszowy, H. A.; Drew, G. M. *J. Org. Chem.* **1982**, *47*, 5153. RSO_2, 2.5 kcal/mol; RS, 0.8 kcal/mol; Corey, E. J.; Feiner, N. F. *J. Org. Chem.* **1980**, *45*, 765 and references therein. CH_3S, 1.0 kcal/mol: Eliel, E. L.; Kandasamy, D. *Ibid.* **1976**, *41*, 3899.

(7) Previous cases of allyl silane osmylation: (a) Vedejs, E.; Campbell, J. B.; Gadwood, R. C.; Rodgers, J. D.; Spear, K. L.; Watanabe, Y. *J. Org. Chem.* **1982**, *47*, 1534. (b) Fleming, I.; Terrett, N. K. *Tetrahedron Lett.* **1983**, *24*, 4151.

(8) Silanes: I or II + KO-*t*-C_4H_9 gives (*Z*)- and (*E*)-pentenols, respectively. Sulfides and sulfones: threo epoxide of 3-penten-2-yl acetate + RSLi affords S_N2 product II (table I, entries 4 and 6); erythro epoxide[9] affords S_N2 product I (Table I, entries 3 and 5); both epoxides also give an isomeric 3-(phenylthio)pentane-2,4-diol, but no other products. Ethers and acetates: conversion to known pentane-2,3,4-triol triacetates.[10]

(9) Berti, G. *Topics Stereochem.* **1973**, *7*, 93. Sharpless, K. B.; Verhoeven, T. R. *Aldrichimica Acta* **1979**, *12*, 63 and references therein.

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transition-state geometries featuring "inside" alkoxy groups are retained in the new proposal, and an X-ray structure reveals similar geometry in the product. Comparison of product X-ray structures with relatively advanced cycloaddition transition states may also prove informative in osymlations, but suitable crystals have not been obtained to date.

Results from several epoxidations are included (Table I)[13a] to underscore the unique nature of interactions observed in the osmylations. The selectivity in epoxidation vs. osmylation is reversed in each of the *E* alkenes! This requires that osmium ligand effects are important and that they can be quite different in *E* vs. *Z* alkenes. Selectivities for epoxidations are rationalized elsewhere,[7b,9,15] but the similarity of our sulfone and silane examples suggests that σ-donor effects may have been overemphasized in the previous discussions of silanes.[7b,15] Caution is appropriate because simple steric effects would favor the same product as σ-donor effects for those allyl silanes studied so far.

In summary, our results do not support a hyperconjugative model for osmylations. Our transition state models are somewhat different and more product-like than Kishi's, but qualitative predictions follow a similar pattern. Since the directive effects in osmylations (and probably, in many other cycloadditions) are mostly steric, one should not expect that olefin conformational and electronic effects will consistently result in the same transition-state geometry regardless of the electrophilic reactant. Empirical correlations may appear to support such models in many cases, but caution is appropriate since only two results are possible.

Acknowledgment. This work was supported by the National Science Foundation.

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Isotopic Multiplets[1] in the ^{13}C NMR Spectra of Cobalt(III) Complexes with Partially Deuterated Coordinated NH_2 or NH Groups. Dihedral Angular Dependence of the Three-Bond Isotope Effects

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Received August 16, 1985

Recent reports have demonstrated that isotopic multiplets[1] observed in the ^{13}C NMR spectra of amides,[2] carbohydrates,[3] or amines[4] with partially deuterated NH or OH groups can be very helpful in spectral assignments. These multiplets are due to upfield deuterium isotope effects on the ^{13}C chemical shifts[5] and can be observed in the slow hydrogen exchange conditions. The magnitudes of the reported isotope shifts for the two-bond effects are about in the range 120–90 ppb, while those for the three-bond effects are about in the range 70–0 ppb. Although understanding

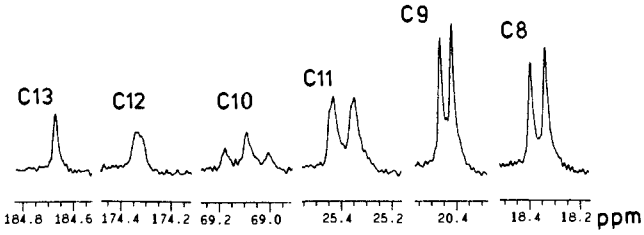

Figure 1. Isotopic multiplets[1] in the ^{13}C resonances (at 100.53 MHz) of the α-amino-α-methylmalonato (AMM) moiety and of the methyl groups in the tetraamine moiety of Λ-β_2-[Co(AMM)(5(*R*),7(*R*)-Me_2-2,3,2-tet[11])]$^+$ (7) observed in a neutral ca. 1:1 H_2O/D_2O mixture. Carbon numbers are same to those of **7** in Table II.

of the factors that govern the magnitudes of these effects is incomplete, the magnitude of the three-bond effect seems to provide information concerning steric features of a molecule.[3d,6] Therefore, elucidation of these factors should contribute significantly to the progress of this technique. This paper presents the first application of the isotopic multiplets[1] to the ^{13}C NMR spectra of the coordination compounds, which can provide interesting examples of dihedral angular dependence of the three-bond isotope effects.[7]

Partial deuteration of the coordinated NH_2 or NH groups in the cobalt(III)–amine systems could be achieved in neutral H_2O/D_2O mixtures. Due to slow exchange between the isotopomers, the isotope effects on the ^{13}C resonances of the α- and β-carbons could give rise to distinct ^{13}C resonances for the individual isotopomers.[8,9] Partial deuteration of a coordinated NH_2 group produces four species, NH_2, NHD, NDH, and ND_2, which cause ^{13}C resonances of the α- and β-carbons to result in quartets or in triplets. The latter case is commonly observed, because, in many cases, isotope effects corresponding to the two ways of monodeuteration are almost equivalent. Partial deuteration of a coordinated NH group produces two species, NH and ND, which cause ^{13}C resonances of the α- and β-carbons to result in doublets. Therefore, the individual carbon gives a characteristic isotopic multiplet[1] according to the type of nitrogens on the observed and the neighboring carbons, which can be very helpful to assign the ^{13}C resonances of coordinated polyamines. Examples of assignments of the $^{13}CH_2$ resonances in [Co(ox)(tetraamine)]$^+$ are listed in Table I.[10] It can be clearly seen that chemical shifts of the $^{13}CH_2$ resonances depend on the type of the nitrogens both on the observed and the neighboring carbons. They tend to shift to lower field with the order $NR_2 > NHR > NH_2 > (CH_2)$.

A very important phenomenon concerning the magnitude of the three-bond isotope effect was observed with α-amino-α-methylmalonato (AMM) complexes. Figure 1 presents typical isotopic multiplets[1] in the ^{13}C NMR spectrum of Λ-β_2-[Co(AMM)(5(*R*),7(*R*)-Me_2-2,3,2-tet[11])]$^+$ (7). C11, β to a coor-

(1) This expression is often used in the literature,[3d] since there is a similarity between these phenomena and the multiplets due to spin–spin couplings. It involves, in fact, a sum of the individual isotope effects on ^{13}C chemical shifts of different isotopomers in the mixture.

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(7) FT carbon-13 NMR spectra were obtained at 100.53 MHz with broad-band proton decoupling on a JEOL GX-400 spectrometer.

(8) The observation of the multiplets could be anticipated from the reported multiplets in the ^{59}Co NMR spectra of the cobalt(III)–amine systems with partially deuterated coordinated NH_2 or NH groups obtained in water. Sudmeier, J. L.; Blackmer, G. L.; Bradley, C. H.; Anet, F. A. L. *J. Am. Chem. Soc.* **1972**, *94*, 757–761. Au-Yeung, S. C. F.; Eaton, D. R. *J. Magn. Reson.* **1983**, *52*, 351–365. Russell, J. G.; Bryant, R. G. *Anal. Chim. Acta* **1983**, *151*, 227–229. Peterson, S. H.; Bryant, R. G.; Russell, J. G. *Ibid.* **1983**, *154*, 211–218.

(9) This sample preparation is remarkably easy compared with the reported cases of amines, which needed to acidify or to choose aprotic solvent such as Me_2SO. In a neutral H_2O/D_2O mixture, the uncoordinated NH_2 or NH group does not cause the isotopic multiplets. On the basis of the remarkable difference in the observable conditions of the isotopic multiplets, it may be possible to differentiate the coordinated nitrogens from the uncoordinated ones. Therefore, this technique can be applied, for example, to the direct determination of the coordinating position in a macromolecule–metal associating system.

(10) Different multiplicities due to the three-bond effects are observed between the pairs of diastereotopic carbons for compound **1**. It should suggest that they are in different steric environment with regard to NH_2 or NH. Therefore, it is potentially possible to assign these pairs of carbons.

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