Table I. Rates of Reaction of Vinyl Triflates in 80% Aqueous Ethanol

Compd	Temp, °C	k, sec^{-1}	$\Delta H^{\ddagger}$, kcal/mol	$\Delta S^{\ddagger}$, eu
1	25.0[a]	9.45×10^{-8}	24.7	−7.7
	50.0[a]	2.59×10^{-6}		
	76.1	$(4.95 \pm 0.28) \times 10^{-5}$		
	100.1	$(5.26 \pm 0.25) \times 10^{-4}$		
1[b]	25.0[a]	6.81×10^{-7}	24.9	−3.3
	50.2	$(1.95 \pm 0.05) \times 10^{-5}$		
	76.1	$(3.72 \pm 0.25) \times 10^{-4}$		
1[c]	50.2	$(9.64 \pm 1.0) \times 10^{-5}$		
2	25.0[a]	1.49×10^{-6}	23.8	−5.3
	50.2	$(3.72 \pm 0.05) \times 10^{-5}$		
	76.1	$(6.29 \pm 0.20) \times 10^{-4}$		
3	25.0[a]	3.67×10^{-8}	25.3	−7.7
	76.2	$(2.25 \pm 0.08) \times 10^{-5}$		
	100.1	$(2.48 \pm 0.08) \times 10^{-4}$		

[a] Extrapolated. [b] 50% aqueous ethanol. [c] NaOH (1.1 equiv) added.

9% methylallene. This product ratio for the *cis* isomer **3** did not change in the presence of a base, such as pyridine, added prior to reaction.[10]

In principle alkylvinyl triflates under solvolytic conditions could undergo reaction according to four possible mechanisms: (a) nucleophilic attack at sulfur with cleavage of the S–O bond, (b) an addition–elimination sequence similar to that observed by Peterson[4] for the arenesulfonates in formic acid, (c) a unimolecular SN1 type ionization to a vinyl cation, and (d) a concerted elimination.

Mechanism a is not expected, for nucleophilic attack on sulfur in sulfates is unlikely, and is further ruled out by the extreme unreactivity of phenyl triflates.[6b,11] Mechanism b is ruled out by the improbability of protonation in neutral aqueous media as well as the absence of ketone as product in the *trans* isomer **2**.

A close examination of the data reveals a mechanism that is a delicate balance between a concerted elimination and a unimolecular ionization involving a vinyl cation. In the *trans*-dimethyl isomer **2**, the only product of reaction is acetylene, while the *cis* isomer **3** also gives methylallene and 2-butanone as product. Although the olefinic products could arise from either concerted elimination or rate-determining formation of a vinyl cation followed by subsequent loss of proton, the ketone must arise from solvent capture of an incipient vinyl cation **4**. The solvolysis rates of isopropenyl triflate (**1**) in 80 and 50% aqueous ethanol correspond to $m = 0.52$, a value comparable to that observed in the solvolysis of simple secondary alkyl systems, such as $m = 0.40$ for isopropyl brosylate.[12] The 37-fold rate acceleration observed in the presence of NaOH, although small, points toward a concerted elimination. Furthermore, the rate of the *trans* isomer **2** is 40 times that of the *cis* isomer **3**, suggesting that the former, which is in a geometrically favorable conformation for concerted elimination, reacts by such a pathway, whereas the *cis* isomer in a geometrically unfavorable configuration undergoes reaction *via* unimolecular ionization and a vinyl cation intermediate. As a test of this hypothesis we prepared the deuterio-*trans* (**2**, R′ = D) and deuterio-*cis* (**3**, R = D) compounds and measured the deuterium isotope effects.[13] $k_H/k_D = 2.09$ was observed for the *trans* isomer **2** in 80% aqueous ethanol at 76°, whereas the value obtained for the *cis* isomer **3** was $k_H/k_D = 1.20$ at 100°. The value of $k_H/k_D = 2.09$ for the *trans* isomer is more consistent with a primary deuterium isotope effect indicative of bond breaking in the transition state and mechanism d, whereas that of the *cis* isomer, $k_H/k_D = 1.20$, is more like a normal β-deuterium isotope effect and more consistent with a simple alkylvinyl cation intermediate.[14]

In summary, we think that, on the basis of the observed products and their invariance in the presence of base, the relative rates, and the deuterium isotope effects, solvolysis of *cis*-2-buten-2-yl triflate (**3**) proceeds through a disubstituted carbonium ion **4**, and represents the first example of a simple alkyl-substituted vinyl cation.

Further mechanistic studies on these and other vinyl triflates are under investigation and will be reported in future papers.

Acknowledgments. The authors are grateful to Professor Paul von R. Schleyer for many stimulating discussions and helpful suggestions, and partial support through National Science Foundation Grant GP 9233. We are indebted to Dr. R. L. Hansen of the Minnesota Mining and Manufacturing Co. for samples of the barium salt of trifluoromethanesulfonic acid.

(10) Products were identified by comparison of retention times with authentic samples and were found to be essentially stable under the reaction conditions, with only methylallene undergoing isomerization to the acetylene, but only to the extent of 5–10%.

(11) Private communication, A. Streitwieser, Jr.

(12) (a) E. Grunwald and S. Winstein, *J. Am. Chem. Soc.*, 70, 846 (1948); (b) A. Streitwieser, Jr., "Solvolytic Displacement Reactions," McGraw-Hill Book Co., Inc., New York, N. Y., 1962.

(13) The deuterio compounds were prepared in the usual manner from CF_3SO_3D. Both low-voltage mass spectrometric analysis as well as nmr indicate 68 ± 3% deuterium incorporation. In numerous attempts under a variety of conditions it proved to be impossible to obtain more than 70% deuteration due to scrambling during addition. The isotope effects reported are extrapolated to 100% deuteration.

(14) There are no values in the literature for the β-deuterium isotope effect on the solvolysis of vinyl derivatives. However, a β-deuterium isotope effect in the acid-catalyzed electrophilic addition of H_2O to $C_6H_5C{\equiv}CD$ involving a vinyl cation is consistent with our value (see D. S. Noyce and M. D. Schiavelli, *J. Am. Chem. Soc.*, 90, 1023 (1968)).

(15) (a) Author to whom inquiries should be sent, at Department of Chemistry, University of Utah, Salt Lake City, Utah 84112; (b) National Science Foundation Predoctoral Fellow, 1969–1970.

Peter J. Stang,[15a] **Richard Summerville**[15b]
Department of Chemistry, Princeton University
Princeton, New Jersey 08540

Received May 6, 1969

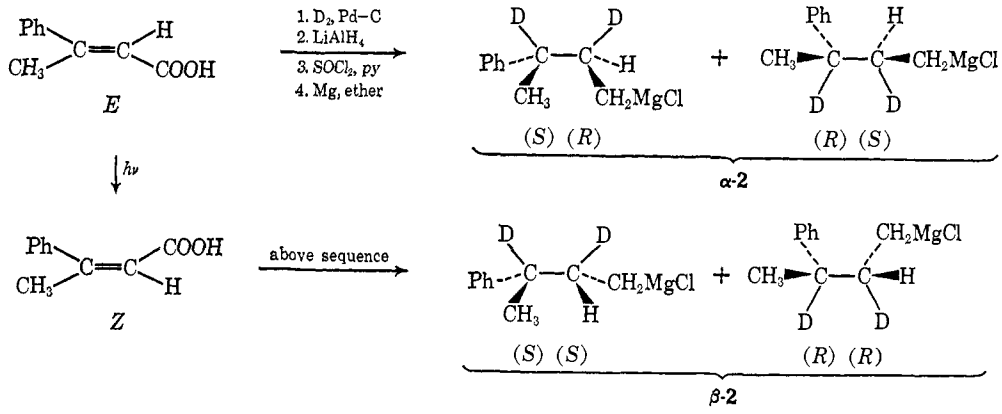
Mediation of a Primary Kinetic Isotope Effect by Asymmetric Induction

Sir:

Reduction of isopropyl phenyl ketone with a Grignard reagent from (*R*)-(−)-3-phenylbutyl chloride gives a 25% enantiomeric excess of (*R*)-(+)-isopropylphenylcarbinol. This reduction has been described in terms of the symmetry principles involved.[1] We have subsequently found that reduction of *t*-butyl phenyl ketone with this Grignard reagent yields an 8% enantiomeric excess of (*R*)-(+)-*t*-butylphenylcarbinol (**4**). Deuterium-labeling experiments with the latter system have revealed some of the mechanistic details of this reaction. Most striking is the observation that the C-3 chiral cen-

(1) J. D. Morrison, D. L. Black, and R. W. Ridgway, *Tetrahedron Lett.*, 985 (1968).

Scheme I



ter in diastereomeric Grignard reagents from 1-chloro-2,3-dideuterio-3-phenylbutane mediates a primary isotope effect (k_H/k_D), which is "normally" in the range of 2 to 3, so that, depending upon which diastereomer of labeled Grignard reagent is used, an unusually large or an inverse isotope effect may be obtained for the reduction of *t*-butyl phenyl ketone.

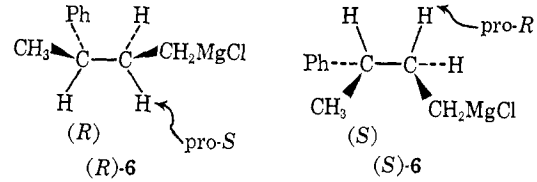
Racemic mixtures of the diastereomeric Grignard reagents[2] were prepared as shown in Scheme I from (*E*)- and (*Z*)-β-methylcinnamic acids. Reaction of these Grignard reagents with *t*-butyl phenyl ketone gave approximately a 50% yield of *t*-butylphenylcarbinol *via* competitive hydride and deuteride transfer with concomitant formation of a partially labeled alkene (**3**). The

$$\underset{\mathbf{2}}{\text{PhCD(Me)CHDCH}_2\text{MgCl}} \xrightarrow[2.\ H_2O]{1.\ t\text{-BuCOPh}}$$

$$\underset{\mathbf{3}}{\text{PhCD(Me)C(H(D))=CH}_2} + \underset{\mathbf{4}}{t\text{-BuC(D(H))(OH)Ph}}$$

H/D ratio[3] of the alcohol is a measure of the primary isotope effect for the Grignard reduction. With β-**2** a corrected[4] k_H/k_D of 8 was obtained, whereas with α-**2** the k_H/k_D was 0.4. A "normal" isotope effect was determined for the reduction of *t*-butyl phenyl ketone with a Grignard reagent from (±)-*threo*-chloro-3-phenyl-2,3-dideuteriopropane (**5**). The value obtained (k_H/k_D = 2.3) is in good agreement with isotope effects determined for other Grignard reductions where there is no influence from neighboring chiral centers.[5] It is assumed that the effect of the C-3 chiral center of **5** is negligible.

The increase in the preference for hydrogen transfer in β-**2**, as compared to the "normal" isotope effect, and the even more dramatic preference for deuterium transfer in α-**2**, are reflections of asymmetric induction due to the chiral C-3 center in **2**. In a previous paper[1] it was tentatively proposed on the basis of the stereochemistry of asymmetric reduction that the *R* enantiomer of **6** transfers the *pro-S* hydrogen preferentially in ketone reductions. The *S* enantiomer would be expected to preferentially transfer the *pro-R* hydrogen. These predictions are unequivocally corroborated by the present results. In either enantiomer of α-**2** the labeled hydrogen is that predicted to be preferentially transferred. It is, in fact, sufficiently favored so that the normal kinetic preference for hydrogen transfer is reversed and an inverse isotope effect results. On the other hand, in either enantiomer of β-**2** transfer of the unlabeled hydrogen is expected to be favored by asymmetric induction. With this isomer a large isotope effect favoring hydrogen transfer is observed due to the reinforcement of asymmetric induction and normal isotope effect factors.



This work demonstrates that significant transition-state energy differences may be observed for reactions of compounds which are epimeric only by virtue of an isotopic disparity at one chiral center.[6] It also presents what is to our knowledge the first example of the asymmetric induction of an inverse isotope effect in a simple acyclic chemical system. The behavior observed is reminiscent of the stereochemistry of certain enzymatic reactions, notably ADH–NADH reductions of aldehydes and ketones,[7] where there is selection of one of the diastereotopic hydrogens from C-4 of a dihydropyridine moiety.

Acknowledgment. We thank the donors of the Petroleum Research Fund, administered by the American Chemical Society, for support of this research.

(2) The prefixes α and β refer to diastereomers of **2** having the opposite and the same chirality symbols, respectively, for the two asymmetric carbons.

(3) The H/D ratios reported were determined by nmr analysis of **4** for deuterium content. Values obtained were in reasonable agreement with those calculated from deuterium analyses of **3**.

(4) The reported values are corrected for incomplete deuterium incorporation at C-2 of the Grignard reagent (*ca.* 85% monodeuteration).

(5) Values for k_H/k_D in the range 1.6 to 2.3 have been obtained for several different Grignard reductions of this type: G. E. Dunn and J. Warkenten, *Can. J. Chem.*, 34, 75 (1956); J. D. Morrison and J. E. Tomaszewski, unpublished results with a 2-phenylethyl-2-*d* Grignard reagent.

(6) Green has recently noted (M. Green, *J. Amer. Chem. Soc.*, 90, 3872 (1968)) that certain isomers of this kind can be distinguished by a stereoselective electron-impact-induced elimination reaction.

(7) For examples and leading references see G. J. Karabatsos, J. S. Fleming, N. Hsi, and R. H. Abeles, *ibid.*, **88**, 849 (1966); R. MacLeod, H. Prosser, L. Fikentscher, J. Lanyi, and H. S. Mosher, *Biochemistry*, 3, 838 (1964); V. E. Althouse, D. M. Feigl, W. A. Sanderson, and H. S. Mosher, *J. Amer. Chem. Soc.*, **88**, 3595 (1966).

James D. Morrison, Robert W. Ridgway
Department of Chemistry, University of New Hampshire
Durham, New Hampshire 03824

Received May 24, 1969