the selenium analogue of **2d**, gave (C_6D_6, 90 °C, sealed NMR tube) exchange products (mass and NMR spectral analysis) in which the chalcogen had *remained attached* to the alkyne fragment, ruling out option 3. Similar reaction of $CpRh[S_2C_2(C_6H_5)_2]$ (20%;[21] mp >250 °C), the rhodium analogue of **2a**, with $CH_3C_5H_4Co(S_2C_2R_2)$, R = *n*-Bu (30%;[21] mp 116–118 °C), produced only CpRh and $CH_3C_5H_4Co(S_2C_2R_2)$ products. Thus, option 2 is operating, probably through the intermediacy of bridging metalladichalcogene dimers.[14a,22]

Finally, in as much as one may regard metal clusters as potential surface analogues,[23] we note that a calculation has predicted accelerated bond scission in alkynes on surfaces covered by chalcogens.[24] Our system provides, at least formally, a homogeneous example of the reverse transformation.

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Supplementary Material Available: A listing of positional and thermal parameters and tables of bond lengths and angles derived from crystallographic analysis of **3** (5 pages). Ordering information is given on any current masthead page.

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Nucleophilic Displacement with a Selectively Solvated Nucleophile: The System $OH^-{\cdot}H_2O + CH_3Br$ at 300 K

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When the familiar nucleophilic displacement reaction[3-6] between OH^- and CH_3Br is run in the gas phase for the selectively solvated nucleophile $OH^-{\cdot}H_2O$, the major product at 300 K is Br^- (reaction 1a). This reaction, for solvated ions in the gas phase, is *not* the corresponding reaction found for solvated ions in solution.

$$OH^-{\cdot}H_2O + CH_3Br \rightarrow CH_3OH + Br^- + H_2O \quad \Delta H^\circ = -31\ \text{kcal/mol} \quad (1a)$$

$$\rightarrow CH_3OH + Br^-{\cdot}H_2O \quad \Delta H^\circ = -43\ \text{kcal/mol} \quad (1b)$$

$$OH^-{\cdot}(H_2O)_n + RX \rightarrow ROH + nH_2O + X^- \quad \text{gas phase} \quad (2a)$$

$$\rightarrow ROH + X^-{\cdot}(H_2O)_n \quad \text{solution} \quad (2b)$$

This result belies[7] the attractive and plausible notion that solvated-ion reactions bridge the gap between the reactions of unsolvated ions in the gas phase and of fully solvated ions in solution.[5]

Table I. Rate Constants and Heats of Reaction

reactants	ΔH°, kcal/mol[a]	k, cm^3/(molecule s) × 10^{10} SIFT (300 K)[b]	FA (300 K)[c]	ICR[d]
$OH^- + CH_3Br$	−55.7	17	10 ± 2	19
$OH^-{\cdot}H_2O + CH_3Br$	−30.7	11	6.3 ± 2.5	
$OH^-{\cdot}(H_2O)_2 + CH_3Br$	−14.3		0.02 ± 0.01	
$OH^-(H_2O)_3 + CH_3Br$	+0.7[e]		<0.002	
$OH^- + CH_3Cl$	−47.5	13	15	16

[a] Estimated for the channel $OH^-{\cdot}(H_2O)_n + CH_3X \rightarrow CH_3OH + nH_2O + X^-$. [b] Estimated accuracy ±50%. [c] Flowing afterglow measurements, ref 4 and 5. [d] Ion cyclotron resonance measurements, ref 3a. [e] The uncertainty in the thermochemistry (~2 kcal/mol) is enough that this could be exothermic.

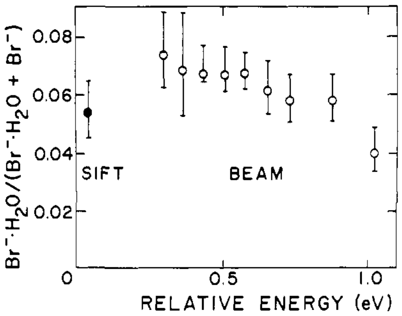

Figure 1. Fraction of $Br^-{\cdot}H_2O$ in the products as a function of relative energy. Open circles, beam results; filled circle, SIFT result (300 K).

Two different techniques have been used here: a selected ion flow tube (SIFT) at 300 K[8,9] and a double mass spectrometer[10] at relative energies down to ~0.3 eV. Solvated ions were produced by electron bombardment of water vapor (~10^{-2} torr). Table I summarizes rate constant data for the reaction of hydroxide ions, hydrated and unhydrated, with methyl halides; our measurements[11] agree acceptably with published values.

The high yield of Br^- (~95%) is seen not to be the consequence of collision-induced dissociation of $Br^-{\cdot}H_2O$ in the flow-tube sampling orifice, since the beam results, taken under single collision conditions, are identical (Figure 1).[12] Nor does the yield of Br^- result from the unimolecular decomposition of vibrationally excited $Br^-{\cdot}H_2O$. First, we find for other nucleophilic displacement reactions involving solvated ions little or no solvation of the leaving group.[13] Second, increasing the relative translational energy does not increase the $Br^-/Br^-{\cdot}H_2O$ ratio (Figure 1).[14]

Br^- is thus identified as the principal *primary* product. Solvate

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[11] Microcanonical rate constants, evaluated from the beam data at the lowest energies, e.g., Figure 1, also show agreement.

[12] Discrimination in the beam experiment, resulting from the kinematics, would favor collection of $Br^-{\cdot}H_2O$.

[13] Supported by limited supplementary studies on higher hydrates and other substrates (CH_3Cl). Hierl, P. M., Paulson, J. F., Henchman, M., manuscript in preparation.

[14] Contrast the strongly exothermic reaction $OH^-{\cdot}(H_2O)_2 + CO_2 = HCO_3^-{\cdot}H_2O + H_2O$ ($\Delta H^\circ = -60$ kcal/mol) where the product ratio $HCO_3^-{\cdot}H_2O/HCO_3^-$ falls from ~10 at ~0.1 eV to ~0.01 at ~1 eV relative energy (Hierl, P. M.; Paulson, J. F., manuscript in preparation).

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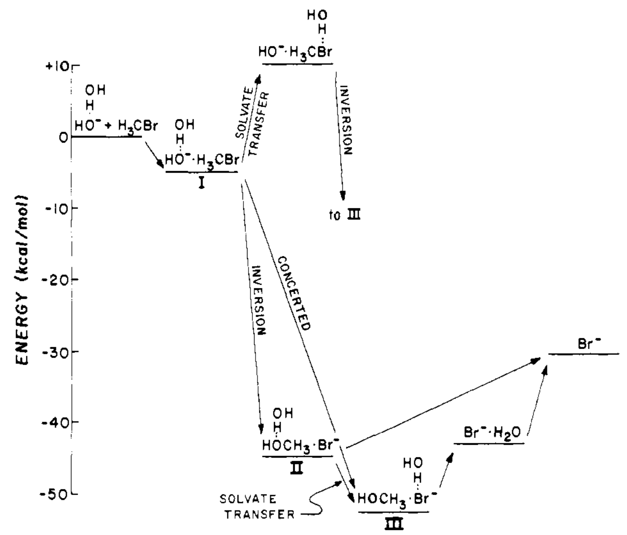

Figure 2. Energies of the reaction intermediates and products, relative to that of the reactants. Thermochemistry from ref 6 and estimates based thereon. Pathways are indicated without showing potential energy barriers.

transfer from nucleophile to leaving group must be inefficient and must couple ineffectively with the Walden inversion[15] of the methyl group.

How can Br^- be formed without involving $Br^-\cdot H_2O$ as an intermediate? Figure 2 shows three possible reactive pathways open to the intermediate I, formed from the reactants:[16] sequential solvate transfer and inversion (upper pathway), concerted solvate transfer/inversion (middle), and sequential inversion and solvate transfer (lower). Since at 300 K the upper pathway is inaccessible energetically, the choice for the intermediate I is between the steps I → II and I → III. We argue that both these steps will show comparable potential energy barriers,[17] but that the concerted process will show the greater "free energy" barrier, resulting from the entropic contribution of the tight transition state for solvate transfer.[3c,18] This argument channels I to II, which is a bromide ion, solvated with a water molecule and a methanol molecule. II contains considerable vibrational energy (~45 kcal/mol), and it has only to desolvate (+~14 kcal/mol) to give Br^-, the principal product observed.[19]

Contrast what happens in the gas phase (reaction 2a) with what happens in solution (reaction 2b). In the gas phase, solvate transfer is inefficient and the product is not solvated.[13] In solution, the product *is* solvated, without the need for the solvate to be transferred. As the displacement proceeds in solution, there is a *concerted* desolvation of the nucleophile and solvation of the leaving group, with different solvent molecules.[20] In solution the role of the bulk solvent, all pervasive, is crucial.

What trends may be identified for these solvated-ion reactions, with increasing solvation number *n*? (1) The rate constants do *not* decrease monotonically, extrapolating to the limiting value for the reaction in solution.[5] Instead, reaction is only possible for that limited range of *n* for which reaction 2a is exothermic. (Here $0 \le n \le 2$,[21] as seen in Table I.) (2) The reaction-coordinate diagrams do *not* transform systematically toward that for the reaction in solution.[5,22] The reaction is not reaction 2b but reaction 2a.

What distinguishes these solvated-ion reactions in the gas phase from reactions in solution is the kinetic role of the bulk solvent. What such solvated-ion reactions can reveal is the kinetic participation of the solvate in the absence of bulk solvent.

Acknowledgment. M.H. acknowledges support from AFOSR (80-0116) and NIH (BRSG S07 RR07044).

Registry No. H_2O, 7732-18-5; OH^-, 14280-30-9; $OH^-\cdot H_2O$, 23138-14-9; $OH^-\cdot(H_2O)_2$, 34118-36-0; $OH^-\cdot(H_2O)_3$, 34118-37-1; CH_3Br, 74-83-9; CH_3Cl, 74-87-3.

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[17] The intrinsic energy barriers (ref 3b) for the two steps are comparable (ref 16), and these are then scaled according to the exothermicities, which are comparable (Figure 2). The existence of a barrier for the process I → II or III follows from the reaction efficiency (ref 3a) being ~50% (Table I).

[18] Where the solvate water must bridge the nucleophile and leaving group (ref 16).

[19] The alternative pathway (II → III) involves solvate transfer. While admittedly exothermic (~−8 kcal/mol), it has an energy barrier (ref 16) and requires another tight transition state (ref 18).

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A Simplified Total Synthesis of Cytochalasins via an Intramolecular Diels-Alder Reaction

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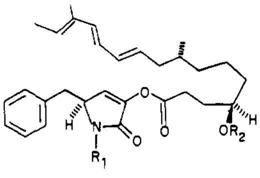
The macrocyclic lactone ring is one of the challenging problems in the synthesis of cytochalasin B and its congeners.[1] We present here a simplification of our original synthesis[1a] that (a) uses an intramolecular version of the Diels-Alder construction from the tetraene **1**[2] and (b) introduces the proper oxidation state in the cyclohexane ring at the end of the synthesis (**2** → **3** → **4**).[3]



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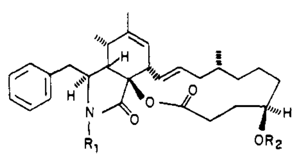

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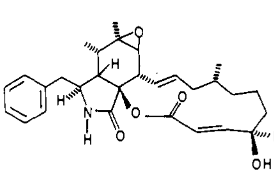

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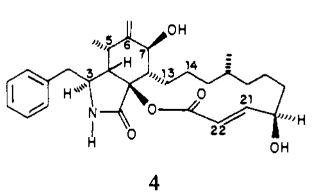

4

Reduction of *N*-carbobenzoxy-(L)phenylalanine methyl ester (2 equiv of DIBAL, −78 °C; 2 N HCl) gave aldehyde **5**,[4,5]

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[1] (a) For a total synthesis of cytochalasin B and leading references, see: Stork, G.; Nakahara, Y; Nakahara, Y; Greenlee, W. G. *J. Am. Chem. Soc.* **1978**, *100*, 7775. (b) For the lactone ring formation see: Masamune, S.; Hayase, Y.; Schilling, W.; Chan, W. K.; Bates, G. S. *J. Am. Chem. Soc.* **1977**, *99*, 6756.

[2] See Corey, E. J.; Petrzilka, M. *Tetrahedron Lett.* **1975**, 2537, for an earlier example of the use of the internal Diels-Alder reaction in the construction of large rings.

[3] The numbering system is taken from: Graf, W.; Robert, J.-L.; Vederas, J. C.; Tamm, Ch.; Solomon, P. H.; Miura, I.; Nakanishi, K. *Helv. Chim. Acta* **1974**, *57*, 1801.

[4] Purification of this readily racemizable aldehyde could be achieved by "flash" chromatography (Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923. The aldehyde was considered to be optically pure as judged by the corresponding phenylalaninol ($NaBH_4$): Ito, A.; Takahashi, R.; Baba, Y. *Chem. Pharm. Bull.* **1975**, *23*, 3081.

[5] All compounds gave spectral data, in particular ^1H NMR ($CDCl_3$) spectra, in agreement with the postulated structures. Mass spectra were taken in a CI mode using methane as reagent gas. Rotations are for pure chloroform solutions and refer to the sodium D line.

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