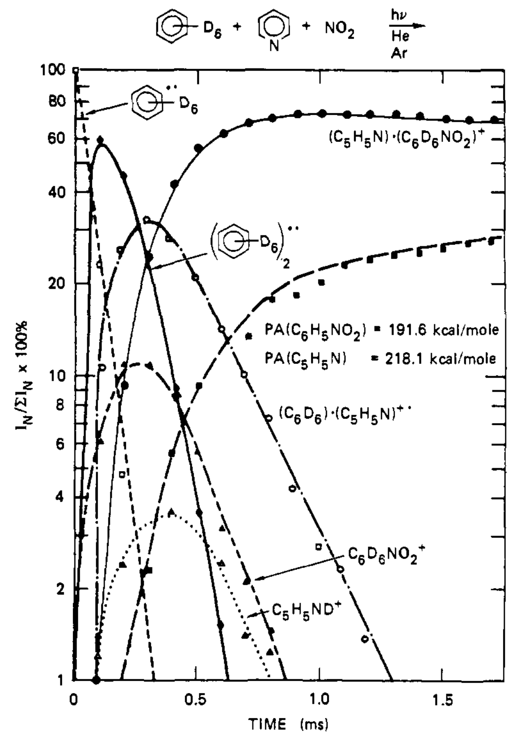

Figure 6. Resolved mass spectra of benzene-d_6, pyridine, and NO_2.

Comparison with Solution Chemistry. Some comparisons and constrasts can be drawn between the solution and the gas-phase results. It is not surprising that a highly deactivated aromatic such as tetrafluorobenzene does not nitrate in the gas phase; the same behavior is observed in solution. In solution, a difluoroquinone is the product instead of a nitroaromatic, whereas in the gas phase no reaction is observed.[13] It is surprising that a highly activated aromatic, such as naphthalene, nitrates slowly in the gas phase. Indeed, in analogy with solution results, one would expect the reaction to occur on every collision. The gas-phase results on the clustered nitronium ion[5-7] parallel our observations on both deactivated and activated aromatics. While it is apparent that there is some barrier to the reaction of activated aromatic radical cations with NO_2 in the gas phase, the origin of this barrier is not now clear.

Conclusion

We have studied the gas-phase chemistry of aromatic radical cations and that of nitronium ion. Under nonsolvated conditions, the nitronium ion plays no part in the nitration mechanism. Rather, the nitronium ion gives only O^+ or e^- transfer. Aromatic radical cations will add NO_2 to give a nitroaromatic product that has been confirmed to be a σ complex. Nitrosations of aromatic radical cations by reaction with NO give only a π complex. This is the first clear example of a reaction of an aromatic radical cation with NO_2 to give a nitroaromatic product. This work affirms that aromatic radical cations are a plausible intermediate in the mechanism for aromatic nitration.

Acknowledgment. We acknowledge the generous support of the Army Research Office, Contract No. DAAG29-80-C-0046, for this work.

Registry No. $C_6H_6^{+\cdot}$, 34504-50-2; $C_6H_5CH_3^{+\cdot}$, 34504-47-7; p-$C_6H_4(CH_3)_2^{+\cdot}$, 34510-22-0; $C_6H_5F^{+\cdot}$, 34468-25-2; $C_6H_5Cl^{+\cdot}$, 55450-32-3; o-$C_6H_4F_2^{+\cdot}$, 65308-08-9; m-$C_6H_4F_2^{+\cdot}$, 65308-07-8; p-$C_6H_4F_2^{+\cdot}$, 59331-60-1; 1,2,4-$C_6H_3F_3^{+\cdot}$, 57164-22-4; 1,2,3,4-$C_6H_2F_4^{+\cdot}$, 57164-19-9; 1,2,4,5-$C_6H_2F_4^{+\cdot}$, 34528-25-1; m-$FC_6H_4CF_3^{+\cdot}$, 88288-93-1; NO_2, 10102-44-0; mesitylene radical cation, 34510-23-1; 1,2,4-trimethylbenzene radical cation, 65018-34-0; phenol radical cation, 40932-22-7; furan radical cation, 66429-00-3; pyridine radical cation, 16399-94-3; naphthalene radical cation, 34512-27-1.

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Gated Reactions

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Received July 7, 1983

Abstract: In dense materials, the initial step for many reactions is the formation of a permissive atomic arrangement within which the reaction proper can proceed comparatively rapidly. A simple but general approach is presented for analyzing the kinetics of such "gated" reactions.

For reactions in dense materials, it is not uncommon to find that the best description of the reaction path involves certain auxiliary coordinates in addition to other more obvious or primitive ones. Perhaps the simplest example is that of vacancy diffusion in a crystal.[1] Here, both for rate calculations and mechanistic descriptions, it is essential to consider displacements of the "gate" atoms between which the diffusing atom must squeeze in addition to the primitive displacement of the diffusing atom. As other examples, reactions that involve charge displacement within a solute molecule immersed in a polar solvent may be dependent upon solvent molecule reorganization,[2-4] and flexible chelating agents such as certain crown ethers may have to assume particular conformations before they can bind ions or other ligands.

Auxiliary coordinates are evidently also required in the analysis of a variety of problems in molecular biophysics. Examples include ligand binding[5,6] and side-chain isomerization[6] in proteins, both of which must in some cases be preceded by extensive structural

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fluctuations that relieve local steric hindrance in the densely packed protein interior. Similarly, intercalation of drugs by DNA may be controlled by breathing motions that involve the unstacking of adjacent pairs of bases. It is also likely that the binding of flexible ligands by receptors may be sensitive to the ligand rearrangement dynamics; binding cannot occur until the ligand has the correct conformation.

Processes of the kind described above have in common the feature that the transition rate along a primitive reaction coordinate is in some cases governed by variations in the auxiliary coordinates. Such reactions can be regarded as gated reactions in that the rate of a local reaction is controlled on a larger scale by the formation of permissive configurations within which the local transformation can proceed relatively rapidly.

Theoretical models for specific types of gated reactions have been described in previous work. For reactions that involve charge redistribution in a polar solvent, solvent effects have, for example, been represented by a generalized frictional force acting along the charge displacement coordinate.[2] For ligand binding to proteins, fluctuations in the protein reactivity have been represented by stochastic absorption terms in diffusion equations.[7-9] The widespread occurrence of gated reactions provides a strong stimulus for the further development of such theoretical work.

Here, we begin the development of somewhat more general models for gated reactions. An important feature of these models is the explicit inclusion of both the primitive and auxiliary (or gate) coordinates in the reaction profile. This feature is considered useful for three reasons. First, the dynamics of the system along the primitive and gate coordinates may differ in their sensitivity to environmental parameters such as viscosity or temperature. Changes in these parameters may alter the extent to which a reaction exhibits gated character. Separate consideration of the coordinates greatly simplifies the analysis of such effects. Second, the coordinate separation allows a more meaningful discussion of reaction mechanisms. It permits the identification of intermediate stable states that may appear in the course of the reaction, and permits useful decompositions of such parameters as the activation energy. Third, recognition of the intrinsic multidimensional character of these reactions will facilitate identification of the best reaction coordinates to use as a basis for computer simulation studies.[10,11]

In the present paper, we describe and analyze a simple contracted state formulation of gated reactions. We begin by describing the standard view of a chemical reaction pictured as a barrier crossing process along a single reaction coordinate. There, all other degrees of freedom are dynamically averaged. this view is contrasted with a more detailed picture in which a gate coordinate is included. We next go on to analyze a simple stochastic model of dynamics on a two-dimensional reaction profile which includes primitive and gate coordinates. We then establish a connection between the rate constant expressions obtained in the two-dimensional and conventional one-dimensional pictures. Some concluding remarks are made in the final section.

Hypothetical Reaction Profiles

For comparison, we first describe in a somewhat schematic sense the conventional picture of a chemical reaction viewed as a free-energy barrier crossing process. As depicted in Figure 1, the reaction is assumed to proceed along a single reaction coordinate x connecting stable reactant and product chemical states designated R and P, respectively. In order for reaction to occur, the system must surmount an intervening activation barrier $\Delta G(\mathrm{R} \rightarrow *)$. The reaction event is described by the dynamics of a "particle" on this free-energy barrier. A fundamental underlying assumption

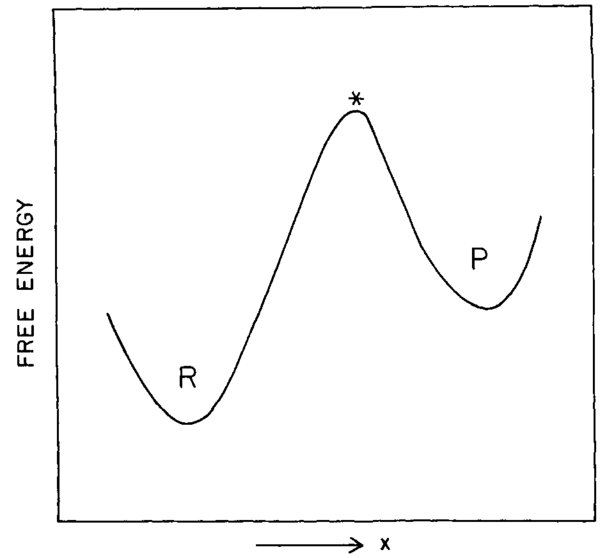

Figure 1. Schematic reaction profile as a function of the primitive reaction coordinate x. The symbols R, P, and * indicate the reactant, product, and activated states, respectively.

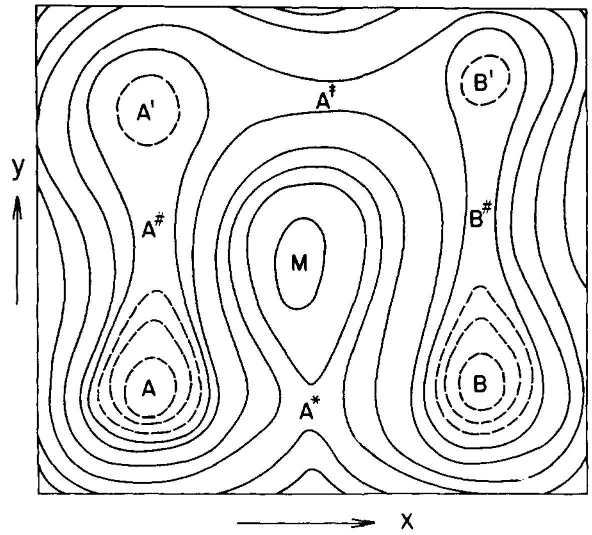

Figure 2. Schematic reaction profile as a function of the primitive coordinate x and a gate coordinate y. Contours indicate the variation in free energy as a function of these coordinates. M is a local maximum, while A, A′, B, and B′ are local minima. The reactant and product regions are in the left and right halves, respectively, and the gate-closed states are in the bottom half.

necessary for the validity of this description is that the relaxation of the system in all degrees of freedom orthogonal to x is rapid on the time scale of motion along x. Thus, the particle effectively samples a free-energy surface which is equilibrium-averaged over all degrees of freedom other than x.

Now contrast this picture with the "gated" view of a chemical reaction. Here, at least one additional coordinate, the gate coordinate y, is included explicitly into the reaction profile, and is considered relevant to the reaction progress. This gives a two-dimensional representation as depicted in Figure 2. Relaxation in all degrees of freedom other than x and y are considered fast or irrelevant, such that the particle samples an equilibrium-averaged free-energy surface as it moves in two dimensions. Regions of space on the free-energy contour map corresponding to stable reactant and product chemical states are labeled A and B, respectively. The system may pass from reactant A to product B via direct motion along the primitive reaction coordinate x through saddle region A*. In the physical context this type of transition corresponds to reaction when only limited excursions along the gate coordinate occur. Such a transition is not preceded or facilitated by prior formation of a permissive gate configuration and

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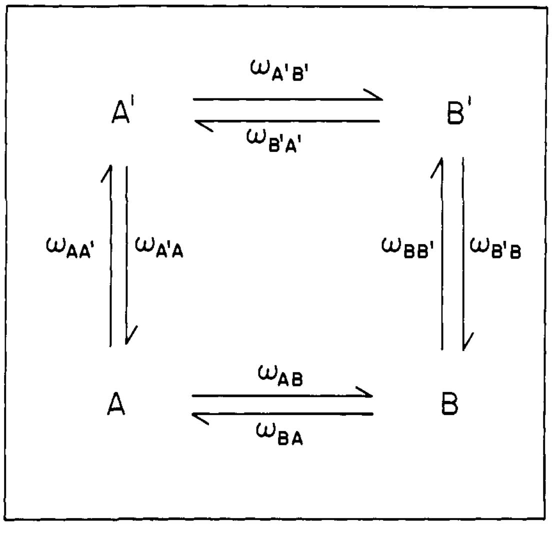

Figure 3. Discrete model of the reactions corresponding to Figure 2.

may be hindered by a large activation barrier. By motion along the gate coordinate from state A, the system may attain intermediate state A′, which is a special reactant state in which the gate is "open". This could correspond to a state in which the surrounding matrix is in a configuration facilitating transition of a reactive type from state A′ to state B′ through a lower saddle region A*.

In the conventional view, the states A and A′ are not distinguished, but are regarded as a single reactant state R, while B′ and B are regarded as state P. The free-energy profile in Figure 1 thus represents an equilibrium average over the *y* coordinate of Figure 2, and the barrier between R and P reflects an equilibrium-weighted contribution from the barriers for the direct A → B and gated A′ → B′ reaction pathways. In the thermodynamic sense, Figure 1, without the auxiliary coordinate, seems to account for both possible reaction pathways. Under what conditions is it necessary to explicitly include the gate coordinate *dynamics* into the overall theoretical framework? This question will be addressed in the following sections.

Simple Contracted Model Analysis

Here, we analyze a simplified or contracted representation of the reaction profile described previously. The four regions of coordinate space identified in Figure 2 are collapsed into discrete chemical states, A, A′, B′, and B. System dynamics are governed by a set of master equations

$$\mathrm{d}p_i(t)/\mathrm{d}t = -\sum_{j\neq i}[\omega_{ij}p_i(t) - \omega_{ji}p_j(t)] \qquad (1)$$

with allowed transitions shown in Figure 3. Here, $p_i(t)$ is the population in state i (=A, A′, B′, B) at time t and ω_{ij} is a transition frequency from i to j. We assume that these transition frequencies may be related to activation free energies by a simple Arrhenius-like form. For example, the frequency ω_{AB} governing the primitive ungated reactive transition A → B is given by

$$\omega_{AB} = \nu_x \exp[-\Delta G(A\rightarrow A^*)/k_BT] \qquad (2)$$

Here, $\Delta G(A\rightarrow A^*)$ is the free energy of activation along the A → B pathway through saddle region A*, k_BT is the Boltzmann constant times temperature, and ν_x is a frequency factor dependent upon dynamics along the primitive coordinate. Similarly, we have

$$\omega_{A'B'} = \nu_x' \exp[-\Delta G(A'\rightarrow A^*)/k_BT] \qquad (3)$$

for the reactive transition along the primitive coordinate when the gate is in an open state. The quantity $\Delta G(A'\rightarrow A^*)$ represents the free-energy barrier height between A′ and B′ through saddle region A*. This is the "gate-open" barrier to reaction. The free energy $\Delta G(A\rightarrow A^\#)$ for opening the gate enters the transition frequency $\omega_{AA'}$ in a similar fashion as

$$\omega_{AA'} = \nu_g \exp[-\Delta G(A\rightarrow A^\#)/k_BT] \qquad (4)$$

The preexponential factor ν_g may differ greatly from ν_x. For example, gate motion may be heavily damped while motion along x may be underdamped. Expressions for the other transition frequencies follow from these in a similar fashion.

The net chemical rate constant k_{AB} for the conversion of A to B along all possible pathways may be extracted by converting eq 1 to the following phenomenological or steady-state rate equation:

$$\mathrm{d}p_A(t)/\mathrm{d}t = -k_{AB}p_A(t) + k_{BA}p_B(t) \qquad (5)$$

This is accomplished by setting intermediate-state time derivatives $\mathrm{d}p_{A'}/\mathrm{d}t$ and $\mathrm{d}p_{B'}/\mathrm{d}t$ equal to zero and eliminating $p_{A'}(t)$ and $p_{B'}(t)$ in the $\mathrm{d}p_A/\mathrm{d}t$ equation in terms of $p_A(t)$ and $p_B(t)$. The resulting expression for k_{AB} is

$$k_{AB} = \omega_{AB} + k_g \qquad (6)$$

Here we have made a natural decomposition of the full rate constant into contributions from the direct ungated pathway (ω_{AB}) and the gated pathway given by

$$k_g = \frac{\omega_{AA'}\omega_{A'B'}\omega_{B'B}}{\omega_{A'A}\omega_{B'B} + \omega_{A'A}\omega_{B'A'} + \omega_{A'B'}\omega_{B'B}} \qquad (7)$$

The extent to which a reaction proceeds preferentially by a gated mechanism can be gauged by the magnitude of k_g relative to ω_{AB}. Criteria for when a reaction is gated can thus be stated in terms of relative free-energy barrier heights and preexponential factors ν_x, ν_x', and ν_g along the two competing pathways. For simplicity in the ensuing discussion, let us assume that the following symmetry exists for the gate-opening transitions

$$\omega_{AA'} = \omega_{BB'} = \omega_{op} \qquad (8)$$

and gate-closing transitions

$$\omega_{A'A} = \omega_{B'B} = \omega_{cl} \qquad (9)$$

That is, gate-opening and -closing rates are given by single characteristic frequencies ω_{op} and ω_{cl}, respectively, regardless of whether the system is on the reactant or product side of the reaction profile. The gated pathway rate constant then simplifies to

$$k_g = \omega_{A'B'}K_g/(1 + \tau_{cl}\tau_{rx}^{-1}) \qquad (10)$$

We now analyze the structure of eq 10. The gated pathway rate constant equals the transition rate $\omega_{A'B'}$ for reactive transitions while the gate is open, times the fraction of time the reactant system is in the open state A′. The latter fraction equals the equilibrium constant K_g for gate opening

$$K_g = \omega_{op}/\omega_{cl} \qquad (11)$$

times a nonequilibrium term $(1 + \tau_{cl}\tau_{rx}^{-1})^{-1}$ accounting for the possibility that the A′ population is not maintained in an equilibrium ratio with the A population. The extent of nonequilibrium is governed by the ratio of the lifetime of the gate-open state $\tau_{cl} = \omega_{cl}^{-1}$ to the relaxation time for reactive saddle-point crossing through the gate-open channel

$$\tau_{rx} = (\omega_{A'B'} + \omega_{B'A'})^{-1} \qquad (12)$$

Let us examine the gated rate constant k_g in two limiting cases. In *case a* we consider the relaxation of the gate coordinate from its open to closed state to be fast relative to rate at which a reactive transition can occur from the gate-open state; thus,

$$\tau_{rx} >> \tau_{cl} \qquad (13)$$

In this limit the gate typically closes before a reactive transition can occur. In terms of free energies, this arises when

$$\Delta G(A'\rightarrow A^*) > \Delta G(A'\rightarrow A^\#) \qquad (14)$$

Equation 10 then reduces to

$$k_g = \omega_{A'B'}K_g \qquad \text{(fast gating)} \qquad (15)$$

The disappearance of the nonequilibrium term implies that the populations of A′ and A are maintained in their equilibrium ratio by rapid gate relaxation. Inserting the Arrhenius-like expressions for quantities in eq 15, we obtain

$$k_g = \nu_x' \exp[-\Delta G(\mathrm{A}\rightarrow\mathrm{A}^{\ddagger})/k_BT] \qquad (16)$$

Thus, we observed that the quantities associated with the process of gating do *not* enter into the gated rate constant in the fast gating limit. The generalized preexponential factor ν_x' is characteristic of dynamics along the primitive coordinate over the gate-open transition ridge. The effective free energy of activation is the difference between the free energy of reactant state A and the saddle region $\mathrm{A}^{\ddagger}$. In the fast gating case, the full rate constant including both mechanisms is then

$$k_{AB} = \nu_x \exp[-\Delta G(\mathrm{A}\rightarrow\mathrm{A}^{*})/k_BT] + \nu_x' \exp[-\Delta G(\mathrm{A}\rightarrow\mathrm{A}^{\ddagger})/k_BT] \qquad (17)$$

The reaction can be considered a gated reaction in the *mechanistic* sense when the second right-hand term dominates, or when (assuming $\nu_x' \approx \nu_x$)

$$\Delta G(\mathrm{A}\rightarrow\mathrm{A}^{*}) > \Delta G(\mathrm{A}\rightarrow\mathrm{A}^{\ddagger}) \qquad (18)$$

In *case b* the gating process is considered to be much slower than the reactive transition while in the gate-open state, or

$$\tau_{rx} << \tau_{cl} \qquad (19)$$

In this limit the reactive transition occurs essentially every time the gate opens. This case is realized (assuming $\nu_g \approx \nu_x'$) when

$$\Delta G(\mathrm{A}'\rightarrow\mathrm{A}^{\ddagger}) < \Delta G(\mathrm{A}'\rightarrow\mathrm{A}^{\#}) \qquad (20)$$

Case b may also result when $\nu_x' >> \nu_g$. The nonequilibrium term $(1 + \tau_{cl}/\tau_{rx})^{-1} \approx \tau_{rx}/\tau_{cl}$ becomes much less than unity, indicating significant depletion of A′ population from an equilibrium ratio K_g. Equation 10 then reduces to

$$k_g = \omega_{op}/(1 + \omega_{B'A'}\omega_{A'B'}^{-1}) \qquad \text{(slow gating)} \qquad (21)$$

The net rate is now controlled by gate-opening frequency ω_{op}, and is modified by the term in parentheses determining what fraction of the reacting population will be on the product side of the transition ridge when the gate eventually recloses. In terms of the Arrhenius-like expressions, we obtain

$$k_g = \nu_g \exp[-\Delta G(\mathrm{A}\rightarrow\mathrm{A}^{\#})/k_BT]/\{1 + \exp[-\Delta G(\mathrm{A}'\rightarrow\mathrm{B}')/k_BT]\} \qquad (22)$$

In this limit the reaction rate constant for a gated reaction ($\omega_{AB} << k_g$) depends predominantly upon the energy requirements to open the gate, and not on the energy required for motion in the primitive coordinate. Furthermore, the dynamical regime operative along the gate direction will now be manifested through frequency ν_g.

Consider the two limiting cases discussed above in the context of the following illustration. Suppose one is concerned with the rate of side-chain rotational isomerizations in the interior of a globular protein.[11] The primitive coordinate x would correspond to the dihedral angle controlling rotation of the side chain, while the gate coordinate y might represent the position of a neighboring structural subunit which must be displaced from its equilibrium position in order to accomodate side-chain rotation. Motion along x might be underdamped, while motion of the bulky subunit might be of a diffusional character, perhaps even dependent on the solvent viscosity. Isomerization of the side chain in absence of gate deformation would be accompanied by a large activation barrier [here, $\Delta G(\mathrm{A}\rightarrow\mathrm{A}^{*})$], such that the gated pathway is the preferred mechanism. However, if the fast gating case (case a) were to apply, the gate would adjust instantaneously to the motion of the side chain, and the side chain would experience an equilibrium-averaged energy of interaction with the gate as rotation occurred. Parameters such as the gate diffusion coefficient would not influence the rate constant. On the other hand, in case b, where gate relaxation is slow, the rate of deformation of the gate would control the reaction rate. Furthermore, if this motion was indeed influenced by such environmental parameters as solvent viscosity, these would then influence the reaction rate through frequency factor ν_g.

The preceding discussion has been made within the simplifying approximations in eq 8 and 9. A more general expression for k_g in the absence of these approximations is

$$k_g = \omega_{A'B'}K_g/(1 + \omega_{A'B'}\omega_{A'A}^{-1} + \omega_{B'A'}\omega_{B'B}^{-1}) \qquad (23)$$

The parenthetic nonequilibrium term now involves two ratios, comparing gating rates with reactive transition rates on both the reactant and product side. This expression corresponds to a result obtained previously for a four-state model analysis of chemical dynamics in which $\omega_{AB} = \omega_{BA} = 0$ (cf. Figure 3).[12]

Connection between One- and Two-Dimensional Results

We now make a connection between our analysis of the rate constant in the gated picture and the result of the conventional view in which an auxiliary coordinate is not included. In the latter picture all motion leading to reaction will appear to occur along primitive coordinate x, and, without the aid of a specialized theoretical description, the preexponential frequency factor will typically be identified as the ν_x quantity previously assigned. The rate constant for barrier crossing will then assume the form

$$k_{AB} = \nu_x \exp[-\Delta G(\mathrm{R}\rightarrow *)/k_BT] \qquad (24)$$

Here, the activation free energy $\Delta G(\mathrm{R}\rightarrow *)$ is the difference between the average free energy along the entire transition ridge *(which includes A^{*} and $\mathrm{A}^{\ddagger}$ and spans both mechanistic pathways) and the average free energy of the reactant state R (which includes A and A′). If the reaction does in fact proceed in large measure by the gated mechanism, one expects the average free energy along the transition ridge to predominantly determined by the free energy in the saddle point region labeled $\mathrm{A}^{\ddagger}$. The free energy of state R will typically be equal to that of state A, such that

$$\Delta G(\mathrm{R}\rightarrow *) \approx \Delta G(\mathrm{A}\rightarrow\mathrm{A}^{\ddagger}) \qquad (25)$$

Thus, in the conventional picture the rate constant would be equivalent to

$$k_{AB} = \nu_x \exp[-\Delta G(\mathrm{A}\rightarrow\mathrm{A}^{\ddagger})/k_BT] \qquad (26)$$

in terms of gated picture quantities. Apart from the possible difference in prefactors, this corresponds to the result of the fast gating limit (case a) of the two-dimensional analysis. This correspondence is anticipated, since in order for the primitive coordinate x to be a good reaction coordinate, relaxation along other degrees of freedom (i.e., y) must be fast. On the other hand, the conventional picture does not at all anticipate case b, in which the reaction is not only gated mechanistically, but the rate is determined by dynamical events in the auxiliary coordinate y. If the reaction considered proceeds by a nongated mechanism ($\mathrm{A} \rightarrow \mathrm{A}^{*} \rightarrow \mathrm{B}$), the conventional picture, expressed by eq 24, would predict a rate constant equivalent to

$$k_{AB} = \nu_x \exp[-\Delta G(\mathrm{A}\rightarrow\mathrm{A}^{*})/k_BT] \qquad (27)$$

in terms of our expanded picture. Here we have again assumed that the free energy of state R is essentially that of state A. This correctly corresponds to ω_{AB} in our analysis, given by eq 2.

Conclusion

In developing microscopic models for chemical reactions, it is standard to adopt a reaction profile in which only a single progress variable is identified. The "best" choice of reaction coordinate often seems quite obvious. By thermodynamic averaging along the x direction, one could then, in principle, determine a free-energy barrier such as that represented in Figure 1. Using an appropriate kinetic model for barrier crossing, one could then obtain a reasonable expression for the rate constant within the context of this reaction profile. Now suppose the reaction of interest does in fact proceed by a gating mechanism. This conventional barrier crossing picture could still be used to predict the rate constant of the gated reaction, *as long as* the relaxation of

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the gate coordinate is fast compared to motion along x. This has been demonstrated above by the correspondence between case a and the one-dimensional analysis. Even so, a meaningful discussion of the gating mechanism would not be possible within the context of the simple one-dimensional reaction profile. We should also point out that, based on results of previous computational studies of the free-energy cost of tyrosine ring rotations in proteins,[10] it may not always be straightforward to obtain adequate equilibrium sampling of the free-energy barrier of a gated reaction along the primitive reaction coordinate. A "best" reaction coordinate which is a combination of the primitive and gate coordinates will facilitate sampling procedures.

A number of important reactive processes in condensed phases may not only be gated, but have rates which are limited or at least influenced by the gate-opening step itself. For these reactions (which correspond to case b in our analysis), the conventional picture is clearly inadequate in making successful predictions of the rate or in understanding the mechanism. For such reactions the inclusion of auxiliary coordinates is essential. Analysis based on a multidimensional reaction profile has the advantage of encompassing all of the various limiting regimes and displaying the interplay of a variety of factors within a single theoretical framework. For example, the extent to which a reaction is gated or gate-limited may vary with changes in environmental parameters that affect gate motion differently than primitive coordinate motion.

Clearly, the specific example of gating presented here lacks the necessary generality to encompass the diversity of gated reactions. For example, in our simple picture there are free-energy minima for gate-open states. These minima (A′ and B′) may not exist in every case. However, the model does serve to illustrate the central ideas pertaining to the concept of gated reactions in a fairly general way and can readily be extended to other specific situations. It seems apparent that the inclusion of auxiliary coordinates into reaction profile maps will be an essential tool for studying complex reactions that occur in condensed phases.

Acknowledgment. This work was supported in part by grants from the Petroleum Research Fund, administered by the American Chemical Society, the Research Corporation (Tennessee Tech), the Robert A. Welch Foundation, and NSF (Houston). J.A.M. is an Alfred P. Sloan Fellow and the recipient of NIH Research Career Development and Camille and Henry Dreyfus Teacher-Scholar Awards.

Experimental and Computed Chiroptical Properties of Thioketones[1]

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Abstract: (+)-(1*S*,3*R*)-4*S*(a)-Methyladamantane-2-thione (**1**), (+)-(1*S*,3*R*)-4*R*(e)-methyladamantane-2-thione (**3**), and (+)-(1*S*,3*R*)-4,4-dideuterioadamantane-2-thione (**5**) were prepared and their circular dichroism (CD) spectra measured and compared with those of the corresponding ketones. The long-wavelength n–π^* CD transitions of the thiones and parent ketones agree in sign and magnitude. Ab initio calculations on thioacetone and methyl ethyl thioketone in the random-phase approximation (RPA) in several basis sets lead to assignment of the two lowest energy observed bands as n–π^* and π–π^* and a third band composed of closely spaced and n–4s and σ–π^* excitations. Similar calculations on **1** and **3** and their keto analogues yield n–π^* rotatory strengths (R) in excellent agreement with experiment and support the applicability of the ketone octant rule to thioketones. An origin-independent analysis of the computed R values suggests that the same mechanism for n–π^* optical activity operates in both classes of compounds.

In contrast to ketones, there are comparatively few known saturated alkyl thioketones.[3] This is in part due to the greater reactivity of C=S (vs. C=O), particularly the greater tendencies toward dimerization and trimerization as well as tautomerization of C=S to the thioenol.[3-5] Consequently most known, stable thioketones are either incapable of enolizing, e.g., thiofenchone,[6] or enolize only with considerable difficulty, e.g., thiocamphor and adamantanethione.[3] These orange-red, saturated alkyl thioketones exhibit an interesting, weak low-lying electronic transition near 500 nm that is generally thought to be similar in nature to the ketone n–π^* transition.[3-8] Theoretical calculations on the electronic spectrum of thioformaldehyde[9a,b] (where the band occurs at 610 nm)[10] and thioacetone[9c] unanimously support this assignment. Solution spectra of thioketones show, in addition, two

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