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ENTROPIC RATE ACCELERATIONS AND ORBITAL STEERING

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Summary

The combination of two bromine atoms to form a bromine molecule cannot be used as a model to estimate the entropic loss of more complex bimolecular reactions of biochemical significance. This reaction has an unusually small entropy change because of the development in the product of rotational entropy which is absent in the monoatomic reactants. In general, the formation of a transition state or monomolecular product from two molecules of reactant, in the gas phase, results in the loss of about 15 Kcal.mole^{-1} of translational and rotational entropy. Effective molarities of up to 10^8 M can be rationalised in terms of entropy changes without the introduction of new chemical concepts or terms.

It has recently been pointed out that intramolecular rate accelerations of up to 10^8 <u>M</u> may be rationalised by considering the different degrees of freedom involved[1]. It was considered unnecessary to introduce new chemical concepts or terms since the bulk of this entropic difference results simply from translational and overall rotational motions. Intramolecular reactions showing "effective molarities" smaller than this may be explained by unfavourable steric and strain effects or a compensating entropy contribution resulting from a loose transition-state or product with low frequency vibrations.[1]

Koshland and coworkers consider that the maximum "proximity effect" is 55 <u>M</u> and that accelerations <u>greater</u> than this require a special explanation.[2] Storm and Koshland introduced the term "orbital steering", to explain some rate accelerations of up to 10^6 <u>M</u>. In its original form orbital steering referred to "the shape of electron orbitals" having "an angular preference far greater than previously estimated"[2]. The necessity of very narrow angular requirements in reactions was criticised because of the lack of experimental evidence[3] and incompatibility with known data.[1,4] Koshland and Dafforn[5,6] then attempted to expand on the meaning "orbital steering". These authors criticised our paper[1] and we believe that some of their statements are incorrect or misleading.

Dafforn and Koshland[6] claimed that we used "measured values of cyclopentadiene dimerisation" to calculate our effective molarity of 10^8 <u>M</u> from entropic sources. Our arguments were based on calculated entropy changes expected for bimolecular reactions and were completely general. We quoted the cyclopentadiene dimerisation simply to show that our calculations were in agreement with experiment. Our calculated changes in translational and rotational entropy are to be expected for any unsymmetrical molecule of average size, since these quantities have only a small dependence upon molecular size. Thus, the formation of a transition state or monomolecular product from two molecules of reactant, in the gas phase, results in the loss of about 50 e.u. associated with translational and rotational motion. This is equivalent to 15 Kcal.mole^{-1} or an effect of about 10^{11} <u>M</u> at 25°C and a standard rate of 1 <u>M</u>. This large entropy loss is partly compensated for by low frequency vibrations in the product or transition state. It is unnecessary to coin special and perhaps misleading phrases to describe further this statistical mechanical approach. The large loss of translational entropy cannot be described as an orientation effect. For example, an encounter controlled reaction with no orientational requirements, in the gas phase can be suitably described by the statistical thermodynamic method. This approach is identical to the hard sphere collision theory of reaction kinetics[7]. Koshland and Dafforn[6] used a reaction of this type, the combination of two bromine atoms, to illustrate the supposed unimportance of translational as opposed to "orientational" effects. Their argument is completely fallacious as is shown by the independent entropy contributions calculated for this reaction (25°, gas phase, 1 M standard state and entropy units in cal. deg.$^{-1}$ mole^{-1}):

	Br·	+	Br·	Br_2	ΔS
S^o trans	32.7		32.7	34.8	-30.6
S^o rot	0		0	16.2	+16.2
S^o vib	0		0	1.3	+ 1.3
S^o elect	2.7		2.7	0	- 5.4
S^o tot	35.4		35.4	52.3	-18.5

The overall loss of translational entropy calculated for the reaction is very large, as expected, and comparable to that found in normal bimolecular associations[1]. The smallness of the net entropy change results simply from the development in the product of a rotational entropy which was absent in the monatomic, or hard sphere, reactants. Calculations for this type of reaction make no direct contribution to the understanding of more complex reactions which invariably involve a net loss of rotational entropy. Hence it is meaningless to compare Koshland and Dafforn's value[6] of 1/K or 55 M with our value of 10^8 M[1].

Koshland and Dafforn[6] appear to have misunderstood our approach since they state that "orientational effects must be disentangled from their overall entropy change". This is precisely what our calculation did by separately calculating the translational and rotational entropy contributions to the total entropy change. For molecules of average size, in the gas phase, the loss of translational entropy contributes more than half of the total loss of translational and rotational entropy.

We have pointed out that despite the lack of a suitable model necessary to dissect the entropic sources in the liquid phase, it is found, empirically, that there is a large loss of entropy for some bimolecular reactions in solution corresponding to about 35 e.u. or a rate factor of 10^8 $\underline{M}^{1}$.

The factor of 55 $\underline{M}$ frequently used to represent the "proximity effect" or translational entropy is simply an entropy of dilution or concentration. In general such small effective molarities will be obtained when two molecules are brought together in a solvent cage or a weakly interacting complex[1]. As the interactions become stronger and the transition state or product becomes tighter i.e. vibrational motions move to higher frequencies, there will be a greater loss of entropy and the effective molarity will increase[1].

Comparable intramolecular and intermolecular reactions which are free of differences arising from potential energy or other effects and yet show small effective molarities are as interesting, or more so, than those showing large rate enhancements.

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