phase to the system. As shown in Figure 1B, plots of carboxyl chemical shift and pH values as a function of concentration exhibited abrupt and discontinuous changes at a unique concentration (29 mM). This unique concentration value was unequivocally defined by the intersection of the two least-squares straight lines observed for carboxyl carbon chemical shift values as a function of concentration (Figure 1B, top). Above 29 mM, pH values remained constant and carboxyl chemical shift values decreased linearly from the value expected for monomeric laurate (184.25 ppm) toward a value expected for predominately micellar laurate ($<$183.1 ppm).[18]

To facilitate the interpretation of these data, the Gibbs phase rule was applied. The formation of micelles in the system shown in Figure 1B resulted in thermodynamic invariance ($F = 0$), as demonstrated by the invariance in pH values and the linear change in chemical shift values above 29 mM.[20,21] Since the system in Figure 1B contained three components (potassium laurate, water, and HCl),[22] the phase rule indicated that, at constant temperature and pressure, two and three phases were present below and above 29 mM, respectively (Figure 1B). Therefore, the micelles formed in this system exhibited the characteristics of a true thermodynamic phase, and a unique cmc value was obtained.

In contrast, the system shown in Figure 1A contained one less phase (no acid-soap crystals) at all concentration values examined. This system contained three components and at least 1 degree of freedom at constant temperature and pressure. This degree of freedom, composition or concentration, had to be defined in order to fix the state of the system. Therefore, the composition and properties of the micellar phase, and hence the true cmc value, could change as a function of concentration, and a unique cmc value could be defined *only at a particular concentration value.* As a result, the measured parameters exhibited gradual and continuous changes as a function of concentration, and an approximate *range* of cmc values was obtained (Figure 1A).

Because of thermodynamic invariance, the micellar phase in Figure 1B had a fixed composition and, by deduction, was homogeneous and monodisperse. This deduction, which was based on the Gibbs phase rule and equilibrium thermodynamics, did not require any special knowledge of the atomic or molecular factors governing the size and shape of micelles. In contrast, in the system shown in Figure 1A, the properties of the micellar phase could have changed as a function of concentration, giving rise to inhomogeneity and polydispersity.

On the basis of the above comparisons, we propose that the gradual and continuous changes often observed near the cmc for ionic amphiphiles in water as a function of concentration[6-10] probably resulted from the presence of 1 or more degrees of freedom in the system. Because of this degree of freedom, such experimental measurements have provided only an approximate range of nonunique cmc values. As suggested by the results shown in Figure 1B, a unique cmc value can be determined if care is taken to work with an experimental systm that is thermodynamically invariant at and above the cmc.

The significance of these findings is 3-fold. First, at least some micelles do exhibit the properties of a true thermodynamic phase and can be treated as such in appropriate theoretical models. Second, cmc values, which have been ill-defined entities[17] and measured by using experimental systems analogous to that shown in Figure 1A, should be redefined as unique values and remeasured by more appropriate experimental systems. Third, systems such as the one shown in Figure 1B, which contain a micellar phase and 0 degrees of freedom above the cmc, provide an opportunity for careful measurements of the properties of a homogeneous and monodisperse micellar phase of well-defined composition. Such studies should facilitate careful comparisons between theory and experiment and clarify our understanding of the molecular factors that govern the size, shape, and formation of micelles.

Acknowledgment. This work was supported by U.S. Public Health Service Grants HL-26335 and HL-07224. D.P.C. was a recipient of the Andrew Costello Research Fellowship of the Juvenile Diabetes Foundation International.

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(19) Cistola, D. P.; Atkinson, D.; Hamilton, J. A.; Small, D. M. *Biochemistry* **1986**, *25*, 2804-2812.

(20) Each chemical shift value represented the weighted average of laurate molecules in fast exchange between the monomer and micellar phases. The linear decrease in chemical shift values with increasing concentration represented an increase in the relative *amounts* of laurate molecules in the micellar vs monomer (aqueous) phases. However, the composition and physical properties of each of these phases did not change above the cmc and were considered invariant.

(21) Independent evidence that micelle formation can result in thermodynamic invariance has been presented elsewhere (ref 18).

(22) In the Gibbs phase rule, it is the *number* of components, rather than the identity of components, that is of importance. Hence, choice of the identity of components is somewhat arbitrary. If the components are chosen as potassium laurate, water, and HCl, then lauric acid is not a chemically indendent species (component). Alternatively, if the components are chosen as potassium laurate, water, and lauric acid, then HCl is not a chemically independent species.

Relative Hydrogen-Bonding Affinities of Imides and Lactams

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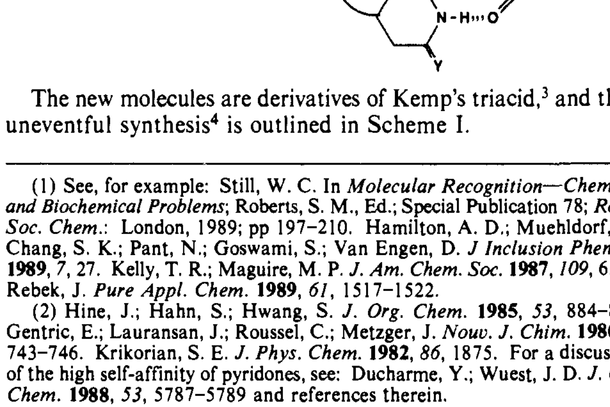
Intermolecular forces, particularly hydrogen bonds, lie at the heart of molecular-recognition phenomena. Synthetic receptors for biorelevant targets provide a means by which the relative hydrogen-bonding capacities of donor and acceptor pairs can be addressed.[1] We compare here imides with lactams and find that the latter show greater hydrogen-bonding affinities. The reduced affinity of imides is apparently related to destabilizing interactions involving the spectator carbonyl.

Previous work[2] with such functionality has established that, in $CDCl_3$, the self-association, or dimerization, is so weak that it is difficult to measure. It is possible, by arranging an intramolecular system (cyclization) (eq 1), to magnify the association to a conveniently measurable level and assess differences at the subkilocalorie level.



(1)

The new molecules are derivatives of Kemp's triacid,[3] and their uneventful synthesis[4] is outlined in Scheme I.

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(1) See, for example: Still, W. C. In *Molecular Recognition—Chemical and Biochemical Problems*; Roberts, S. M., Ed.; Special Publication 78; *Royal Soc. Chem.*: London, 1989; pp 197-210. Hamilton, A. D.; Muehldorf, A.; Chang, S. K.; Pant, N.; Goswami, S.; Van Engen, D. *J Inclusion Phenom.* **1989**, *7*, 27. Kelly, T. R.; Maguire, M. P. *J. Am. Chem. Soc.* **1987**, *109*, 6549. Rebek, J. *Pure Appl. Chem.* **1989**, *61*, 1517-1522.

(2) Hine, J.; Hahn, S.; Hwang, S. *J. Org. Chem.* **1985**, *53*, 884-887. Gentric, E.; Lauransan, J.; Roussel, C.; Metzger, J. *Nouv. J. Chim.* **1980**, *4*, 743-746. Krikorian, S. E. *J. Phys. Chem.* **1982**, *86*, 1875. For a discussion of the high self-affinity of pyridones, see: Ducharme, Y.; Wuest, J. D. *J. Org. Chem.* **1988**, *53*, 5787-5789 and references therein.

(3) Kemp, D. S.; Petrakis, K. S. *J. Org. Chem.* **1981**, *46*, 5140. Commercially available from the Aldrich Chemical Co. For a convenient synthesis, see: Rebek, J., Jr.; Askew, B.; Killoran, M.; Nemeth, D.; Lin, F.-T. *J. Am. Chem. Soc.* **1987**, *109*, 2426-2431.

Scheme I

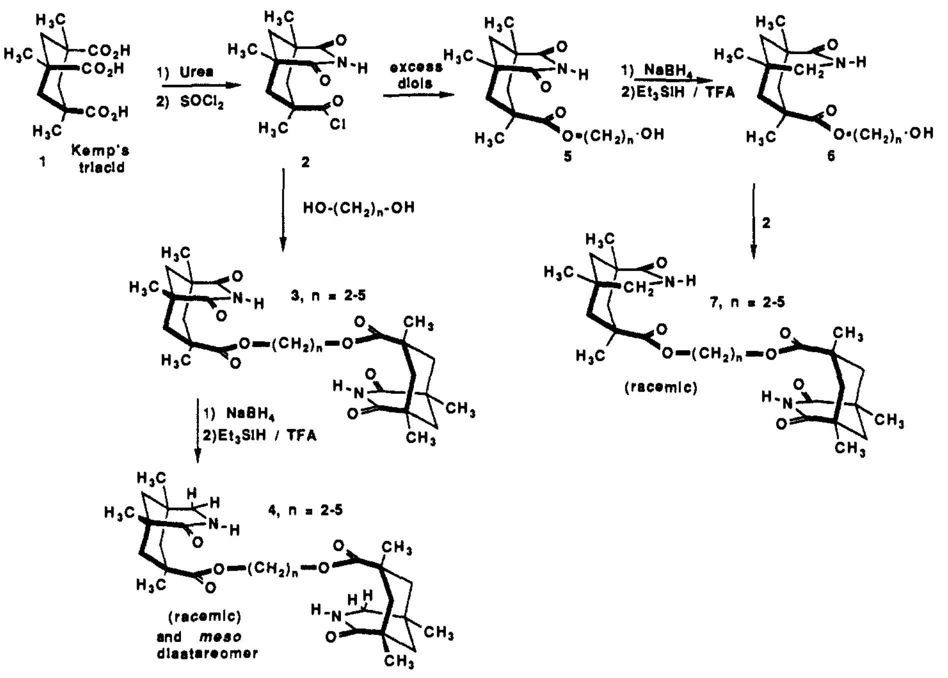
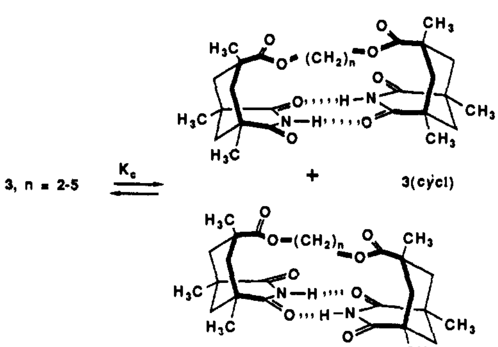


Table I. Cyclization Data, $CDCl_3$, 25 °C

	imide–imide (eq 2)	lactam–lactam (eq 3)	lactam–imide (eq 4)	
ν free	7.42	5.1	5.1	7.42
ν cyclic	10.40	8.6	7.54	11.93

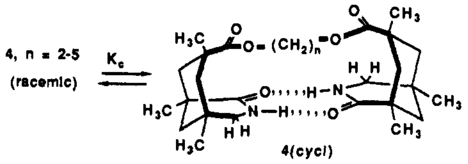
	imide–imide (eq 2)				lactam–lactam (eq o)			lactam–imide (eq 4)		
n	ν_{obsd}	% cyclic	K_{obsd}	K_{calcd}(corr)	ν_{obsd}	% cyclic	K_{calcd}	ν_{obsd}	% cyclic	K_{calcd}
2	9.29	63	1.7	0.85	8.11	86	6.1	6.92/10.87	75	3
3	9.90	83	5.2	2.6	8.47	96	24	7.23/11.47	87–90	8
4	8.36	32	0.45	0.22	6.76	48	0.92	5.75/9.42	27–44	0.43–0.78
5	8.59	39	0.64	0.32	7.04	55	1.2	6.06/9.46	39–45	0.66–0.82

The chemical shifts of the exchangeable protons were found to be concentration independent in **3**, **4**, or **7**. The NMR data for free and bound forms is given in Table I, along with the association constants observed at 25 °C. The values for the imide–imide interaction were statistically corrected since there are two ways for the complex to form (eq 2). It was assumed[5] that hydrogen bonds occurred in pairs throughout this study.

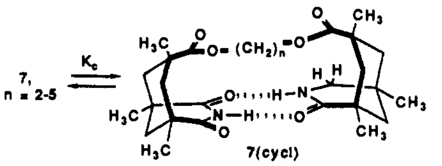


(2)

The lactams[6] consistently show a higher tendency to self-associate (eq 3) than the corresponding imides, even though the latter have the statistical advantage. In the hybrid structures **7**, the tendency to cyclize was between those of the diimides and dilactams. The values reported are calculated independently from the two chemical shifts; the range may indicate that some single hydrogen bonds exist in the C_4 and C_5 species of eq 4.



(3)



(4)

The overall results show the favorable effect of lactams in cyclic hydrogen-bonded arrays, compared to imides. Jorgensen[7] has recently proposed that secondary interactions alter the effective strength of hydrogen bonds. For the cases at hand, e.g., **8** and **9**, the spectator oxygens of the imides are expected to destabilize the hydrogen-bonded array as shown. If this be the cause, each such interaction costs the system ca. 0.4 kcal/mol under these conditions. The enhanced acidity of the imide NH is of no advantage in hydrogen bonding to imides or lactams, whereas it is an important factor in base-pairing to adenines.[8] The implications

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(4) All new compounds were characterized by a full complement of high-resolution spectra.

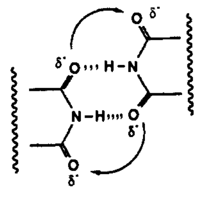
(5) Molecular modeling indicated that cyclic hydrogen-bond arrays were geometrically feasible for all of the molecules; the C_4 spacers, however, experienced eclipsing in such structures.

(6) The meso and racemic forms of **4** were readily separated by chromatography; the meso compounds showed N–H resonances between 5.26 and 6.0 ppm, consistent with very little self-association.

(7) Jorgensen, W.; Pranata,' J. *J. Am. Chem. Soc.*, in press.

(8) See, for example: Kyogoku, Y.; Lord, R. C.; Rich, A. *Proc. Natl. Acad. Sci. U.S.A.* **1967**, *57*, 250–257.

are that lactams or, more generally, amides will be better complements to peptides in the design of structures for their molecular recognition.



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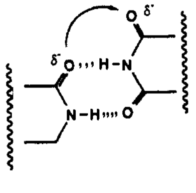

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Acknowledgment. We thank the National Institutes of Health for support and Professor W. Jorgensen for helpful discussions.

Absolute Kinetics of Dichlorocarbene in Solution[†]

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Dichlorocarbene is the cornerstone of singlet carbene reactivity. Moss has thoroughly characterized carbenic selectivity in cyclopropanation reactions.[1,2] The reactivity of any singlet carbene (:CXY) may be standardized by comparison of its reactivity toward a "standard" set of alkenes with that of dichlorocarbene ($:CCl_2$). Amazingly, however, the absolute kinetics of this important reactive intermediate have not been measured to date.[3] This is primarily due to the lack of a suitable photolabile precursor. Herein, we report a clean photolytic source of $:CCl_2$ and the first absolute rate constants for reaction of $:CCl_2$ with olefins in solution.

7,7-Dichlorodibenzo[*a*,*c*]bicyclo[4.1.0]heptane (**1**)[4] proves to be a suitable photochemical source of $:CCl_2$.[5,6] UV (280 nm) photolysis of 1×10^{-3} M **1** in hexane generates phenanthrene (**2**) with a quantum efficiency of 0.078[7] and essentially quantitative chemical yield. Under similar conditions, photolysis of **1** in cyclohexene yields the $:CCl_2$ adduct (**3**) in ≥90% yield. A clean photoextrusion of $:CCl_2$ is also indicated by production of **2** and **3** as the principal products[8] following 266-nm laser irradiation of 1×10^{-4} M **1** in cyclohexene. Encouraged by these results and with hope of direct optical detection of $:CCl_2$ in solution,[9] we used laser flash photolysis (LFP) to investigate the photodecomposition of **1** in cyclohexane (C_6H_{12}) (Scheme I).

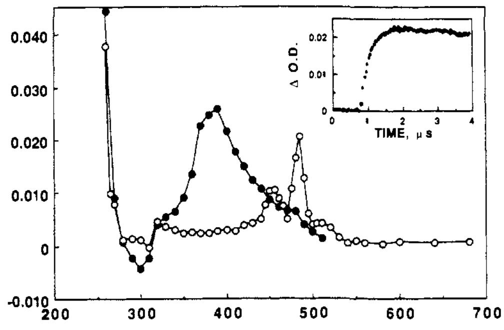

Figure 1. Transient absorption spectra observed 1.02 and 1.13 μs after 266-nm LFP of 5×10^{-5} M **1** in N_2-saturated C_6H_{12} (○) and 1×10^{-4} M **1** in air-saturated C_6H_{12} containing 5.24×10^{-4} M pyridine (●), respectively. Insert shows a representative single-exponential growth ($k_{\text{exptl}} = 4.1 \times 10^6$ s^{-1}) of pyridinium ylide **4** monitored at 400 nm.

Scheme I

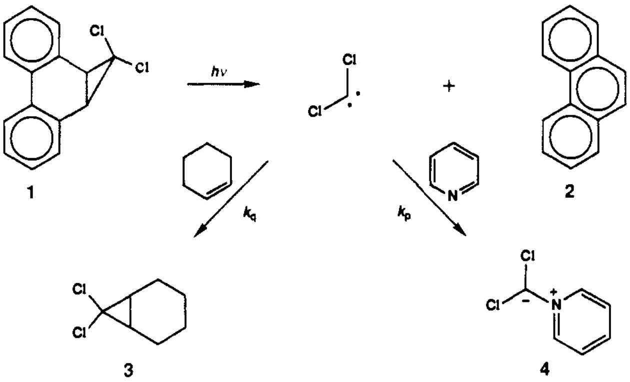

Table I. Absolute Rate Constants for Reaction of Dichlorocarbene[a] and Phenylchlorocarbene[b] with Olefins

substrate	$:CCl_2$ k,[c] $M^{-1}\,s^{-1}$	$Ph\ddot{C}Cl$ k, $M^{-1}\,s^{-1}$
$Me_2C{=}CMe_2$	$(3.81 \pm 0.16) \times 10^9$	2.8×10^8
$MeCH{=}CMe_2$	$(2.23 \pm 0.24) \times 10^9$	1.3×10^8
trans-$MeCH{=}CHEt$	$(6.31 \pm 0.63) \times 10^7$	5.5×10^6
c-C_6H_{10}	$(3.50 \pm 0.12) \times 10^7$	
$CH_2{=}CH$-*n*-C_4H_9	$(1.08 \pm 0.05) \times 10^7$	2.2×10^6

[a] This work, measured by monitoring the competitive kinetics of formation of pyridinium ylide **4** at 400 nm in cyclohexane at 21 °C; see text. [b] Data taken from ref 23. Rates were measured in isooctane. [c] Errors represent ±2 standard deviations.

Unfortunately, LFP (266 nm, ~8 mJ)[10] of 5×10^{-5} M **1** in N_2-saturated C_6H_{12} does *not* result in an absorption band in the 250–750-nm regime that can be attributed to singlet $:CCl_2$.[11] Instead, the well-known triplet–triplet absorption spectrum of phenanthrene (λ_{max} = 485 nm, shoulder = 460 nm)[12] is observed

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[†] This paper is dedicated to Professor Wolfgang Kirmse on the occasion of his 60th birthday.

(1) For a review of carbene selectivity, see: Moss, R. A. *Acc. Chem. Res.* **1980**, *13*, 58–64.

(2) See also: (a) Moss, R. A.; Jones, M., Jr. *Reactive Intermediates*; Jones, M., Jr., Moss, R. A., Eds.; Wiley-Interscience: New York, 1981; Vol. 2, Chapter 3. (b) Moss, R. A.; Jones, M., Jr. *Reactive Intermediates*; Jones, M., Jr., Moss, R. A., Eds.; Wiley-Interscience: New York, 1978; Vol. 1, Chapter 3. (c) Moss, R. A., Jones, M., Jr., Eds. *Carbenes*; Wiley-Interscience: New York, 1975; Vol. II. (d) Moss, R. A., Jones, M., Jr., Eds. *Carbenes*; Wiley-Interscience: New York, 1973; Vol. 1. See, in particular: Moss, R. A. *Ibid.* Chapter 2. (e) Kirmse, W. *Carbene Chemistry*, 2nd ed.; Academic Press: New York, 1971. (f) Hine, J. *Divalent Carbon*; Ronald Press: New York, 1964.

(3) For reports of gas-phase fluorescence quenching rates of $:CCl_2$, see: Tiee, J. J.; Wampler, F. B.; Rice, W. W., Jr. *Chem. Phys. Lett.* **1980**, *73*, 519–521. Huie, R. E.; Long, N. J. T.; Thrush, B. A. *Ibid.* **1977**, *51*, 197–200.

(4) The synthesis of **1** has been previously described. Joshi, G. C.; Singh, N.; Pande, L. M. *Synthesis* **1972**, 317.

(5) Photolysis of the parent hydrocarbon, 9,10-dihydro-9,10-methanophenanthrene, generates products identical with those from photolysis of diazomethane. Richardson, D. B.; Durrett, L. R.; Martin, J. M., Jr.; Putman, W. E.; Slaymaker, S. C.; Dvoretzky, I. *J. Am. Chem. Soc.* **1965**, *87*, 2763–2765.

(6) For a review of carbene generation by photochemical cycloelimination, see: Griffin, G. W. *Angew. Chem., Int. Ed. Engl.* **1977**, *10*, 537–547.

(7) Determined by potassium ferrioxalate actinometry.

(8) Determined by comparison with authentic samples of **2** and **3** by GC analysis.

(9) There has been a report of a weak absorption spectrum, ranging from 440 to 560 nm, that was attributed to $:CCl_2$, formed by the reaction of carbon atoms with molecular chlorine in Ar and N_2 matrices at 14 K. Milligan, D. E.; Jacox, M. E. *J. Chem. Phys.* **1967**, *47*, 703–707.

(10) The LFP equipment is described elsewhere. Nagarajan, V.; Fessenden, R. W. *J. Phys. Chem.* **1985**, *89*, 2330–2335.

(11) Reactivity is not expected from the lowest triplet $:CCl_2$, which is predicted to be 13.5 kcal/mol above ground-state singlet $:CCl_2$. Bauschlicher, C. W., Jr.; Schaefer, H. F., III; Bagus, P. S. *J. Am. Chem. Soc.* **1977**, *99*, 7106–7110.

0002-7863/90/1512-3217$02.50/0