Flavins as modular and amphiphilic probes of silica microenvironments

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The amphiphilic and solvochromatic characteristics of flavins are utilized as a non-invasive polarity sensor for silica-based media.

Zeolites, molecular sieves and other porous media are crucial components in catalysis and separation technology.[1,2] In these systems, surface structure is a key determinant of performance. To determine surface and pore polarities, both silicas[3] and sol–gels[4] have been doped with various dyes. These dyes have generally relied upon large hydrophobic aromatic groups, with charged functionality as the sensing element. This creates the potential for perturbation of local environments through both dopant size and functionality.[5]

N^{10}-isobutyl flavin **1** (Fig. 1) and flavin mononucleotide (FMN) **2** possess isoalloxazine units with highly solvochromic S_0–S_2 transitions: λ_{max} (FMN) **2** occurs at 374 nm in aqueous media and 358 nm in ethanolic solution,[6] while λ_{max} (**1**) occurs at 349 nm in chloroform and 335 nm in carbon tetrachloride.[7] The amphiphilicity of the heterocyclic flavin nucleus plays two key roles in microenvironment sensing. First, it allows solublization without aggregation[8] in virtually any solvent using non-interfering sidechains at the N^{10} position. Second, it provides a non-invasive probe for the characterization of dynamic media. We report here the application of flavins **1** and **2** as solvochromic probes of silicate microenvironments.

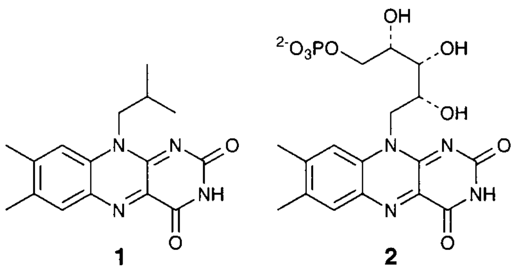
In initial investigations, we explored the environment of silica gel environment. Flavin **1** in chloroform has a λ_{max} of 349 nm (Fig. 2). When commercial grade silica gel[9] was soaked with a chloroform solution of **1** (providing an approximate matching of refractive index), the λ_{max} shifted to 374 nm, indicating the flavin was responding as expected to the polar surface of the silica gel.

In further studies, we used flavin to probe the polarity of 'MCM-type' silicates. The final preparation of these porous silica materials involves calcination at high temperatures in which the polar Si–OH functionalities on the interior silica surface revert to Si–O–Si *via* dehydration.[10] When a non-calcined, templated silica material[11] was soaked with a chloroform solution of **1**, the λ_{max} (S_0–S_2) was 374 nm. This indicates that the surface was highly polar with surface functionality consisting primarily of Si–OH groups. However, the λ_{max} occurred at 349 nm with a calcined MCM-41 type material,[12] confirming no interaction between the flavin and the interior surface (Fig. 2). This is consistent with the low surface density (8–27%) of silanols present in calcined MCM-41.[13]

With the ability of flavin to sense polarity in preformed, static environments established, we next explored the application of this sensing methodology to dynamic systems. Previous studies had seen relatively minor changes in polarity in silicate matrices during their formation *via* the sol–gel process, a result that could arise from 'templating' effects by the sensing molecule. To explore polarity changes in these systems, flavin silicate sols were prepared by the addition of aqueous solutions of flavin **2** to tetramethylorthosilicate. After sonication, homogeneous and transparent yellow sols were obtained which subsequently solidified yielding the flavin **2** functionalized sol–gels. In these gels, the flavin provides a direct probe the polarity of the microenvironment within the developing sol–gel silicate. In the sol phase, the λ_{max} of flavin **2** occurred at 374 nm, confirming the essentially aqueous nature of the sol–gel at preparation. Polarity changes indicative of a two-step transformation were observed. During the initial stages of gelation a large decrease in polarity was observed, arising from release of methanol during orthosilicate hydrolysis. After this initial phase, the λ_{max} moved steadily to shorter wavelengths, reaching a limiting value of 360 nm (Fig. 3). This slower process can be attributed to the decrease in silanol concentration during the formation of the silicate matrix.

When these methanol-rich sol–gels were allowed to dry under ambient conditions, the λ_{max} shifted to longer wavelengths, reaching a final value of 370 nm (Fig. 3). This red shift arises from the diffusion of methanol out of the silicate matrix, resulting in shrinkage of the silicate structure.[14] Constricting the region surrounding the flavin. In consequence, the polar Si–OH functionalities of the silicate matrices interact with the immobilized flavin, creating a microenvironment slightly less polar than water.[15]

In conclusion, we have shown flavins nucleus to be extremely capable microenvironmental probes of silicate-based media. The amphiphilicity and solvochromicity of the isoalloxazine nucleus, coupled with its non-invasive nature, make these



1 **2**

Fig. 1 N^{10}-*iso*butyl flavin **1** and flavin mononucleotide (FMN) **2**.

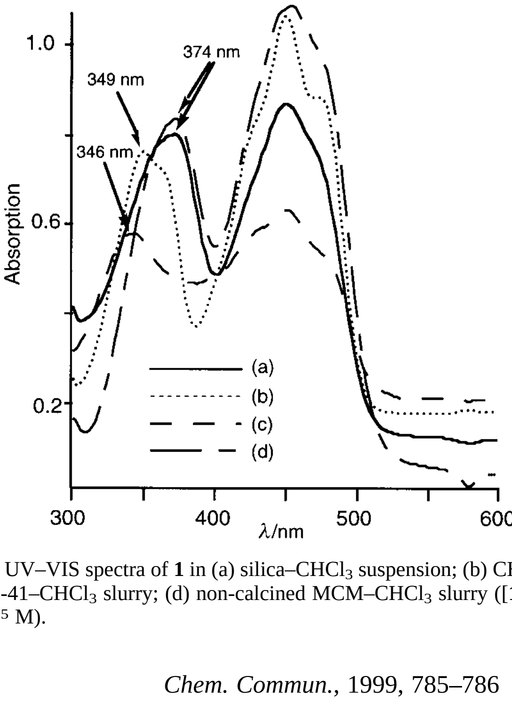


Fig. 2 UV–VIS spectra of **1** in (a) silica–$CHCl_3$ suspension; (b) $CHCl_3$; (c) MCM-41–$CHCl_3$ slurry; (d) non-calcined MCM–$CHCl_3$ slurry ([**1**] = 7.0 $\times 10^{-5}$ M).

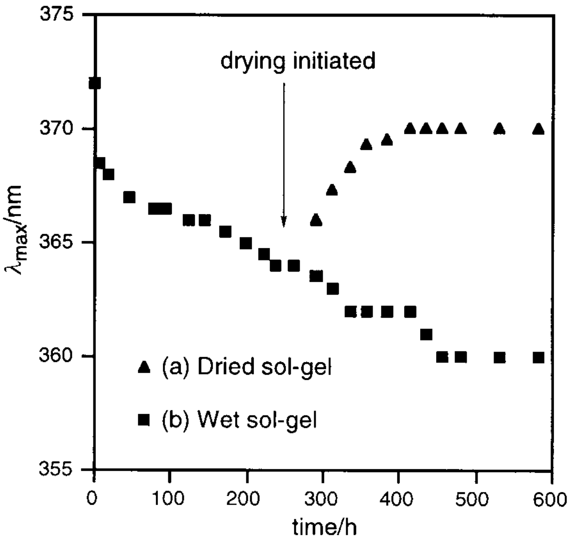


Fig. 3 Plot of λ_{max} for the S_0–S_2 transition of **2** as a function of sol–gel formation.

systems effective probes of polarity for both static and dynamic systems.

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