Studies on the inclusion complexation between intramolecular charge transfer probe *trans*-ethyl *p*-(dimethylamino) cinamate and β-cyclodextrin in presence of ionic and nonionic surfactants

T. Sanjoy Singh [a], Sivaprasad Mitra [b,*]

[a] Department of Chemistry, Assam University, Silchar – 788011, India
[b] Department of Chemistry, North-Eastern Hill University, Shillong 793022, India

ABSTRACT

The intramolecular charge transfer (ICT) fluorescence of *trans*-ethyl *p*-(dimethylamino) cinamate (EDAC) is used to monitor the complexation behavior of this probe with surfactants/β-CD by steady state and picosecond time-resolved fluorescence spectroscopy. The ICT fluorescence band intensity was found to increase with concomitant blue shift in presence of surfactants/β-CD. The encapsulation behavior was further characterized by increase in emission yield as well as lifetime values. Detailed analyses of the spectroscopic data indicate that the probe forms 1:1 complex with β-CD in aqueous medium. However, in presence of surfactants, 1:1 complex is formed below the critical micelle concentration (cmc) value; whereas, 1:2 complexes are formed under fully micellized condition.

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1. Introduction

Cyclodextrins are cyclic compounds containing six to eight glucose units, popularly known as α-, β-, or γ-cyclodextrin, respectively. They are known to form inclusion complexes with various low-molecular weight compounds, ranging from nonpolar aliphatic molecules to polar amines and acids [1]. Recently, much attention has been devoted to cyclodextrins as cyclic component for the construction of supramolecular architecture because of their well-defined ring structure and affinity for different class of compounds with varying size and shape. Although, cyclodextrins are known to form inclusion complexes with large compounds like metallocenes or polymers in different mechanisms [2,3], a large variety of organic molecules act as guest to form stable molecular assemblies inside the cyclodextrin nanocavities due to the so called "hydrophobic effect" [4]. The unique property of cyclodextrins to encapsulate organic compounds inside its hydrophobic central cavity makes them potential candidate as extremely efficient molecular vehicles for drug delivery. Furthermore, the reduced polarity and restricted geometry of the interior

cyclodextrin cavities give an opportunity to study different photo-physical properties in tailored environmental conditions. Non-covalent intermolecular forces are believed to play a key role on the complex formation and its stabilization. This leads to widespread application in pharmaceutical chemistry, food technology, analytical chemistry, chemical synthesis and catalysis [5–7].

Inclusion complexes formed between surfactants and CDs have also received a lot of attention [8–35], partly because these systems can be used to mimic the effect of cyclodextrins on phospholipids, a major constituent of cell membrane [36,37]. The long organic chains (tail group) of surfactants tend to reside in the hydrophobic cavity of cyclodextrins and for ordinary surfactants, 1:1 and 1:2 surfactant–cyclodextrin complexes are believed to exist [37–39]. Very recently, Lu et. al. [40] used the supramolecular assembly of β-CD and nonionic surfactant TX-100 as a precursor to synthesize mesoporous silica microtubules.

The inclusion complexes between surfactants and CDs have been studied by a number of physical methods such as fluorescence spectroscopy [8–10,15,18,20,22,23], NMR [24,25], conductivity [26,27], surface tension [12,28,29], isothermal titration calorimetry [14], ultrasonic relaxation [30,31], UV–visible spectroscopy [32,33], induced circular dichroism (ICD) [34] and electromotive force [35]. However, the reported interaction patterns and the association constants of cyclodextrin with the same surfactants are greatly different depending on which physical method

* Corresponding author. Tel.: +91 364 272 2634; fax: +91 364 255 0486.
  E-mail addresses: smitra@nehu.ac.in, smitranehu@gmail.com,
sivaprasadm@yahoo.com (S. Mitra).
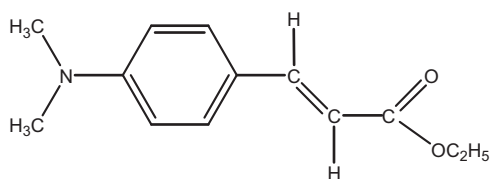
Scheme 1. Structure of *trans*-ethyl *p*-(dimethylamino) cinamate (EDAC).

has been used. Park et. al. [8,9] was the first to suggest for competitive method using a fluorescent probe which gave reasonable results since they were based on better theoretical models [11].

Intramolecular charge transfer (ICT) process in electron donor–acceptor systems seems to be extremely important phenomenon in chemistry and biology. The extreme sensitivity of charge transfer probes to polarity prompted a large number of studies of this process in a variety of cyclodextrin cavity [41–46]. In a recent study, it was found that the ICT probe *trans*-ethyl *p*-(dimethylamino) cinamate (EDAC, scheme 1 for structure) is extremely sensitive to solvent polarity and that the fluorescence properties show very good correlation with solvent polarity parameter [47]. The characterization of locally excited (LE) and ICT states was done and the change in dipole moment in the ground and excited states were calculated from steady state spectral measurements in a series of solvents. The large change in ICT fluorescence spectra with solvent polarity prompts us to use EDAC as a probe to study the encapsulation in β-CD cavity. The complexation behavior of EDAC–CD and binding properties of EDAC in β-CD as host were compared with the complexation behavior of EDAC–CD and binding properties of EDAC in presence of ionic and nonionic surfactants.

2. Experimental

The synthesis and purification of ICT probe (*trans*)-ethyl *p*-(dimethylamino) cinamate (EDAC) was described elsewhere [47]. β-cyclodextrin was obtained from Aldrich Chemical Co., and used as received without further purification. Nonionic (triton-X 100, TX-100), anionic (sodium dodecyl sulfate, SDS) and cationic (cetyltrimethyl ammonium bromide, CTAB) surfactants were all obtained from Aldrich Chemical Co., and used as received without further purification. The water used as solvent in all the measurements was obtained from Elix10 water purification system (Millipore India Pvt., Ltd.).

Steady-state absorption spectra were recorded on a Perkin-Elmer model Lambda25 absorption spectrophotometer. Fluorescence spectra were taken in a Hitachi model F-4500 spectrofluorimeter and all the spectra were corrected for the instrument response function. Quartz cuvettes of 10 mm optical path length received from Perkin-Elmer, USA (part no. B0831009) and Hellma, Germany (type 111-QS) were used for measuring absorption and fluorescence spectra, respectively. In both fluorescence emission and excitation spectra measurements, 5 nm bandpass was used in the excitation and emission side. Fluorescence quantum yields (ϕ_f) were calculated by comparing the total fluorescence intensity under the whole fluorescence spectral range with that of a standard (quinine sulfate in 1 M sulfuric acid) using the following equation as described before [48].

$$\varphi_f^i = \varphi_f^s \frac{F^i}{F^s} \frac{1-10^{-A^s}}{1-10^{-A^i}} \left(\frac{n^i}{n^s}\right)^2 \tag{1}$$

where, A^i and A^s are the optical density of the sample and standard, respectively and n^i is the refractive index of solvent at 293 K.

Time-resolved fluorescence decay properties of the cyclodextrin encapsulated fluorophores in presence of fixed surfactants concentration were measured by picosecond time correlated single photon counting (TCSPC) technique as implemented in the time-resolved spectrofluorimeter FL-920 (Edinburg Instruments, UK). The samples were excited at 365 nm and emission was collected with magic angle configuration at the respective fluorescence peak position using 4096 channels with 10 ns time window. The instrument response function (IRF, FWHM ~100 ps) was calculated using a dilute solution of ludox and by collecting the emission at the excitation wavelength. The experimentally obtained fluorescence decay traces, $I(t)$, were analyzed by the non-linear least-square iterative convolution method based on Lavenberg–Marquardt algorithm and expressed as a sum of exponentials with Eq. (2).

$$I(t) = \sum_i \alpha_i \exp(-t/\tau_i) \tag{2}$$

where, α_i is the amplitude of the ith component associated with fluorescence lifetime τ_i such that $\sum \alpha_i = 1$.

3. Results and discussion

3.1. Interaction of EDAC with different heterogeneous media

3.1.1. In surfactants

The absorption spectrum of aqueous solution of EDAC shows a broad and unstructured band with the maximum centered at ~365 nm and the fluorescence emission spectra maximum at 485 nm which is originated from the intramolecular charge transfer state [48]. The absorption maxima for the aqueous solutions of EDAC were practically unaffected in presence of surfactants; whereas, the fluorescence spectra were strongly dependent on the amount of surfactants in solution (Table 1). Gradual addition of surfactants (SDS, CTAB and TX-100) is associated with a blue shift in the emission maximum along with an increase in fluorescence quantum yield (Fig. 1) suggesting that the

Table 1
Spectral characteristics and quantum yield of fluorescence of EDAC in various environments at pH=7.2 (buffer solution).

Medium	λ_{abs}[a] (nm)	λ_{fl}[b] (nm)	$\Delta\nu_{FWHM}$[c] (cm^{-1})	$\Delta\nu_{0,0}$[d] (cm^{-1})	$\Delta\nu_{SS}$[e] (cm^{-1})	ϕ_F[f] (10^{-3})
Water	360	485	2638	23,191	7159	3.2
3.98 mM SDS	363	482	2860	21,964	6801	4.9
15.6 mM SDS	370	464	2805	23,868	5475	38.6
0.46 mM CTAB	363	480	3044	22,727	6714	6.9
5.24 mM CTAB	370	461	2804	24,114	5335	76.8
0.15 mM TX-100	364	482	3061	23,572	6725	5.9
0.5 mM TX-100	366	453	3394	25,236	5247	35.8
3.98 mM SDS +8.2 mM β-CD	384	450	2947	22,677	3819	52.9
15.6 mM SDS +8.2 mM β-CD	369	463	2869	23,918	5501	40.1
0.46 mM CTAB +6.5 mM β-CD	384	452	3179	22,922	4396	37.7
5.24 mM CTAB +12.3 mM β-CD	369	462	2914	24,158	4976	78.3
0.15 mM TX-100 +9.6 mM β-CD	385	452	3173	23,654	3850	58.6
0.5 mM TX-100 +9.5 mM β-CD	370	460	3489	25,254	5287	45.1

[a] Absorption maxima.
[b] Fluorescence maxima.
[c] Fluorescence spectral width at half maximum.
[d] Intersection of normalized absorption and fluorescence emission spectra.
[e] Stokes shift.
[f] Fluorescence yield.