

Self-Assembly of Nonionic Surfactant Tween 20@ 2β -CD Inclusion Complexes in Dilute Solution

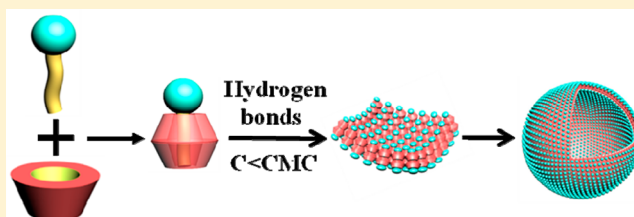
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Supporting Information

ABSTRACT: It has long been considered that the addition of cyclodextrins (CDs) disfavors the self-assembly of surfactants in dilute solutions since the hydrophobic effect is destroyed upon the formation of the hydrophilic CD/surfactant inclusion complex. However, in this work, we found that β -CD/nonionic surfactant inclusion complexes are able to self-assemble into vesicles in dilute solutions, namely in solutions with concentration lower than the CMC of surfactants. When using Tween 20 as a model surfactant, HNMR and MS measurements indicate that the building block for the vesicles is the channel type Tween 20@ 2β -CD inclusion complex. Structure and IR analysis suggests that the self-assembly of hydrophilic Tween 20@ 2β -CD is driven by H-bonds between both the headgroup of Tween 20 and the hydroxyl groups of β -CD. The self-assembly of the inclusion complex between the β -CD and the nonionic surfactant in dilute solution is found to be a general phenomenon. Undoubtedly, surfactant@ 2β -CD inclusion complex can be a novel building block for nonamphiphilic self-assembly, which provides a new physical insight for the influence of cyclodextrins on the self-assembly of surfactants.



INTRODUCTION

Cyclodextrins (CDs) are oligosaccharides of six, seven, or eight D-glucopyranose units (named as α , β , and γ -CD, respectively) linked by α -1,4 glycoside bonds, which form a doughnut ring structure with a hydrophilic exterior and a hydrophobic cavity.¹ The hydrophobic cavity is an ideal harbor in which poorly water-soluble molecules can shelter their hydrophobic parts.² Therefore, CDs are able to form host–guest complexes with most surfactants by including their hydrophobic tails into the cavities.^{3,4} Due to the hydrophilic nature of the outer surface of the cyclodextrin, the surfactant/CD inclusion complex is a soluble entity.^{2,5} As a result, the hydrophobic effect is destroyed after addition of CDs into the aqueous solution of surfactants, which results in disassembly of aggregates formed by surfactants in dilute solution. For instance, the micelles are known to be broken upon addition of α or β -CD in aqueous solution of many surfactants.^{2,3,6,7}

However, recently, Jiang et al. reported that in concentrated or semiconcentrated solutions, cyclodextrin/ionic surfactant (CD/IS) inclusion complexes can spontaneously self-assemble into lamellar structures, annular-ring tubes, and vesicles, depending on the total mass concentration. These self-assemblies were driven exclusively by H-bonds, but ionic repulsion was considered crucial for their stability.^{4,8} Nonionic surfactant/CD inclusion systems only leads to precipitates due to the less of sufficient repulsive forces between the head groups.^{4,8} In contrast, a recent report by Xu et al. reveals that vesicles can be formed as well in the semiconcentrated inclusion system of nonionic surfactant Triton X114 and β -CD.⁹ This implies that the electrostatic repulsion is

perhaps not necessarily required in building self-assembled structures in surfactant/CD inclusion systems. Then a question arises: is it general for the surfactant/CD inclusion complexes to self-assemble in water? Do they still self-assemble in dilute solution? Obviously, fundamental work has to be carried out to understand the solution behaviors of surfactant/CD inclusion complexes.

Herein, we report on the first systematic study on the self-assembling properties of nonionic surfactant/CD inclusion complexes. Tween 20 is selected as the model surfactant. We found that self-assembly may occur for the Tween 20: CD = 1:2 inclusion system where the concentration of Tween 20 is as low as 0.03 mM. This extremely low concentration indicates that the surfactant/CD inclusion complex may behave as a building block for molecular self-assembly even in dilute solutions, which is very different from the literature results to date.^{6,10,11} Since hydrogen bonding is the predominant driving force for the self-assembly in this system, the surfactant/CD inclusion complexes can be used as bricks to build nonamphiphilic self-assemblies.^{8,9} Such supramolecular self-assemblies can be degraded with α -amylase and are stable in the presence of ethanol. This greatly facilitates their application in food, cosmetics, and pharmaceuticals.^{12–14} In addition, we found that such self-assembling ability is universal when Tween 20 is replaced with other nonionic

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surfactants such as AEO 3, AEO 9, Tween 40, Tween 60, Tween 80, and Triton X100 in the inclusion system.

EXPERIMENTAL SECTION

Materials. Polysorbate 20 (Tween 20, analytical grade) was purchased from China Pharmaceutical Co. and used as received. β -Cyclodextrin (β -CD) with a water content of 14% and Rhodamine B were purchased from Sinopharm Chemical Reagent Co. Water (H_2O) used in this work was redistilled from potassium permanganate.

Sample Preparation. For concentrated or semiconcentrated samples, desired amounts of β -CD, Tween 20, and water were weighed into test tubes to obtain a constant β -CD/Tween 20 molar ratio of 2:1 and then the samples were heated to obtain isotropic solutions. Lower concentration samples were prepared by dilution of the semi-concentrated solutions. Then the solutions were thermostatically incubated at 25 °C (for at least 24 h) to allow Tween 20/ β -CD system self-assemble sufficiently.⁸

Characterization. Dynamic light scattering (DLS) measurements were conducted on an ALV/DLS/SL5022F light scattering-apparatus, equipped with a 22 mW He–Ne laser (632.8 nm wavelength) with a refractive index matching bath of filtered toluene surrounding the cylindrical scattering cell. The samples were filtered by 450 nm filters. The scattering angle was 90°.

The morphology of the self-assemblies was observed in a JEOL-100CX II transmission electron microscope (TEM). The samples were prepared with negative-staining and freeze-fracture methods. For a negatively stained specimen, a drop of sample was placed on 230 mesh copper grids coated with Formvar film. Excess water was removed with filter paper followed by negatively staining the film with uranyl acetate. After removal of the excess staining liquid by filter paper, the samples were placed at room temperature to dry for TEM observation. For freeze fractured ones, a small amount of sample was placed on a 0.1 mm thick copper disk and then covered with a second copper disk. The sample was frozen by plunging into liquid propane cooled by liquid nitrogen. Fracturing and replication were performed on a freeze-fracture apparatus (BalzersBAF400, Germany) at –140 °C. Pt/C was deposited at an angle of 45° to shadow the replicas, and C was deposited at an angle of 90° to consolidate the replicas. The resulting replicas were observed in a JEM-100CX electron microscope.

For ¹H NMR measurements, stock solutions of Tween 20 ($C = 0.5$ mM) and β -CD with different ratios were prepared in D₂O. For two-dimensional rotating frame nuclear Overhauser effect spectroscopy (ROESY) measurement, the D₂O solution which contains 1 mM Tween 20 and 2 mM β -CD was adopted. All of the measurements were performed on an AVANCE III 500 M Hz NMR (Bruker, Switzerland).

AFM measurements were performed in tapping mode under ambient condition on a Veeco D3100 AFM. FT-IR measurements were performed on Nicolet Magna IR 750 equipped with an infrared microspectrography. The sample solutions were dropped on the slide and then allowed to dry at room temperature before FT-IR measurements.

Encapsulation Measurements. Rhodamine B was chosen as a model guest which is hydrophilic. To encapsulate Rhodamine B into the cavity of the Tween 20/ β -CD vesicles ($C_{\text{Tween 20}} = 3$ mM, $C_{\beta\text{-CD}} = 6$ mM), 24 μ M Rhodamine B solution was used as solvent. Then the system was thermostatically incubated at 25 °C (for at least 24 h) to reach equilibrium. The unencapsulated Rhodamine B was removed by dialyzing the sample against the colorless empty Tween 20@ β -CD vesicle suspension. The dialysate was changed every 30 min. The separation process was completed when the UV–vis absorption of the dialysate at 554 nm vanished. The concentrations of encapsulated Rhodamine B before and after dialysis were determined for the working plot of Rhodamine B (554 nm). The encapsulation efficiency EE% was evaluated using this relation: $EE\% = C/C_0 \times 100\%$ (C and C_0 are the concentration of Rhodamine B before and after dialysis, respectively). The controlled release of Rhodamine B was realized by addition of α -amylase into the system. Two milliliters of Rhodamine B loaded vesicle suspension in the presence of 20 U/mL α -amylase was enclosed in a dialysis membrane and incubated in colorless empty Tween 20@ β -CD vesicle suspension. The empty vesicular suspension was changed at

regular time intervals, meanwhile the UV/vis absorbance at 554 nm for the suspension in the dialysis bag was measured.

RESULTS AND DISCUSSION

Macroscopic Phase Behavior of Tween 20/ β -CD Mixed Systems. With increasing concentration, the Tween 20/ β -CD mixed systems are divided into two regions. In region I ($C = 0.03$ –20 mM) (Figure 1a), the solutions are water-like

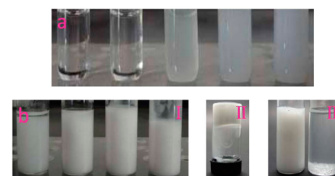


Figure 1. (a) Macroscopic photos of the Tween 20/ β -CD samples ($C_{\text{Tween 20}} = 0.15, 1, 3, 10, 15$ mM). (b) I macroscopic photos of Tween 20/ β -CD complexes ($C = 6, 10, 15, 25$ wt %) ($C_{\text{Tween 20}} = 20, 30, 50, 100$ mM), II The photos of Tween 20/ β -CD complexes ($C = 10$ wt %) ($C_{\text{Tween 20}} = 30$ mM, $C_{\beta\text{-CD}} = 60$ mM) in an inverted tube, III The macroscopic photos of Tween 20/ β -CD complexes ($C = 10$ wt %) ($C_{\text{Tween 20}} = 30$ mM, $C_{\beta\text{-CD}} = 60$ mM) and β -CD ($C_{\beta\text{-CD}} = 60$ mM).

but the turbidity increases with increasing concentration. In region II ($C = 6$ –25 wt %; 20–100 mM; Figure 1b), the solutions are opalescent and viscoelastic. At the concentration of 6 wt % ($C_{\text{Tween 20}} = 20$ mM, $C_{\beta\text{-CD}} = 40$ mM), the solution separates into two phases after incubated for about 96 h (Figure 1b). Further increase of concentration leads to whitish homogeneous viscoelastic phases. Control experiments indicate that the single solution of β -CD or Tween 20 does not phase separate at the same CD or Tween 20 concentration, suggesting that the macroscopic phase behavior in the Tween 20/ β -CD mixed systems originates from the inclusion complexes. In Figure 1b III, we show that the aqueous solution of β -CD is clear, whereas macroscopic phase transition occurs upon the addition of Tween 20, verifying the formation of Tween 20/ β -CD inclusion complex.

H NMR Study of the Complexation of β -CD with Tween 20. To confirm the formation of inclusion complexes between Tween 20 and β -CD, and to determine the complexation ratio, both 1D and 2D HNMR (ROESY) study were carried out.^{15–18} Because the complexation between host and guest molecules will result in significant encapsulation-induced chemical shifts of the guest molecules,¹⁹ determination of the complexation ratio between β -CD and Tween 20 and the association site becomes possible according to chemical shifts of protons (1D HNMR) in Tween 20.

Figure 2a shows that upon addition of β -CD to the Tween 20 solution, all of the ¹H NMR signals assigned to the protons in the alkyl chain of Tween 20 shift toward downfield, suggesting the inclusion of the alkyl chain to the cavity of β -CD, because the polarity for the cavity in β -CD is slightly larger than that for the hydrophobic core of micelles.¹ Meanwhile, both the chemical shift and the peak shape for protons in the ethylene oxide groups of Tween 20 keep unchanged, which indicates that ethylene oxide groups are not encapsulated into the cavity of β -CD.²⁰ In other words, Tween 20 was included into β -CD only with its alkyl chain. In accordance with this, only the signal correlations between the protons in the cavity of β -CD and those for the alkyl chain of Tween 20 were observed in a ROESY measurement (Figure 2b). This clearly confirms that host–guest interaction indeed occurred between β -CD and Tween 20.

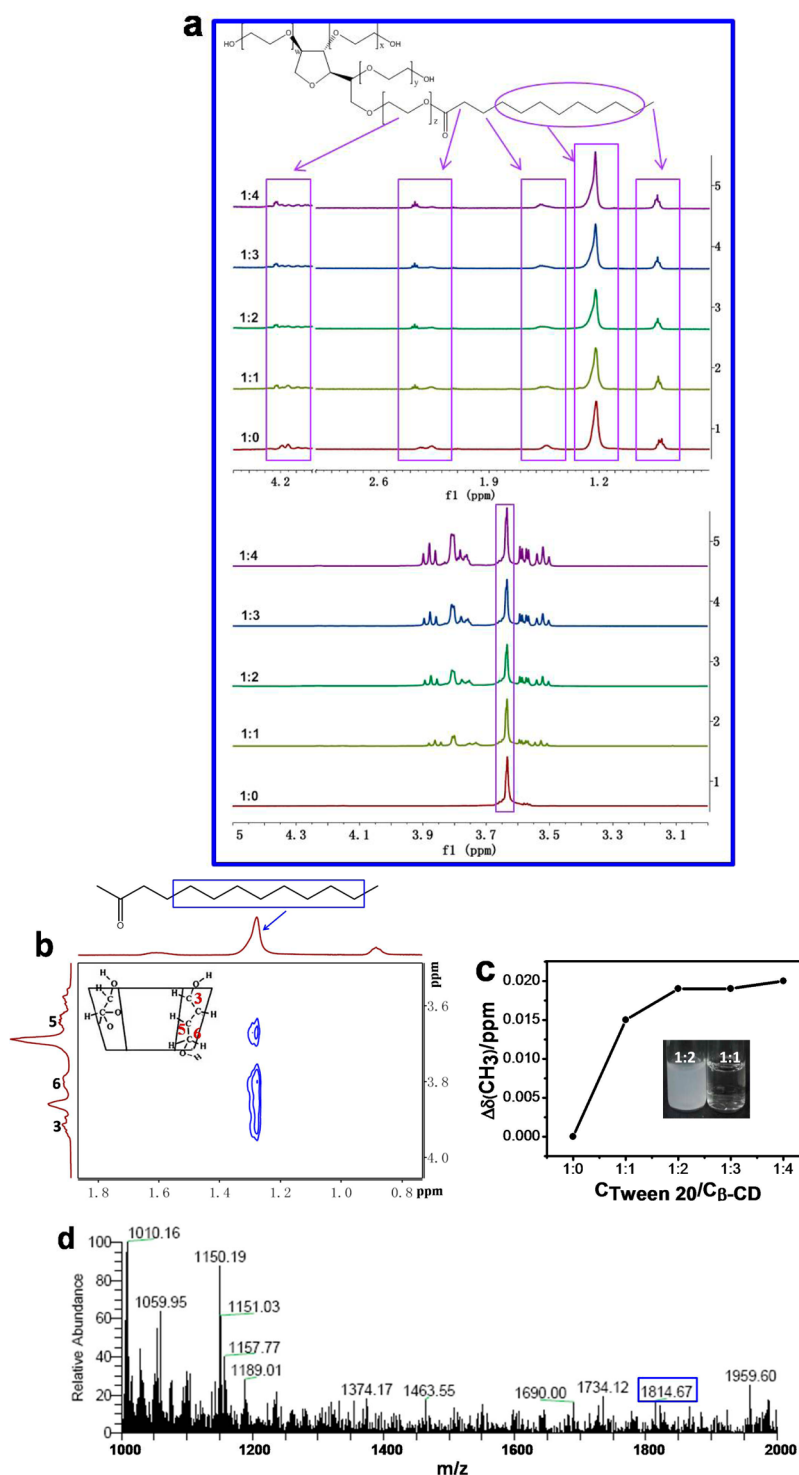


Figure 2. (a,b) 1D and 2D ^1H NMR results for the Tween 20/ β -CD mixed system. (c) The chemical shifts change of Tween 20s CH_3 versus Tween 20/ β -CD concentration ratios ($C_{\text{Tween 20}} = 0.5 \text{ mM}$). (d) The MS results of Tween 20/ β -CD complexes ($C_{\text{Tween 20}} = 1 \text{ mM}$) in positive mode.

The ^1H NMR measurements also allow determination the host: guest ratio in the inclusion complex. As demonstrated in Figure 2c, the chemical shift for CH_3 of Tween 20 keeps changing as Tween 20: β -CD ratio shifts from 1:0 to 1:2; the largest shift occurs at the ratio of 1:2, and remains almost unchanged with further increasing the ratio. Although the chemical shift change from the ratio 1:1 to 1:2 is not very large, the turbidity of 1:2 mixture is drastically increased in comparison with that of the 1:1 mixture (inset in Figure 2c).

Meanwhile, DLS results (Figure S1 of the Supporting Information, SI) also demonstrate that the aggregates at the ratio of 1:1 and 1:2 are completely different.²¹ Therefore, we infer that the stable and equilibrium inclusion complexes have the form of Tween 20@2 β -CD channel type inclusion complex, like the SDS@2 β -CD complex in our previous work.^{4,8}

To further determine the presence of Tween 20@2 β -CD inclusion complexes, MS measurements were carried out for the

1:2 mixture of Tween 20/ β -CD. As demonstrated in Figure 2d, a peak for $[\text{Tween 20} + 2\beta\text{-CD} + 3\text{H}_2\text{O} + 2\text{K}]^{2+}$ ($m/z = 1814.6$) is observed, verifying the existence of Tween 20@ 2β -CD.²¹ Other peaks in Figure 2d represent the fragments of Tween 20 @ 2β -CD.

Next, we examined the structure of the self-assemblies in the inclusion systems. It is worth noting that vesicles were observed in the β -CD/Tween 20 system even at the concentrations of Tween 20 as low as 0.03 mM (Figure 3a,b) which is far below the

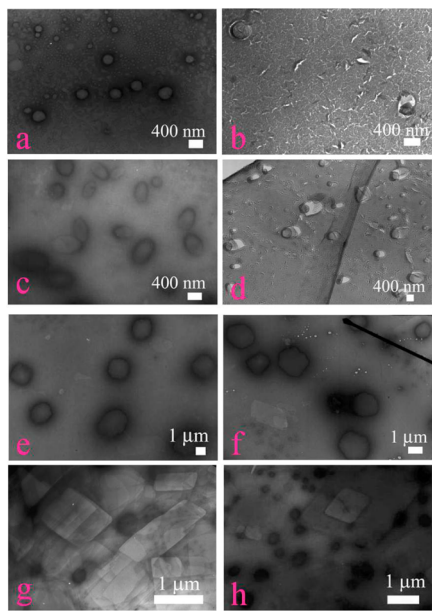


Figure 3. (a,b) TEM and FF-TEM images of 0.03 mM β -CD/Tween 20 system; (c) and (d) TEM and FF-TEM images of 1 mM β -CD/Tween 20 system, (e) TEM images of 15 mM β -CD/Tween 20 system in the region I. (f–h) TEM images of the self-assembled structures in the region II of β -CD/Tween 20 system ($C_{\text{Tween 20}} = 20, 30, 100$ mM).

CMC of Tween 20.²² Obviously, this result significantly contradicts with the accepted effect of β -CD on surfactants in dilute solutions, namely, break of the micelles and other aggregates.

The size of the vesicles increases with increasing concentration. In Figure 3e, we show that micrometer meter-sized vesicles were observed in the Tween 20 solution with a concentration of 15 mM.

Since both Tween 20 and β -CD are pharmaceutical-applicable components, the formation of large vesicles in the β -CD/Tween 20 system is expected to be useful in food and pharmaceutical industries.²³ Further increase of concentration leads to phase and self-assembly transitions. As demonstrated in Figure 3g,h, both vesicles and flakes are observed in the solution of 30 and 100 mM, which locates in region II of Figure 1. This concentration dependent behavior is similar to that observed by Jiang et al., and we will not go into more detail here.²¹

Since the formation of vesicles in the 0.03 mM Tween 20/ β -CD system is rather surprising, further confirmation of the presence of vesicles was carried out with AFM. One drop of the inclusion solution was spin-coated onto a mica surface. AFM images revealed the presence of disks with an average diameter of about 200 nm. There are also some small ones about 50 nm in the back ground. This dimension is in good agreement with the particle size observed under TEM, which confirms that vesicles are indeed formed in the Tween 20/ β -CD systems at concentrations below the CMC of Tween 20. In Figure 4b we show a sectional height profile of a collapsed vesicle, where the height is about 6.8 nm. Considering the symmetric structure of vesicles, this height indicates that the thickness of the vesicle shell is 3.4 nm. As we know that the height for β -CD is 0.79 nm,²⁴ which is about a quarter of 3.4 nm. This indicates that the vesicle membrane is probably composed of bilayers of the channel type Tween 20@ 2β -CD inclusion complexes, as revealed in our previous work.⁸ The apparent larger thickness than that of 4β -CD indicates the headgroup of Tween 20 also contributes to the membrane thickness.

In order to verify that the vesicles were formed by Tween 20/ β -CD complexes rather than by the individual component of Tween 20 or β -CD, control experiments were carried out with DLS and TEM. Figure 5a shows that Tween 20 on its own only self-assemble into micelles. In contrast, β -CD can form colloidal particles whose average hydrodynamic radius is similar to that of the β -CD/Tween 20 mixed system. To eliminate the possibility that the vesicles were formed by the self-aggregation of β -CDs, we studied the microstructures in the β -CD solution of the same concentration as that in the β -CD/Tween 20 inclusion system ($C_{\text{CD}} = 6$ mM). The results in Figure 5b,c show that β -CD itself can self-assemble into polymorphological aggregates, which is in line with literature reports.^{25,26} In addition, it was reported that the critical aggregation concentration for β -CD is 3 mM.²⁵ However, vesicles are already observed in the Tween 20 and β -CD mixed system at the concentration of β -CD below 3 mM.

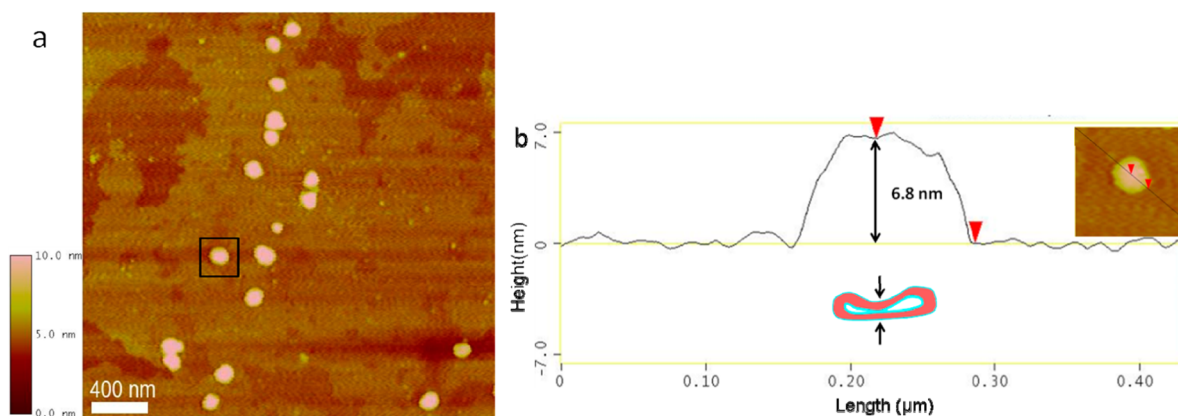


Figure 4. (a) Images acquired by AFM for the 0.03 mM Tween 20/ β -CD samples. (b) Sectional height profile of a collapsed vesicle chosen in a.

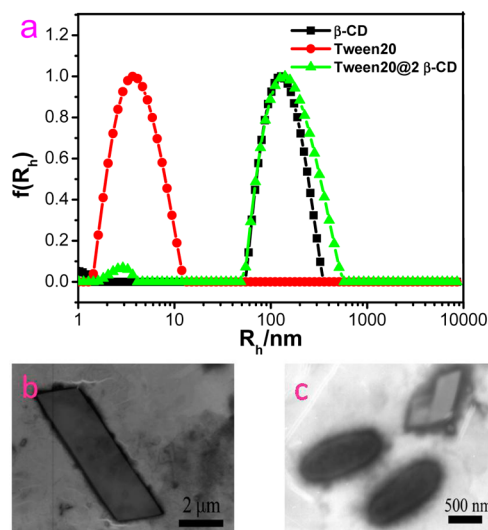


Figure 5. (a) DLS results of Tween 20, β -CD, Tween 20@2 β -CD aqueous solution ($C_{\text{Tween 20}} = 3 \text{ mM}$, $C_{\text{CD}} = 6 \text{ mM}$). (b,c) TEM micrographs of the β -CD ($C_{\text{CD}} = 6 \text{ mM}$) sample.

This strongly suggests that the aggregates observed are resulted from the self-assembly of Tween 20/ β -CD inclusion complexes.

IR Study of the Formation of H-Bonds. Next we are interested in studying the driving forces for the vesicle formation in the dilute solution of Tween 20@2 β -CD. First of all, hydrophobic effect can be ruled out since the inclusion complex is hydrophilic. Then the most possible driving force is hydrogen-bonding which has been reported present predominantly in supramolecular systems containing hydroxyl groups.^{4,8,9,27} In our study, both the headgroup of Tween 20 and the inclusion complexes of Tween 20@/2 β -CD possess many hydroxyl groups. In addition, addition of urea, which is well-known to form strong hydrogen bonds with hydroxyl groups,²⁸ significantly decreases the turbidity of the system (Figure S2 of the SI). This phenomenon is in analogy with previous reports,²¹ suggesting that the aggregates are indeed driven by hydrogen bonds between the hydroxyl groups. To determine who contributes more in the H-bonding, IR measurements were performed for Tween 20, β -CD,

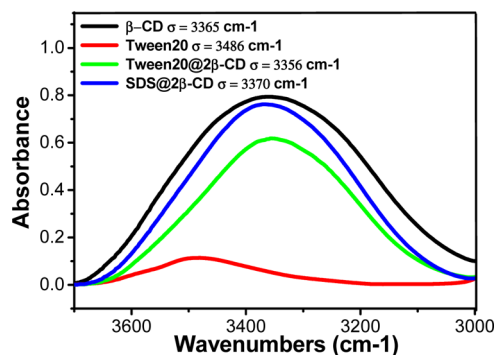
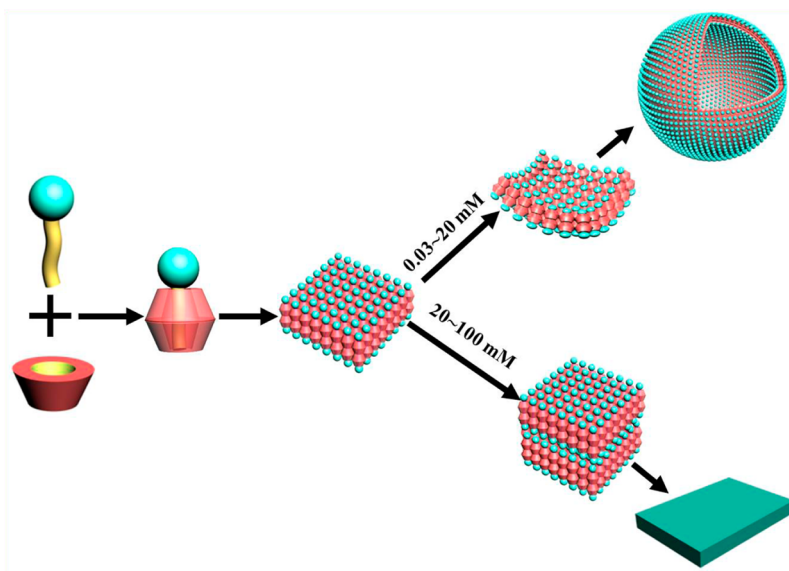


Figure 6. Micro-FTIR result of the hydroxyl peak of Tween 20 ($C_{\text{Tween 20}} = 1 \text{ mM}$), β -CD ($C_{\text{CD}} = 2 \text{ mM}$), Tween 20@2 β -CD ($C_{\text{Tween 20}} = 1 \text{ mM}$, $C_{\text{CD}} = 2 \text{ mM}$), SDS@2 β -CD ($C_{\text{SDS}} = 1 \text{ mM}$, $C_{\text{CD}} = 2 \text{ mM}$).

and Tween 20@2 β -CD. In order to make a contrast experiment with our previous studies,⁸ that for the complexed system of SDS@2 β -CD was also performed. Figure 6 demonstrates that the OH vibration of the hydroxyl peak of β -CD/ionic surfactant SDS complexes moved to a higher wavenumber of 3370 cm^{-1} when compared with that for the OH in β -CD at 3365 cm^{-1} . Since SDS@2 β -CD cannot self-aggregate at the concentration of 1 mM ,⁸ the higher wavenumber indicates the presence of the weaker hydrogen-bonds due to the repulsive electrostatic interactions between the SDS head groups. In contrast, upon the addition of β -CD into the Tween 20 solution, the hydroxyl peak of Tween 20@2 β -CD inclusion complex appears at the lower wavenumber of 3356 cm^{-1} , whereas that for the hydroxyl peak of Tween 20 occurs at 3486 cm^{-1} , suggesting the formation of strong hydrogen bonding.^{29,30} This indicates that the H-bonds in the Tween 20@2 β -CD systems arise from the headgroup of Tween 20 and the hydroxyl group of β -CD together. It is also the reason why β -CD/nonionic surfactant Tween 20 complexes can still self-assemble into vesicles even at the concentrations of the inclusion complexes as low as 0.03 mM .

According to the above results, the following schematic self-assembly behavior of Tween 20@2 β -CD complexes is proposed (Scheme 1).⁸ When Tween 20 and β -CD in aqueous solutions are mixed, the inclusion complex Tween 20@2 β -CD are formed, which tends to assemble in a parallel way to form infinite

Scheme 1. Illustration of the Self-Assembly Behavior of Tween 20/ β -CD Complexes



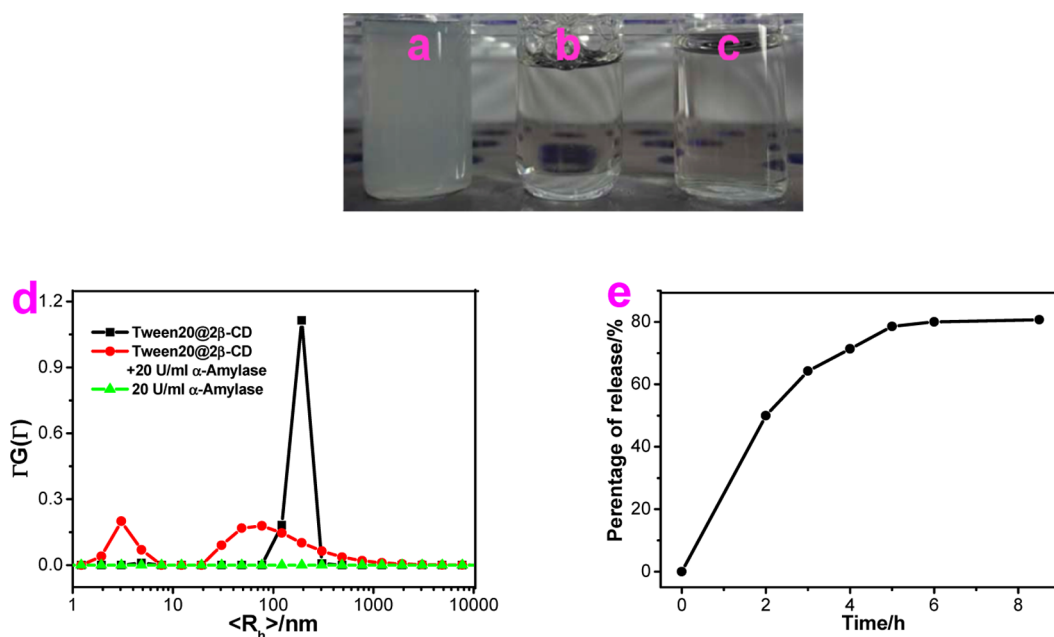


Figure 7. Macroscopic photos of (a) 3 mM Tween 20@2β-CD sample, (b) 3 mM Tween 20@2β-CD sample added 20 U/mL α-amylase, (c) 20 U/mL α-amylase solution. (d) DLS results of 3 mM Tween 20@2β-CD, 3 mM Tween 20@2β-CD sample with addition of 20 U/mL α-amylase, and the 20 U/mL α-amylase solution, (e) The release of Rhodamine B from the vesicles of Tween20@2β-CD upon addition of 20 U/mL α-amylase.

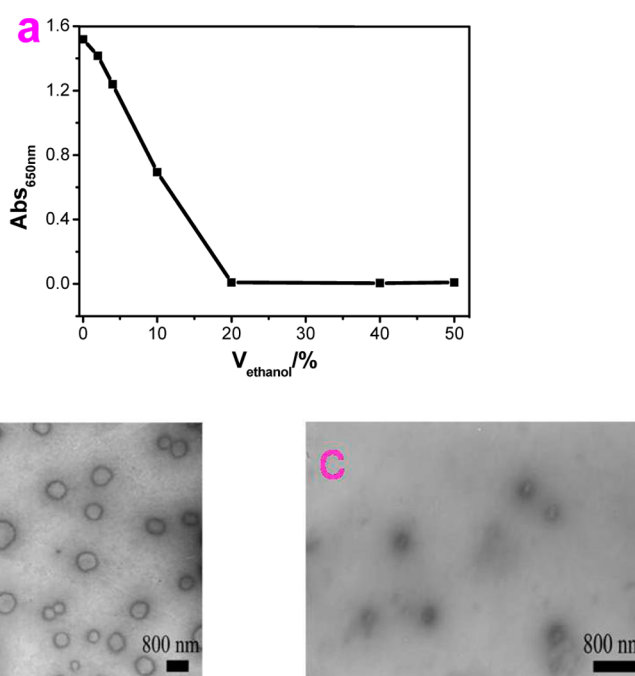


Figure 8. (a) Variation in absorbance in the Tween 20@2β-CD ($C_{\text{Tween 20}} = 3 \text{ mM}$, $C_{\text{CD}} = 6 \text{ mM}$) system with various volume of ethanol. (b,c) TEM images of the Tween 20@2β-CD ($C_{\text{Tween 20}} = 3 \text{ mM}$, $C_{\text{CD}} = 6 \text{ mM}$) system with 40% and 50% ethanol.

two-dimensional (2-D) bilayer driven by hydrogen bonding.³¹ In region I ($C = 0.03\text{--}20 \text{ mM}$), the bilayer membranes bend into vesicles. In region II ($C = 6\text{--}25 \text{ wt } \%$) (20–100 mM), the bilayer membranes stack closely into the flakes.

Biodegradability and Some Resistibility to Ethanol of Tween 20@2β-CD Complexes. Here we attempt to test if the addition of α-amylase can destroy the vesicles,^{32,33} which is very relevant to making the Tween 20@2β-CD inclusion system suitable for pharmaceutical applications. Figure 7 shows that upon addition

of α-amylase, the system becomes transparent; meanwhile DLS measurements suggest that vesicles tend to disappear. This means that the Tween 20@2β-CD inclusion system is indeed biodegradable, which facilitates its further application as a delivery vehicle in the food and pharmaceutical arenas.³⁴ For instance, Rhodamine B can be encapsulated as a model hydrophilic guest into the Tween 20@2β-CD vesicles, and the encapsulation efficiency is 4.5%. Upon addition of α-amylase, 80% Rhodamine B can be released within 6 h (Figure 7e).

With regard to the applications of Tween 20@2 β -CD complexes in cosmetics and pharmaceuticals, it is necessary to study the stability of the vesicles against ethanol since the latter is often applied in these two formulations.¹³ Figure 8 shows that although the turbidity of the system gradually decreases with the addition of ethanol, vesicles still exist even at a volume fraction of ethanol of 50%. This means that the vesicles do resist ethanol, which endows them with potential applications in cosmetics and pharmaceuticals.

Ubiquitous Self-Assembly for β -CD/Nonion Surfactant Complexes in Dilute Solution. The above results indicate that the self-assembly of the nonionic surfactant@2 β -CD inclusion complex is a universal behavior. This anticipation is further verified when Tween 20 was replaced with other nonionic surfactants, such as AEO 3, AEO 9, Tween 40, Tween 60, Tween 80, and Triton X100. All of the inclusion complexes self-assemble into vesicles in dilute solution at a host–guest stoichiometry of 2:1 (Figure 9). This finding drastically challenges the well-known

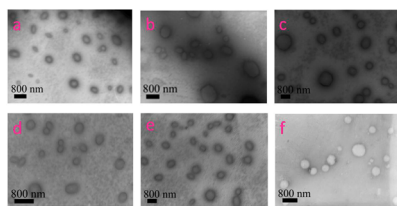


Figure 9. (a–f) TEM micrographs of 0.5 mM β -CD/nonionic surfactant samples (nonionic surfactant: AEO 3, AEO 9, Tween 40, Tween 60, Tween 80, and Triton X100, respectively).

knowledge that in dilute solutions, the complexation between CD and surfactants disfavors self-assembly. It indicates that the 2:1 inclusion complex can act as a building block for construction of nonamphiphilic molecular self-assembly which is predominantly driven by hydrogen bonding.

CONCLUSIONS

In summary, we found that β -CD/nonionic surfactant Tween 20 complexes can self-assemble not only in concentrated solution, but also in dilute solution. Even when the concentration is decreased to 0.03 mM which is below the CMC of Tween 20, vesicles are still formed, and the 2:1 inclusion complex of Tween 20@2 β -CD was verified to be the building block in these vesicles. The driving force for the formation of these vesicles is hydrogen bonding both between the headgroup of Tween 20 and that between the hydroxyl groups of β -CDs. These nonamphiphilic vesicles are biodegradable and resistible to ethanol. We anticipate that Tween 20@2 β -CD complexes are an ideal system as a vehicle or carrier for active ingredients in cosmetics and pharmaceutical applications. In addition, it is a universal phenomenon for the self-assembly of 2:1 inclusion complex of nonionic surfactant@2 β -CD in dilute solution, which not only indicates that the surfactant@2 β -CD inclusion complexes are a novel kind of building block for molecular self-assembly, but also makes a new discovery for the role of CD on amphiphiles in dilute solution.

ASSOCIATED CONTENT

Supporting Information

DLS results. This material is available free of charge via the Internet at <http://pubs.acs.org/>.

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Notes

The authors declare no competing financial interest.

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