Fast and facile preparation of CTAB based gels and their application for Au and Ag nanoparticles synthesis

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Abstract:

Gel-like mesophase of Cetyltrimethylammonium bromide (CTAB) was synthesized by adjusting water to surfactant molar ratio (W₀) in the range of 40-83. Significantly, no additional salt, gelating agent or co-surfactant was utilized to promote the gelation process. The gel formation process was found to be highly dependent on the water to surfactant molar ratio (W₀) with the lowest value of W₀ (40.5) resulting in rapid gel formation. Scanning electron microscope analysis revealed that the gel comprised of interconnected cylindrical structures. The presence of hydrogen bonding in the gels was confirmed using Fourier Transform Infrared spectroscopy (FTIR). All the gel samples were found to be highly viscoelastic in nature with the gel sample prepared using lowest water content exhibiting highest viscosity. Furthermore, Au and Ag containing CTAB gels were also explored as precursors for the preparation of spherical Gold (Au) and Silver (Ag) nanoparticles by using Sodium borohydride (NaBH₄) as the reducing agent. The effect of NaBH₄ concentration on the particle size and morphology of the Au and Ag nanoparticles has also been studied.

Keywords: Nanostructures, Chemical synthesis, optical properties, Fourier transform infrared spectroscopy (FTIR), rheology
1. Introduction:

Amphiphilic molecules such as surfactants, detergents and lipids have a natural tendency to self-assemble into different types of exotic structures in response to perturbations in the surrounding medium and conditions. Out of these amphiphiles, surfactants in particular have garnered huge interest among researchers as these molecules play an important role in many chemical processes of both basic and applied sciences. Surfactants can attain a wide range of colloidal self assemblies e.g. micelles, reverse micelles, vesicles and reverse vesicles by organizing themselves in response to the change in composition of medium, temperature and pH etc [1-5]. These self assemblies are believed to originate when the concentration of the surfactants exceeds the critical micelle concentration (CMC). An increase in the concentration of surfactant beyond the CMC leads to the formation of highly rigid semisolid mass, termed as mesophase [6]. These mesophases are constructed of surfactant self assemblies organized in various types of possible phases including cubic, hexagonal and lamellar phases [7]. Surfactant self-assemblies in these mesophases are themselves joined through the supramolecular interactions. Recently, different types of mesophases have gained huge interest among chemists owing to their wide application spectrum, including cosmetics, drug delivery, biomimetics and as building blocks for the fabrication of nanomaterials [8-11]. A huge variety of mesophases e.g. wormlike micelles, lamellar phases and liquid crystals etc.
have been studied [6, 10, 12]. Wormlike micelles (WLMs) which consist of transient viscoelastic network of grown cylindrical micelles are one of the extensively studied mesophase systems. It is known that the controlled addition of external stimuli e.g. salts and co-surfactant to the micelles, promotes the axial growth of spherical micelles to cylindrical micelles [13, 14]. Water plays a pivotal role in the formation of these giant micelles and it has been observed that the water molecules facilitate the bridging of surfactant molecules by undergoing hydrogen bonding with the polar head group of the surfactant [15]. This hydrogen bonding of water with the polar head group enhances the critical packing parameter (CPP) value through expanding head group area, which induces the transformation of spherical micelles to cylindrical micelles [8]. In literature, WLMs have been prepared by mixing of surfactants with either aromatic compounds or salt additives e.g. cetyltrimethylammonium bromide with KBr salt, sodium salicylate [16], 1-napthol [17] and anthracene derivatives [18]. Reverse wormlike micelles (RWLMs), which exhibit analogous gel-like behavior to wormlike micelles have also been synthesized; however, unlike the plethora of reports on wormlike micelles, there are only a handful of documented reports on the preparation of RWLMs and in most of these reports lecithin [13, 15, 19, 20] has been adopted as surfactant.

Surfactant self-assemblies have been widely explored for obtaining metallic nanostructures with desired dimensions and morphologies. In fact, mesophases such as wormlike micelles, liquid crystals and lamellar phases etc. have been studied extensively as soft templates for the synthesis and growth of nanoparticles. Highly rigid and gel-like organized structure of these mesophases endows control over the particle size, shape and also avoids the aggregation among nanoparticles due to steric crowding. Mesophases have been shown to serve as an efficient reaction medium for the fabrication of nanoparticles of various metals such as Au, Ag, Pt and Pd [21-23]. Bouchama et al. [21], fabricated wormlike micelles doped with metal nanoclusters of Pd, Ru, Ag, Au and Cu. In their study, a rigid viscoelastic gel was
obtained by mixing sodium dodecyl sulfate (SDS) and water at a ratio of 1:2.5 in the presence of 5 wt% n-pentanol, which was further doped with externally prepared hydrophobized metal nanoclusters. Siril and co-workers [22] have grown palladium nanowires by exploring CTAB and SDS based hexagonal mesophases as soft template. The gelatinous hexagonal mesophase containing Palladium source was obtained by mixing tris(dibenzylideneacetone)dipalladium(0) (Pd$_2$(DBA)$_3$) solution in toluene with surfactant (CTAB/SDS) dissolved in brine solution in the presence of n-pentanol. To obtain the Pd nanostructures, the as prepared mesophase was then exposed to hydrazine vapors to initiate the reduction and growth of Pd nanoparticles. Abidi et al [10], prepared Au nanoparticles within CTAB lamellar mesophase by combining CTAB/hexanol/aqueous salt solution in various ratios. The as-prepared lamellar mesophase loaded with gold salt was then exposed to $\gamma$-radiation to synthesize Au nanoparticles.

In the present work, we report a quick and facile synthesis approach for the preparation of CTAB based gelatinous mesophase by judiciously controlling the water to surfactant molar ratio ($W_0 = [\text{Water}]/[\text{Surfactant}]$) in the reaction mixture. Unlike several previously published reports [10, 13, 14, 16-18], no additional salt, gelating agent or co-surfactant is utilized for facilitating the gel formation, as the use of external stimulants (salts) can cause contamination of the final gel product. The influence of water content on the structural and rheological properties of the gels has also been investigated. As CTAB is a well known capping molecule for the controlled synthesis of Au and Ag nanoparticles, we have therefore explored these CTAB based gels for the fabrication of Au and Ag nanoparticles. The use of Au, Ag metal complex with CTAB in gel form instead of solution form restricts the nanoparticles growth via the controlled release of the metal ions into the reaction medium containing reducing agent. Metal containing gels prepared using this method are very much stable and can be stored for several days in closed vials.
2. Materials and methods:

2.1 Materials:

All chemicals, including Cetyltrimethylammonium bromide (SRL Chemicals) LR, Auric chloride (AuCl₃) (Alfa Aesar) LR, Silver nitrate (AgNO₃) (CDH Chemicals) LR, n-Hexane (CHEMLABS) LR, Sodium borohydride (NaBH₄) (CHEMLABS) LR were used as received without any further purification. Deionized water was used for the preparation of all aqueous solutions.

2.2 Preparation of pristine CTAB gel:

For obtaining CTAB based gelatinous mesophase, CTAB was mixed with n-hexane, followed by the addition of deionized water (W₀ 62.3) under vigorous stirring at a reaction temperature of ~30°C. Furthermore, two other gel samples with different W₀ (41.5 and 83) were also prepared. All the as prepared gel samples were stored by dipping them in n-hexane in tightly closed vials. For W₀ of 62.3, it was observed that the addition of water to the CTAB/n-hexane mixture instantly leads to the formation of gel phase (Fig.-1(b)). In the case of gel prepared using lowest W₀ (41.5), the addition of water to the CTAB/n-hexane mixture resulted in the quick formation of a very thick translucent gel (Fig-1(a)); however nearly 10 ml of n-hexane was left behind un-reacted in the mixture. The mass of the gel was also found to be less, as compared to the gel prepared by maintaining the W₀ at 62.3. Gel formation using highest W₀ (83) took significantly longer time as compared to the other two samples. In this case, the reaction mixture was stirred for a few seconds after the addition of water and then left stationary for 15 minutes, which led to the formation of translucent gel (Fig-1(c)). Among all these gel
samples, the gel prepared using intermediate \( W_0 \) (62.3), exhibited transparency, whereas the other two gel samples were found to be translucent in appearance. Nevertheless, all the gels were found to be strong enough to entrap a magnetic bit (~5.45 gm), even when the beakers were held upside down. For further discussion, the gel samples prepared using \( W_0 \) of 41.5, 62.3 and 83 are named as sample a, b and c respectively.

### 2.3 Preparation of Au and Ag containing CTAB gel:

For the preparation of Au containing CTAB gels, CTAB was first added to 20 ml n-hexane, under stirring, followed by the addition of 0.05M aqueous solution of \( \text{AuCl}_3 \) maintaining the water to surfactant molar ratio at 41.5. Similar to the addition of water, the addition of aq. \( \text{AuCl}_3 \) solution leads to the formation of a yellow coloured gel which changes into red after some time (Fig.1 (d)). For the synthesis of Ag containing CTAB gel, 0.05M \( \text{AgNO}_3 \) aqueous solution was added to the reaction mixture, again maintaining the water to surfactant ratio at 41.5. The addition of \( \text{AgNO}_3 \) aqueous solution resulted in the quick formation of a white colour gel (Fig. 1(e)). Both, the red colour of \( \text{AuCl}_3 \) and white colour of \( \text{AgNO}_3 \) gel samples, indicate the formation of metal complex with CTAB, which is further confirmed by UV-Vis analysis. Unlike pristine gels, in the case of salt containing gels, all of the n-hexane was not consumed during gel formation and a small volume was usually leftover. The as prepared gels were stored by dipping them into n-hexane in tightly capped vials.

### 2.4 Preparation of Au and Ag nanoparticles:

For the preparation of Au nanoparticles, two batches of 450 mg of the Au/CTAB gels were dispersed in 10 ml of 0.1M and 0.15M \( \text{NaBH}_4 \) aqueous solutions, respectively. The reaction mixtures were then stirred vigorously which resulted in the appearance of brick red (0.10M \( \text{NaBH}_4 \)) and violet (0.15M \( \text{NaBH}_4 \)) coloured suspensions, indicating the formation of Au
nanoparticles. For Ag nanoparticles, again two batches of 450 mg of the Ag/CTAB gels were dispersed in 10 ml of 0.05M and 0.25M NaBH$_4$ aqueous solutions respectively. The reaction mixtures were stirred vigorously which resulted in the appearance of yellow (0.05M NaBH$_4$) and greenish-yellow (0.25M NaBH$_4$) coloured suspensions, indicating at the formation of Ag nanoparticles. The as prepared Au and Ag nanoparticles suspensions were diluted by adding 10 ml of deionized water.

3. Characterization details:

FTIR spectra of samples were recorded using ATR FTIR spectroscopy (Thermo Scientific Nicolet™ iS™5 FTIR) with diamond ATR accessory. Gel samples were taken out from the sealed vials and immediately mounted on the ATR crystal. During the FTIR measurement room temperature was kept ~20°C to avoid the drying of wet gels. Spectra were collected in transmission mode from 4000 to 400 cm$^{-1}$. Steady and dynamic rheological measurements were performed on a rotational rheometer (MCR 302, Anton Paar, Austria) equipped with cone plate geometry having cone angle 2°, with the temperature controller set at 25°C. To avoid the evaporation from the samples, a solvent trap was employed. Strain value ($\gamma$), obtained from the linear viscoelastic region was used for performing dynamical rheological measurements. Dynamical frequency spectra were recorded in the linear viscoelastic regime of each sample in the frequency region from 0.01 to 100 rad s$^{-1}$. Morphology and microstructure of wet and dried gels were investigated using environmental scanning electron microscope (ESEM) model FEI Quanta 200F with oxford-EDS system IE 250 X Max 80. UV-Vis spectra of aqueous dispersion of metal containing CTAB gels and nanoparticles samples were recorded using UV-Vis spectroscopy (Thermo Scientific Evolution 201). In case of Au nanoparticle samples, absorbance was recorded in the range of 350-800 nm whereas for Ag nanoparticles, scans were executed within the range of 250-800 nm. Morphologies and elemental
compositions of the nanoparticles samples were investigated using Transmission electron microscope (TEM) (TECNAI G²20 S-TWIN) coupled with EDX. For the TEM sample preparation, nanoparticle suspensions were sonicated for 15 minutes after which one drop of the sonicated samples were mounted on the carbon coated copper grids and then subjected to ambient vacuum drying. X-ray analysis was performed using Rigaku miniflux X-ray diffractometer within 2θ range of 30-80°. In order to obtain powder samples for XRD analysis water was evaporated from Au and Ag nanoparticles suspensions (0.05M) through ambient drying. To probe the crystal phase formed in both samples, 2θ values and inter-planar distances were compared with the standard JCPDS files.

4. Results and discussion:

4.1 ESEM analysis of the gels:

Environmental SEM images of both wet and dried gel are shown in the Fig. 2. It can be clearly observed from these images that the wet gel is composed of giant cylindrical structures which are branched and interconnected (Fig. 2 a, b). Furthermore, higher magnification images show that the diameter of these cylindrical structures is in the range of ~ 400-600 nm (fig. 2b). However, after drying, the diameter of these cylindrical structures is reduced and appears to be ~300 nm (Fig. 2 c, d). Gels are composed of swollen hexane rich cylindrical structures and therefore the reduction in their diameter upon drying can be explained by the possible evaporation of fluid content. While, a significant reduction in the volume of gel upon drying was observed, the network of interconnected cylindrical structures was still preserved.

4.2 FTIR analysis of gel:
FTIR spectra of pristine CTAB, n-hexane and CTAB gel are shown in the Fig. 3a. The FTIR spectrum of pristine CTAB exhibits bands for asymmetric and symmetric C-H scissoring vibrations of CH$_3$-N$^+$ at 1486 and 1430 cm$^{-1}$ respectively. Bands positioned at 960 and 718 cm$^{-1}$ can be assigned to C-N$^+$ stretching and rocking mode of the methylene chain [24]. However, all of the signature bands of pristine CTAB are not visible in the FTIR spectrum of the CTAB gel. The FTIR spectrum of the CTAB gel comprises of a wide band centred around 3377 cm$^{-1}$, which can be attributed to the stretched hydrogen bonded O-H groups, confirming the inter-molecular hydrogen bonding between water and surfactant [25]. Bands at 1378 and 1462 cm$^{-1}$, which are also present in the FTIR spectrum of n-hexane, can be assigned to CH$_3$ and CH$_2$ bending modes, respectively. Peak at 1645 cm$^{-1}$ can be assigned to the H-O-H bending vibrations [26]. Similar type of FTIR spectrum has been observed for CTAB based worm like micelles prepared using sodium salicylate by Gupta et al. [16].

Furthermore, the effect of water content on the structural properties of the gel was also investigated using FTIR analysis. Fig. 3b depicts the FTIR spectra of all three gel samples; in particularly highlighting the wave number region in which O-H stretching bands appears. Previously, it has been reported that the O-H stretching band shifts to lower frequencies with an increase in the water content in the reverse micelles [27]. In our samples, the O-H stretching band appears at 3376.41, 3373.60 and 3362.61 cm$^{-1}$ for gel samples prepared at W$_0$ of 41.5, 62.3 and 83, respectively, thus showing an increase in the frequency on decreasing the water content.

4.3 Rheology analysis:

Fig. 4(a) shows the plot between viscosity and shear rate for the pristine CTAB gel samples prepared using three different water to surfactant molar ratios (41.5, 62.3 and 83). In the case of sample-a, prepared using the lowest W$_0$ (41.5), the viscosity at lower shear rates is found to be more than 10$^5$ Pa; with an increase in the shear rate accompanied by a
reduction in the viscosity. No plateau in the viscosity vs. shear rate curve is observed, which indicates that the sample exhibits more elastic, cross-linked polymer gel like behavior [28]. However, in the case of samples b (\(W_0=62.3\)) and c (\(W_0=83\)), the shear viscosity remains unchanged in the lower frequency regime and a plateau is observed. As the frequency increases, shear thinning takes place suggesting a non-Newtonian viscoelastic behavior of the gels [29] which confirms the presence of transient network of cylindrical micelles in these samples. The value of viscosity is highest for the sample with lowest water content (sample a) and an increase in the water content results in the reduction of the viscosity, suggesting that the excess water content may disrupt the gel network.

Fig. 4(b) shows the dynamic rheology measurement of the CTAB gel samples where storage modulus (\(G'\)) and loss modulus (\(G''\)) are plotted as functions of frequency (\(\nu\)). It can be easily observed from the plot that through the entire frequency range, \(G'\) is dominating over \(G''\) revealing the elastic nature of the samples. At lower frequencies, the gap between moduli become narrow but the curves don’t intersect, suggesting that the relaxation time for the samples is very high. An ideal gel should show frequency independent moduli throughout the frequency range, with infinite values of relaxation time and viscosity [13]. However in the present case, each modulus exhibits weak frequency dependency, which suggests that the sample relax at very slow rate and the viscosity of the sample is very high, but nevertheless, has a finite value. The CTAB gel sample having the lowest water content, sample a, exhibits plateau modulus \(G_p\) in the range of \(10^3-10^5\) Pa. Increase in the \(W_0\) from 41.5 to 62.3 and further 83, causes the softening of gels, causing a suppression in the elastic character and a reduction in the moduli. To further study the viscoelastic properties of the gels, dynamic frequency sweep was performed on each gel sample. Linear viscoelastic regime determined from dynamic stress sweep was used for the dynamic frequency sweep. Dynamic stress sweep plots of all the gel samples are depicted in Fig 4 (c). It can be clearly
observed from the graphs that the range of stress in which the storage modulus (G’) and loss modulus (G") are independent of stress is different for all the three gel samples. The range of stress in which the storage modulus (G’) and loss modulus (G") are independent of stress is found to be 0.01-50, 0.01-20 and 0.01-10 Pa for samples a, b and c, respectively. As all of the samples are very much stable in stress range 0.01-10 Pa, so for performing the dynamic frequency sweep (0.01-10 Hz) measurement the stress value was fixed at 3 Pa for sample a and 1 Pa for samples b and c. Fig. 4 (d) shows the stress controlled dynamic frequency sweep plots for all three gel samples. For all the samples, G’ and G" appear to be independent of frequency; with G’ remaining higher than G", revealing the stability of the gels against the external force in the whole frequency range. Results obtained from strain and stress controlled dynamic frequency sweep are very much similar in trend; in both the cases, an increase in the water content resulted in the reduction of G’ value which suggest that lower water content favors the formation of gel with higher elasticity.

4.4 UV-Vis analysis of Au, Ag containing CTAB gels and Au, Ag nanoparticles suspensions:

The Au and Ag containing CTAB gels were dispersed in water, producing orange and white color suspensions, respectively. The UV-Vis spectra of these suspensions are compared with the spectra of starting precursors, aqueous AgNO₃ and AuCl₃ solutions in Fig.5. While the UV-Vis spectrum of AuCl₃ aqueous solution exhibits a single peak at 290 nm, which may arise due to ligand-metal charge transfer [30]; the UV-Vis spectrum of Au-CTAB suspension has two peaks at 259 and 393 nm. The absorption peak at 259 nm can be assigned to the vibrational frequencies of [AuBr₂]⁻, while the peak at 393 nm confirms the formation of complex of cetyltrimethylammonium ion (CTA⁺) with [AuBr₄]⁻([CTA⁺][AuBr₄]⁻) [31]. Similarly, the absorption spectrum of Ag-CTAB suspension contains two peaks at 234 nm and 291 nm which can be assigned to the formation of AgBr [32].
The absorption spectra of Au and Ag nanoparticles prepared using different concentration of aq. NaBH₄ solutions is shown in the Fig.6. The UV-Vis spectrum of Au nanoparticles prepared using 0.1M NaBH₄ solution (Au-0.1M), exhibits a sharp peak at 511 nm, which is the characteristic surface plasmon resonance peak of Au nanoparticles [33]. On increasing the concentration of NaBH₄ from 0.1M to 0.15M, the colour of the nanoparticles suspension changed from brick red to violet and the corresponding plasmon peak also red shifted to 525 nm (Au-0.15M), suggesting the formation of larger particles (Fig. 6a). In the case of Au nanoparticles prepared using higher concentration of NaBH₄ (0.15M) the absorption spectrum starts from a higher absorbance value and the peak intensity also decreased which indicates agglomeration among Au nanoparticles [34, 35]. The agglomeration among particles in the case of higher NaBH₄ concentration is also clearly visible in the TEM images (Fig. 7(b1)). Figure 6 (b) depicts the absorption spectra of the Ag nanoparticles prepared using two different concentrations of aq. NaBH₄ solution. The UV-Vis spectrum of Ag nanoparticles prepared using 0.05M concentration of NaBH₄ (Ag-0.05M) exhibits a peak centred at 410 nm which is the characteristic surface plasmon peak for Ag [36]. The absorption peak itself is quite sharp and well defined, which indicates narrow particle size distribution. On increasing the concentration of NaBH₄ from 0.05 to 0.25M, an increase in the absorbance was observed, suggesting an increase in the population of Ag nanoparticles in the sample (Ag-0.25M).

4.5 Structural analysis of Au and Ag nanoparticles (XRD, TEM and EDAX analysis):

The TEM images of Au and Ag nanoparticles prepared using CTAB gels are shown in Fig. 7. For Au-0.1M sample, the particle size was found in the range of 5-10 nm (Fig. 7a1, a2) and ~10 nm for Au-0.15M sample (Fig. 7b1 and b2). It was observed that an increase in the concentration of NaBH₄ solution not only affected the particle size, but also altered the resulting morphology of the particles. In the case of Au-0.1M sample, most of the particles are spherical; while at higher
concentration of NaBH₄ (0.15M), particles with mixed morphology such as spherical, elliptical (Fig. 7b1) and dendrimeric structures (Fig. 7b2) were observed. An intermediate concentration of NaBH₄ (0.13M) did not significantly alter the morphology of the particles (Fig-S1), wherein all the particles were found to be spherical, with a slight increase in their size. In the case of Ag nanoparticles prepared using 0.05M NaBH₄ solution (Ag-0.05M) most of the particles are spherical in size and well dispersed (Fig 7c1 and c2). Further increase in the concentration of NaBH₄ from 0.05 to 0.25M led to an increase in the particle size as well as a change in their morphology from being predominantly spherical to elliptical (Fig 7d1 and d2). However, unlike the Au nanoparticles, the change in the overall morphology of the Ag nanoparticles was not very significant. The chemical composition of the Au and Ag nanoparticles suspension was also investigated using the energy dispersive X-ray analysis (EDX). As shown in supporting information, Fig. S2 (a, b), peaks corresponding to Au and Ag are observed which confirms the presence of Au and Ag in the samples. Furthermore, the presence of Au and Ag was also confirmed through the XRD analysis. The XRD of Au nanoparticles (Fig S3 (a)) consists of peaks with d-values of 2.3738, 2.0819 and 1.4475 Å which match with the standard d-values of cubic phase of gold (JCPDS 4-784). XRD spectrum of Ag nanoparticles (Fig. S3 (b)) exhibits peaks with d-values of 2.3717, 2.0538, 1.4467 and 1.2385 Å which are in close proximity with the standard d-values for the cubic phase of silver (JCPDS- 4-783). X-ray diffractograms of both metal nanoparticles samples exhibit broad peaks suggesting presence of particles with nano-dimensions.

5. Conclusions:

In summary, gel-like mesophase of CTAB has been successfully synthesized by precise adjustment of water to surfactant molar ratio. No external stimuli such as salts, gel forming agents or co-surfactant was utilized to reinforce the gelation process resulting in the formation of “contaminant-free” gels. It was found that the water to surfactant molar ratio dictates
the gel formation process and also affects the rheological properties of the gel significantly. An increase in the water content resulted softening of gels and decrease in the viscosity. Furthermore, Au and Ag containing CTAB gels were utilized as precursors for the synthesis of Au and Ag nanoparticles. The CTAB gels were able to control the growth of Au and Ag nanoparticles even at very high concentration of the reducing agent due to the controlled release of metal-surfactant complex from the CTAB gels. The particle size and morphology of the nanoparticles were found to be highly dependent on the concentration of the NaBH₄. In the case of Au nanoparticles, an increase in the concentration of NaBH₄ from 0.1 to 0.15M, resulted nanoparticles with higher diameter and mixed morphology however in case of Ag nanoparticles increase in the NaBH₄ concentration didn’t affect the morphology much though a slight increase in the particle size was observed. Thus, our proposed method of judicious control of water to surfactant ratio provides “contamination free” stable CTAB gels which can be further utilised to synthesise size, morphology controlled Au, Ag nanoparticles via the reduction of metal-surfactant complexes. We believe that apart from Au and Ag, these CTAB based gels can be doped with salts of other metals such as copper (Cu), platinum (Pt) and palladium (Pd) also and thus can be utilized as precursor for the nanoparticles preparation of these metals too.

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References:


Figure captions:

Fig. 1 Digital photographs of CTAB gel samples prepared using different water to surfactant molar ratio ($W_o$) (a) 41.5 (b) 62.3 (c) 83 (e) Au containing CTAB gel (d) Ag containing gel

Fig. 2 ESEM images of (a, b) wet gel samples and (c, d) dried CTAB gel samples

Fig. 3 (a) FTIR spectra of CTAB gel, CTAB and n-hexane; (b) FTIR spectra of CTAB gel prepared using different water to surfactant molar ratios (highlighted O-H stretching bands region)

Fig. 4 (a) Viscosity as a function of shear rate (s$^{-1}$) for CTAB gel samples prepared using different water to surfactant molar ratios (b) Change in the $G'$ and $G''$ as a function of $w$ obtained through oscillation frequency sweep measurements for all three CTAB gel samples at 25°C. (c) Dynamic stress sweep plots for all three gel samples (d) $G'$ and $G''$ as a function of frequency (Hz).

Fig. 5 UV-Vis spectra of Au-CTAB and Ag-CTAB gels

Fig. 6 UV-Vis spectra of Au and Ag nanoparticles prepared using different concentration of NaBH$_4$ (a) Au nanoparticles (b) Ag nanoparticles

Fig. 7 TEM images of Au and Ag nanoparticles prepared using various concentration of NaBH$_4$ (a1, a2) Au-0.10M (b1, b2) Au-0.15M (c1, c2) Ag-0.05M (d1, d2) Ag-0.25M
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