Supporting Information

Size and Optically Tunable Ethyl Cellulose Nanoparticles as Carriers for Organic UV Filters

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1. Preparation of ECNPs and Investigation of the Particle Size Range

In Figure 1 we found that ECNPs could be prepared with sizes ranging from 50 nm to 165 nm. Attempts to prepare larger particles than 165 nm resulted in bimodal, very polydisperse distributions of particles as shown in Figure S1 below.

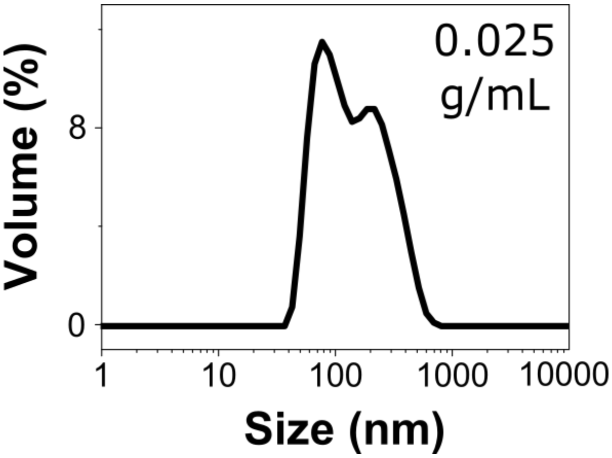

Figure S1. Size distribution as determined by DLS for when 0.025 g mL^{-1} EC in ethanol is used for the antisolvent precipitation. Note that the DLS measurement shows a very polydisperse bimodal distribution of particles.

The yield of ECNPs for the series in which increasing concentrations of EC in ethanol solution were used for the antisolvent precipitation was quantified (100 × particles formed mass/mass of EC originally added). Yield values (Figure S2) were determined by taking 10 mL of the dispersion and drying in a glass vial at 80 ^{o}C overnight. The mass of the dried particles was then measured, multiplied by 5 (to correspond to the total 50 mL dispersion), and then this value was divided by the initial mass of EC added. This was done two-fold. We see that the yield decreases for the larger concentrations of EC in ethanol. Thus, higher concentrations of EC in ethanol allow the preparation of larger ECNPs but the yield is sacrificed.

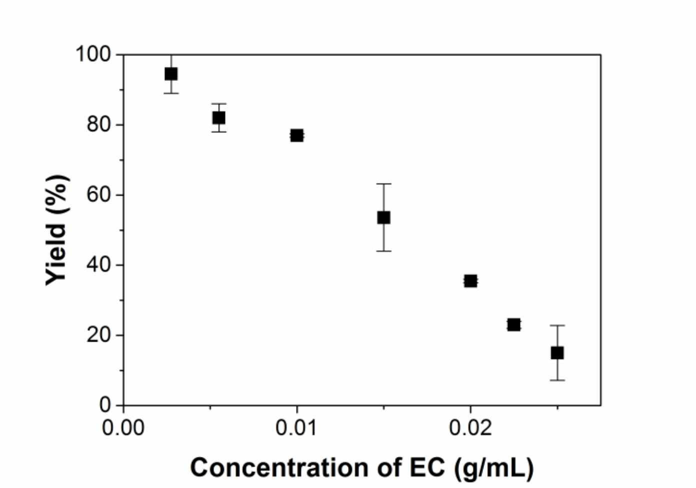

Figure S2. The yield for the series is plotted as a function of the concentration of EC in ethanol. The two in the series concerning the lowest two concentrations of EC in ethanol ($1.6x10^{-3}$ g mL^{-1} and 2×10^{-3} g mL^{-1}) are not measured because the particle sizes for the lowest three concentrations were all similar.

The complete raw data set for Figure 1i, Figure S1 (conc. EC in ethanol 2.50×10^{-2} g mL^{-1}) and Figure S2 can be found in Table S1 below. Both the mean and modal average are reported for the particle size for completeness but the graph in Figure 1i only uses the values for the mean average particle size.

Table S1. The raw data for Figure 1i.

Conc. of EC in ethanol (g mL^{-1})	Particle size modal average (nm)	Particle size mean average (nm)	Particle size error (modal average, nm)	Particle size error (mean average, nm)	PDI	PDI diameter (nm)	Yield average (%)	Yield error (%)
1.60 ×10^{-3}	**35**	**50**	**0.197**	**0.280**	**0.230**	**23.7**	**-**	**-**
2.00 ×10^{-3}	**37**	**58**	**0.639**	**0.540**	**0.280**	**30.9**	**-**	**-**
2.75 ×10^{-3}	**39**	**53**	**0.630**	**0.784**	**0.204**	**23.9**	**94.5**	**5.5**
5.50 ×10^{-3}	**64**	**71**	**0.277**	**0.389**	**0.158**	**27.4**	**82.0**	**4.0**
1.00 ×10^{-2}	**87**	**100**	**0.239**	**0.373**	**0.157**	**39.3**	**77.0**	**0.5**
1.50 ×10^{-2}	**113**	**118**	**0.921**	**1.164**	**0.135**	**42.4**	**53.6**	**9.6**
2.00 ×10^{-2}	**148**	**146**	**0.176**	**0.224**	**0.126**	**52.8**	**35.5**	**0.5**
2.25 ×10^{-2}	**177**	**160**	**0.265**	**0.482**	**0.136**	**60.7**	**23.0**	**1.0**
2.50 ×10^{-2}	**206**	**165**	**5.231**	**1.064**	**0.243**	**83.1**	**14.7**	**7.8**

2. Loading of UV filters into ECNPs (71 nm) and Investigation of the Maximum Particle Loadings

Table S2 shows the compositions of a series of 7 ECNP dispersions which were prepared by dissolving constant amounts of EC and increasing amounts of UV filter into ethanol before undergoing the antisolvent precipitation.

Table S2. Compositions of the amounts of EC and UV filter initially dissolved in 50 mL ethanol for the three series of seven dispersions (one series of 7 dispersions for each UV filter).

Dispersion	Mass of EC (g)	Mass of UV filter oxybenzone/ avobenzone/octinoxate (g)	UV filter added expressed as a weight percentage (wt%)
1	0.275	0.007	2.4
2	0.275	0.014	4.8
3	0.275	0.021	7.1
4	0.275	0.028	9.0
5	0.275	0.055	16.0
6	0.275	0.138	33.4
7	0.275	0.275	50

Interestingly, despite the larger amounts of precipitating material, we found that the resultant particle sizes were constant for all dispersions (70 nm) except the ECNPs dispersion containing the highest loading of octinoxate (90 nm). In Figure S3 below we see the DLS measurement for this dispersion which contains the highest loading of octinoxate (Figure S3a) compared with the DLS measurements which contain the highest loadings of avobenzone and oxybenzone (these spectra are identical to the spectra of non-loaded ECNPs prepared from the same concentration of EC in ethanol). The DLS measurements of all other ECNP dispersions in the series were also identical to Figure S1b and Figure S1c below, with an average particle size of 70 nm.

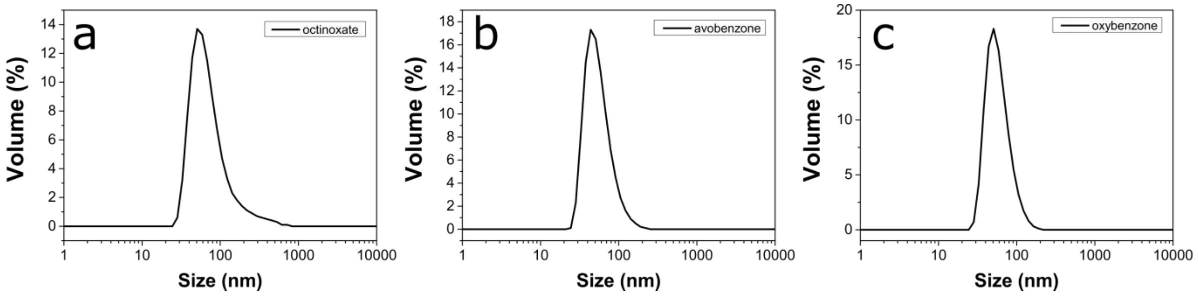

Figure S3. Size distributions as determined by DLS for the ECNP dispersions which contained the largest loadings of UV filter. (a) ECNPs with incorporated octinoxate (54.5wt%). Mean average particle size 90 nm. (b) ECNPs with incorporated avobenzone (7.8wt%). Mean average particle size 70 nm. (c) ECNPs with incorporated oxybenzone (13.8wt%). Mean average particle size 70 nm.

When attempting to prepare ECNPs with large amounts of encapsulated UV filter we would dissolve large amounts of the UV filter in ethanol along with the ethyl cellulose before undergoing the antisolvent precipitation.

When large amounts of UV filter avobenzone were dissolved in ethanol (before undergoing the antisolvent precipitation) we found that the ECNPs would become saturated and the excess UV filter would form a secondary set of larger droplets (Figure S4). We hypothesize that the secondary set of larger particles are likely stable droplets of pure UV filter (or possibly droplets of UV filter stabilized with some EC at the interface) because performing the antisolvent precipitation with only UV filter avobenzone (and no EC) resulted in *only* similarly-sized larger particles (Figure S5).

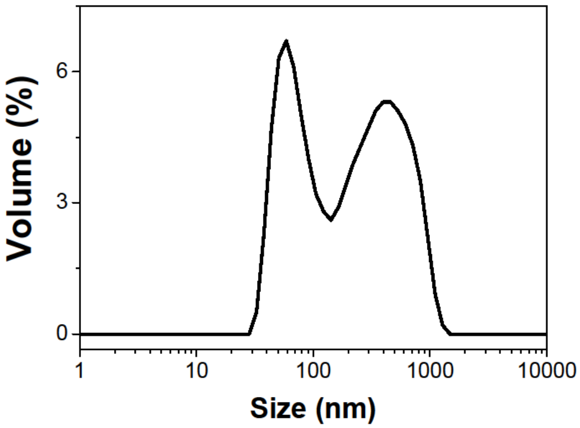

Figure S4. Size distribution as determined by DLS for the dispersion in which EC (0.275 g) and avobenzone (0.275 g) were dissolved in ethanol (50 mL) before undergoing the antisolvent precipitation. Note the bimodal distribution in which larger micron-sized particles are formed as well as the expected ECNPs.

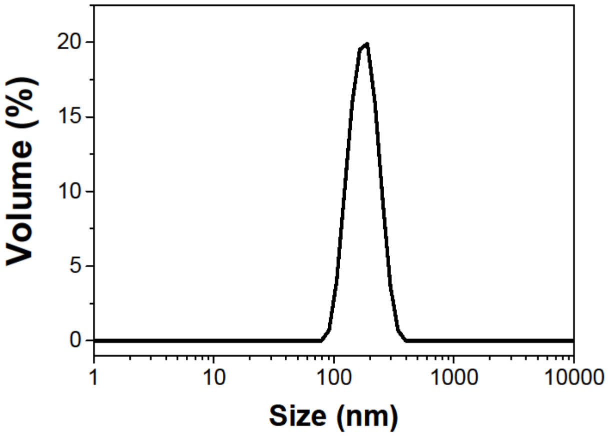

Figure S5. Size distribution as determined by DLS for the dispersion in which *only* avobenzone (0.275 g) was dissolved in ethanol (50 mL) before undergoing the antisolvent precipitation. Note the formation of larger, self-stabilized avobenzone particles.

A similar story is seen when using large amounts of octinoxate instead of avobenzone. Figure S6 shows the DLS measurement for when large amounts of octinoxate was dissolved in ethanol along with ethyl cellulose and larger particles are observed. We therefore hypothesize again that the secondary peaks in the DLS measurement in Figure S6 are likely due to stable particles of either pure octinoxate or octinoxate droplets partially stabilized with EC because performing the antisolvent precipitation with only UV filter octinoxate (and no EC) resulted in *only* similarly-sized larger particles (Figure S7).

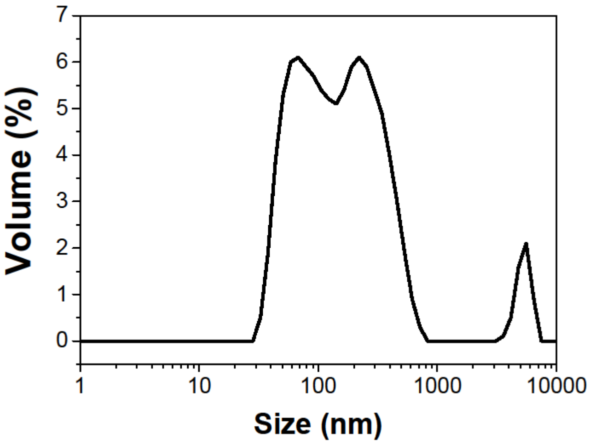

Figure S6. Size distribution as determined by DLS for the dispersion in which EC (0.275 g) and octinoxate (0.55 g) were dissolved together in ethanol (50 mL) before undergoing the antisolvent precipitation. Not the multimodal distribution in which larger (micron sized and greater) particles are formed as well as the ECNPs.

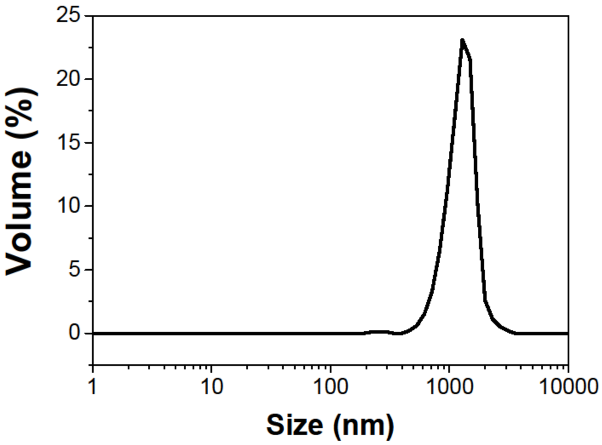

Figure S7. Size distribution as determined by DLS for the dispersion in which only octinoxate (0.55 g) was dissolved in ethanol (50 mL) before undergoing the antisolvent precipitation. Note the formation of large micron sized self-stabilized octinoxate particles.

Lastly, we also investigated preparing particles with larger loadings of oxybenzone. Moreover, we wanted to investigate whether the particle size was mostly determined by the total mass of precipitating material or mostly determined by the total mass of precipitating ethyl cellulose. Therefore, here we used half the usual concentration of EC (half of 0.0055 g mL^{-1}, thus 0.0028 g mL^{-1}) along with an equal concentration (0.0028 g mL^{-1}) of UV filter. The total concentration of precipitating material is therefore 0.0055 g mL^{-1}, however, half of this is ethyl cellulose and half of this is UV filter oxybenzone. Therefore, we dissolved a total mass of 0.275 g in a 1:1 ratio (0.138 g of EC and 0.138 g of UV filter) in ethanol before doing the antisolvent precipitation procedure.

We found this resulted in a bimodal particle distribution (Figure S8), similar to what we saw previously with attempting higher loadings of avobenzone and octinoxate. Again, we hypothesize that the peaks in the DLS measurement were due to ECNPs (presumably with encapsulated UV filter too) as well as larger stable droplets of pure oxybenzone/droplets of pure oxybenzone stabilized with some EC at the interface - because Figure S9 shows that similarly-sized large particles are formed when performing the antisolvent precipitation with *only* oxybenzone (and no EC). Interestingly, in Figure S8 we also found that the modal average particle size of the ECNPs was 40 nm – lower than when precipitating 0.0055 g mL^{-1} of *only* ethyl cellulose. (N.B. we compare the modal average values here instead of mean because the mean average is disrupted by the fact the measurement is bimodal) According to Table S1, performing the antisolvent precipitation with 0.0028 g mL^{-1} of EC would predict a modal average particle size of around 40 nm. We therefore hypothesize that the concentration of ethyl cellulose is the principal factor in the resultant ECNP particle size.

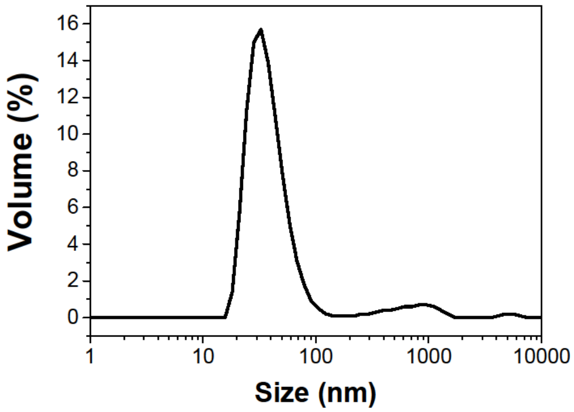

Figure S8. Size distribution as determined by DLS for the dispersion in which EC (0.138 g) and oxybenzone (0.138 g) were dissolved in ethanol before undergoing the antisolvent precipitation. Note the existence of micron sized particles along with the ECNPs.

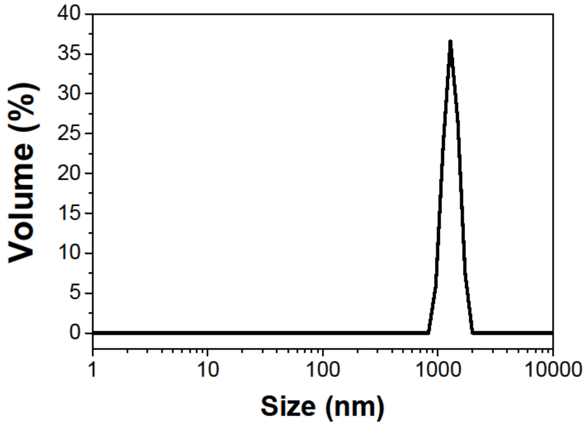

Figure S9. Size distribution as determined by DLS for the dispersion in which only oxybenzone (0.275 g) was dissolved in ethanol (50 mL) before undergoing the antisolvent precipitation. Not the formation of micron sized self-stabilized particles of pure oxybenzone.

The complete raw data set for Figure 4 can be found in Table S3 below.

Table S3. All the data used for Figure 3. The measurements were performed in triplicate therefore the values for the loaded UV filter below are an average of three measured values. This is the source of the standard error.

UV filter added (wt%)	Loaded oxybenzone (wt%)	Standard error (wt%)	Loaded octinoxate (wt%)	Standard error (wt%)	Loaded avobenzone (wt%)	Standard error (wt%)
2.4	3.1	0.02	1.4	0.33	0.9	0.05
4.8	5.2	0.09	4.0	0.54	3.3	0.09
7.0	6.2	0.19	5.9	0.18	5.8	0.11
9.1	8.0	0.41	7.9	0.43	7.0	0.50
16.6	13.5	3.90	15.8	0.25	7.8	0.55
33.3	13.8	3.18	32.8	0.64	7.0	0.45
50	11.8	1.20	54.5	2.50	-	-

3. Loading of UV filters into larger ECNPs and Investigation of the Maximum Particle Loadings

We investigated the maximum loading values of the three UV filters oxybenzone, avobenzone, and octinoxate into larger ECNPs to give further mechanistic insight. If the UV filter were to be exclusively present on the surface of the ECNPs, we would expect that larger particles would result in a smaller weight percentage of loaded UV filter because the surface area to volume ratio is lower for larger particles. In fact, we find that the maximum loading of oxybenzone and avobenzone in the ECNPs is considerably greater (27.8 wt% and 28.4 wt% respectively) when the ECNPs are larger (Figure S10), and the loading of octinoxate remains similar (47.2 wt%). This is evidence that the UV filters are distributed throughout the particles and are not exclusively at the surface.

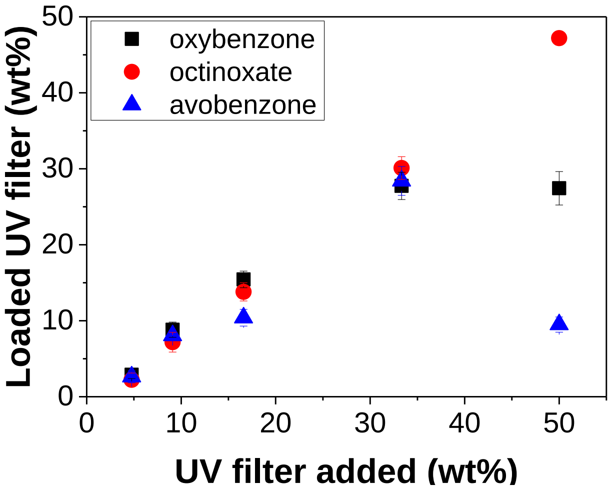

Figure S10. Amount of UV filter loaded into the larger ECNPs (~100 nm, see exact sizes for all dispersions in Table S5) as a function of the amount of UV filter dissolved in the solvent phase in the synthesis. Actual values are reported in Table S4.

The complete raw data set for Figure S10 can be found in Table S4 below. The measurements were performed in duplicate to obtain the error values.

Table S4. All the Data for Figure S10.

UV filter added (wt%)	Loaded oxybenzone (wt%)	Standard error (wt%)	Loaded octinoxate (wt%)	Standard error (wt%)	Loaded avobenzone (wt%)	Standard error (wt%)
4.8	2.9	0.5	2.2	0.9	2.6	0.8
9.1	8.8	1	7.2	1.3	8.1	0.5
16.6	15.4	1.1	13.8	1.2	10.4	1.1
33.3	27.8	1.8	30.1	1.5	28.4	1.9
50	27.4	2.2	47.2	0.9	9.5	1.0

The particle size data for the dispersions of larger ECNPs with loaded UV filters can be found in Table S5 below.

Table S5. The Particle Size Data and PDI for the Dispersions in Figure S10.

UV filter added (wt%)	Particle size mean average (nm)	PDI width (nm)
	Oxybenzone	
4.8	106	40
9.1	99	41
16.6	101	42
33.3	104	46
50	108	50
	Avobenzone	
4.8	105	39
9.1	101	44
16.6	104	41
33.3	119	49
50	115	68
	Octinoxate	
4.8	106	39
9.1	105	43
16.6	110	47
33.3	109	44
50	177	111

4. Co-Encapsulation of UV Filters with an Antioxidant Photostabilizer

Below we show the absorption profile for ECNPs with encapsulated α-tocopherol (EC: 0.275 g, α-tocopherol 0.028 g). Note the absorbance of the α-tocopherol at ~ λ = 280-300 nm.

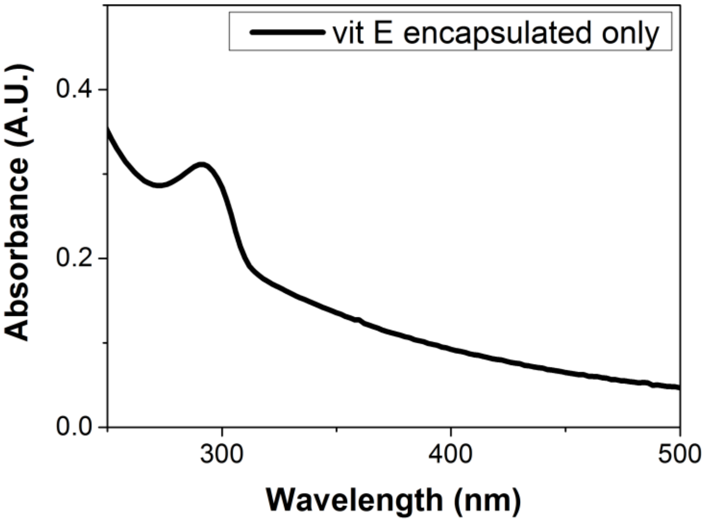

Figure S11. Absorption spectrum of ECNPs with α-tocopherol incorporated.