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# Characterization of hydrosoluble fraction and oligomers in poly(vinylidene chloride) latexes by capillary electrophoresis using electrophoretic mobility modeling

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12

13 **ABSTRACT.**

14 The characterization of hydrosoluble oligomers in latexes is an important topic in emulsion  
15 polymerization since oligomers are suspected to be responsible for latex destabilization. In this  
16 work, the hydrosoluble fraction of poly(vinylidene chloride) latexes synthesized by emulsion  
17 polymerization of three monomers (acrylic acid, methyl acrylate, vinylidene chloride) was  
18 characterized by capillary electrophoresis (CE). CE using direct UV detection permitted to  
19 estimate residual monomers and surfactants concentrations contained in the latexes serums.  
20 Water soluble oligomers, polymerization initiator (persulfate) and other inorganic anions were  
21 detected by indirect UV detection. The oligomers content in the dry extract of serum was  
22 estimated to be about 6% (% m/m) represented mainly by 9 different compounds belonging to  
23 3 different families. Using a semi-empirical electrophoretic mobility modeling, the charge  
24 number of these oligomers was estimated to be -2 and the molar masses were estimated in the  
25 range of ~300-550 g.mol<sup>-1</sup>. Oligomer samples obtained by surfactant-free polymerization, with  
26 different initial monomers proportions, provided qualitatively 14 different oligomers, including  
27 the 9 oligomers previously detected in the serums. Finally, the latex was characterized  
28 (electrophoretic mobility and zeta potential) using its serum as a background electrolyte. This  
29 approach could be very useful to study the behavior of the latexes, and possibly destabilization  
30 effect, in analytical conditions very close to its real environment / applications.

31 **Keywords:**Capillary electrophoresis, indirect UV detection, latex, hydrosoluble fraction,  
32 serum, oligomers, emulsion polymerization, electrophoretic mobility modeling.

## 33 **1. Introduction**

34 Nowadays, emulsion polymerization is widely used in the synthesis of heterogeneous polymer  
35 colloids, especially when a hydrophobic monomer is involved. In this process, the hydrophobic  
36 monomer is polymerized in an aqueous phase in presence of a surfactant playing a stabilizer  
37 role [1-4]. The emulsion polymerization allows for preparing more complex nanoparticles,  
38 controlling the polymerization rate, particles concentration and molar masses as well as limiting  
39 high temperature and viscosity problems[5]. This technique is the basis of a massive global  
40 industry that is expanding due to the versatility of the reaction and the ability to control  
41 properties to produce monodisperse latex particles used in coating, paints or in sustained release  
42 drug delivery systems. Poly(vinylidene chloride) is one example of latexes finding numerous  
43 applications in pharmaceutical and food industries. It has high barrier properties (or low  
44 permeability) to water, oxygen[6] and aroma[7] due to its high degree of crystallinity[8].

45 The mechanism of emulsion polymerization, where water acts as a continuous medium in which  
46 initiator is soluble, relies on the oligomeric radicals entry into the latex particle [9-11]. The  
47 entry occurs when oligomers chain reaches a certain length, it becomes insoluble in the aqueous  
48 phase. Oligomers radicals may terminate in the aqueous phase to produce hydrophilic species.  
49 These hydrophilic oligomers, which are not adsorbed onto the latex particle, remain in the  
50 aqueous phase of the latex (called the serum); together with other compounds such as salts, ionic  
51 surfactants, residual monomers, initiators, inhibitors, or degradation hydrophilic compounds.  
52 The presence of these hydrosoluble species may have a significant influence on the latex  
53 physico-chemical characteristics. It was reported that these oligomers are an important  
54 parameter affecting the polymerization process as well as the emulsion stabilization [12-16].  
55 Several studies were focused on the characterization of hydrosoluble oligomers, especially to  
56 model the entry of radicals in emulsion polymerization. Gilbert et al. calculated values for the  
57 degree of polymerization to be reached, for entry into a latex particle, and they found 2 for

58 polystyrene, 7-8 for poly(vinyl acetate) and 4-5 for poly(methyl methacrylate) and poly(vinyl  
59 chloride) [13]. They also obtained, experimentally, 2 for polystyrene using isotachopheresis  
60 (ITP) [17]. Eleveld et al. used liquid chromatography to separate charged and uncharged  
61 oligomers formed during emulsion polymerization [18]. Poehlein et al. separated oligomers of  
62 low molar mass by membrane filtration and characterized them by Fourier transform infrared  
63 spectroscopy (FTIR) and mass spectrometry (MS) [19]. The same group succeeded to  
64 determine oligomer molar mass by MS and the critical size to be captured by particle to be  
65 about 5-6 monomers of vinyl acetate, which is in good agreement with their theoretical value  
66 obtained by modeling [12]. Mean values of 8-9 were obtained for methyl methacrylate by  
67 means of MS and size exclusion chromatography (SEC) [20]. Van Herk and co-workers have  
68 recently developed a semi-quantitative method for oligomer analysis by MALDI-TOF-MS  
69 giving valuable information about the molar mass distribution which were similar to SEC  
70 results [11]. Independently, SEC and IR spectroscopy were used to measure oligomer size and  
71 entry rate [21]. Many techniques, such as SEC, <sup>1</sup>H-NMR and GC, were employed by Yuan et  
72 al. to characterize oligomers in the serum of latex based on styrene, butadiene and acrylic acid  
73 copolymerization. When the proportion of the latter monomer was increased, the concentration  
74 of hydrosoluble oligomers, particle number and the polymerization rate increased [22]. Salovey  
75 and co-workers used scanning electron microscopy (SEM) for size determination and SEC for  
76 monitoring oligomers formation [23,24]. Recently, dynamic light scattering technique (DLS)  
77 was developed for the determination of monomers concentration in the latex particle [25]. On  
78 the other hand, Cottet et al. demonstrated the possibility to separate oligo(styrene sulfonate) by  
79 free solution CE [26,27]. Later, Castignolles et al. demonstrated that CE provides better  
80 resolution than SEC for the separation of oligo(acrylic acid) with separation according to their  
81 tacticity [15].

82 Beyond the hydrosoluble fraction, latex particles can be characterized after synthesis by  
83 different techniques. In literature,  $^1\text{H-NMR}$  is often employed for composition determination,  
84 differential scanning calorimetry (DSC) as a technique for glass transition temperature ( $T_g$ )  
85 determination, DLS and SEM for size distribution estimation, and SEC for the separation and  
86 molar mass determination [23, 28-30]. FTIR and TGA (thermal gravimetric analysis) were used  
87 for the verification of grafting percentage of functional groups on the particle surface [31]. Zeta  
88 potential ( $\zeta$ ) is an important parameter for characterizing suspension stability. Basically, zeta  
89 potential determination requires the measurement of both electrophoretic mobility ( $\mu_{ep}$ ) and  
90 hydrodynamic radius ( $R_h$ ), combined to theoretical or numerical equations (known as O'Brien-  
91 White-Ohshima modeling), setting the relationship between  $\zeta$ ,  $\mu_{ep}$  and  $R_h$  [32-37].  $\mu_{ep}$  is  
92 often measured by Laser Doppler Velocimetry (LDV) while  $R_h$  is generally obtained by DLS  
93 on the same instrumentation. Alternatively, CE can be used for nanoparticle  $\mu_{ep}$  determination  
94 [37-39] while Taylor dispersion analysis (TDA) [40-42] provides the  $R_h$  determination using  
95 the same CE equipment. Therefore, CE instrumentation is well adapted for zetametry of  
96 nanoparticles, providing additional information on the charge density distribution /  
97 polydispersity [43,44].

98 The aim of this work was the characterize PVDC (polyvinylidene chloride) latexes and their  
99 hydrosoluble fraction by CE techniques. CE methods were developed for a quantitative  
100 estimation of the hydrosoluble fraction, for the detection and characterization of hydrosoluble  
101 oligomers and for the characterization of the latex in electrophoretic conditions close to its  
102 applications.

## 103 **2. Experimental section**

### 104 **2.1. Chemicals and samples**

105 Dowfax 2A1 surfactant was produced by the Dow Chemical Company. Vinylidene chloride  
106 (VDC) was supplied by Fluka. Arginine was purchased from Avocado (Heysham, England).

107 Acrylic acid (AA), methyl acrylate (MA), ammonium persulfate, sorbic acid, boric acid, lithium  
108 hydroxide, sodium hydroxide, pyromellitic acid (1,2,4,5 benzenetetra-carboxylic acid),  
109 polyoxyethylene (23) lauryl ether (Brij 35 of  $M \sim 1198 \text{ g mol}^{-1}$ ) and hydroxypropylcellulose  
110 (HPC,  $M_w 10^5 \text{ g mol}^{-1}$ ) were from Sigma-Aldrich (Steinheim, Germany). Deionized water was  
111 further purified with a Milli-Q system from Millipore (Molsheim, France).

112 Latexes and oligomers were provided by Solvay (Tavaux, France). Non confidential  
113 information about their synthesis is reported in this section. Latexes were prepared by semi-  
114 continuous emulsion polymerization using Dowfax 2A1 as a surfactant and in the presence of  
115 a buffering agent at  $4 \text{ g.L}^{-1}$  (note that the chemical nature was not specified by the manufacturer).  
116 Ammonium persulfate and ascorbic acid were used as polymerization initiators. Oligomers  
117 were prepared in similar experimental conditions but in the absence of Dowfax 2A1 surfactant.  
118 Latexes and oligomers are composed of 3 monomers: VDC, MA and AA. In this work, 5 latex  
119 and 5 oligomer samples were prepared at different monomers ratios; with increasing VDC to  
120 MA proportions from latex 1 to 5 and from oligomer 1 to 5. AA proportion relative to the two  
121 other monomers was kept constant for all samples. It is worth noting that, at the end of  
122 oligomers synthesis, the residual monomers were stripped off with a rotavapor until the mass  
123 of the final product was constant.

## 124 **2.2. Serum preparation**

125 The serum of different latexes was prepared by centrifugation of latex suspensions using Sig-  
126 ma 3K12 instrument ( $6935 \text{ t/min}$ ,  $5000 \text{ g}$ ,  $3 \times 120 \text{ min}$  at  $20 \text{ }^\circ\text{C}$ ). Supernatants were collected  
127 after each 120 min centrifugation cycle using a micropipette and submitted to a new  
128 centrifugation cycle. After the third cycle, a trans-parent supernatant (serum) was collected and  
129 stocked at room temperature.

## 130 **2.3. Dry extract determination**

131 2 mL of serum was placed in a small hemolysis tube and frozen in liquid nitrogen. The tube  
132 was freeze dried overnight at a pressure of about 0.7 mbar and -80°C using Cryotec freeze dryer  
133 instrument (Saint Gely du Fesc, France). The serum dry extract was determined in g.L<sup>-1</sup> by  
134 weighing the tube before ( $m_0$ ), after ( $m_1$ ) the serum addition and after the freeze-drying step  
135 ( $m_2$ ), according to:  $1000 \times (m_2 - m_0) / (m_1 - m_0)$ .

#### 136 **2.4. Latex size determination.**

137 The z-average particle diameter ( $D_z$ ) and the dispersity factor of highly diluted samples (PDI)  
138 were measured by dynamic light scattering (DLS) (NanoZS from Malvern Instruments) at 173°  
139 at 20 °C.

#### 140 **2.5. Capillary electrophoresis**

141 CE was carried out on a G1600 Agilent 3D-CE instrument (Waldbronn, Germany) equipped  
142 with a diode array detector. Fused silica (Composite Metal Services, Worcester, UK) or  
143 hydroxypropylcellulose (HPC) coated fused silica capillaries of 50 cm (41.5 cm to the UV  
144 detector)  $\times$  50  $\mu$ m I.D.  $\times$  375  $\mu$ m O.D., were used. The capillary temperature was set at 25°C.  
145 Data were collected at 200 nm in direct UV detection mode and at 254 nm in indirect UV  
146 detection mode.

147 New fused silica capillaries were conditioned by performing the following washes: 1 M NaOH  
148 for 30 min, 0.1 M NaOH for 15 min and water for 10 min. The temperature of the capillary  
149 cartridge was set at 25 °C. Between runs, fused silica capillary was flushed at 1 bar with 0.1 M  
150 NaOH for 3 min then with the BGE for 5 min. For HPC coated capillaries, the capillary was  
151 flushed, between runs, at 1 bar with water for 2 min, then with the BGE for 5 min.  
152 Electropherograms were plotted in effective mobility scale using the following equation for  
153 fused silica capillaries:

$$154 \quad \mu_{ep} = \left( \frac{1}{t} - \frac{1}{t_{eo}} \right) \frac{IL}{V} \quad (1)$$



155 where  $t$  is the migration time and  $t_{eo}$  is the migration time of the electroosmotic marker.  $V$  is the  
156 applied separation voltage,  $L$  is the total capillary length and  $l$  is the capillary length to the  
157 detection point. In the case of HPC coated capillaries, for which the EOF mobility is very low  
158 (typically about ~2-4 TU calculated by Vigh method [45], where TU stands for Tiselius Units,  
159  $1 \text{ TU} \equiv 10^{-9} \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$ ), the electropherograms were converted into mobility scale using chloride  
160 ion as a mobility marker ( $\mu_{ep} = -72.5 \text{ TU}$  in 6 mM pyromellitic / 48 mM arginine BGE).

## 161 **2.6. HPC capillary coating**

162 Capillary coating was performed using a 5% (% m/m) HPC solution prepared at room  
163 temperature and left overnight to eliminate bubbles. The capillaries (50  $\mu\text{m}$  I.D.) were filled  
164 with the polymer solution using a syringe pump at 0.03 mL/h. A stream of  $\text{N}_2$  gas at 3 bar was  
165 used to remove the excess of HPC solution and was maintained during the immobilization  
166 process of the HPC film performed by heating the capillary in a GC oven (GC-14A, Shimadzu,  
167 France). Temperature program was: 60 °C for 10 min followed by a temperature ramp from  
168 60°C to 140 °C at 5 °C/min and finally, 140 °C for 20 min. Before use, the coated capillaries  
169 were rinsed with water for 10 min.

## 170 **2.7. Capillary electrophoresis of hydrosoluble fraction**

171 For direct UV detection mode, a 100 mM lithium borate buffer, pH 9.2 was used. It was  
172 prepared by dissolution of 100 mM boric acid with 50 mM LiOH in water. For indirect UV  
173 detection mode, two different BGE were used. The first BGE was composed of 6 mM sorbic  
174 acid / 12 mM arginine / 5 mM Brij 35, pH 8.9 and was used for the analysis of moderately  
175 mobile species (-20 to -35 TU). The second BGE was composed of 6 mM pyromellitic acid /  
176 48 mM arginine, pH 9.4 and was used for the analysis of highly mobile species (-35 to -75 TU).

## 177 **2.8. Capillary electrophoresis of latex in its serum**

178 Uncoated fused silica capillaries were used. The serum, prepared as previously mentioned by  
179 latex centrifugation, was used as BGE. All samples were prepared by dilution in the serum.

## 180 **3. Results and discussion**

### 181 **3.1. Estimation of the quantity of hydrosoluble oligomers in serums**

182 As mentioned in the Chemicals section, latexes (and thus serums) may contain different  
183 components. Among all the initial ingredients, only some of them are water soluble (AA,  
184 inorganic ions, buffering agent, Dowfax 2A1 surfactant). But the hydrosoluble fraction of the  
185 latex (serum) may also contain charged oligomers of different compositions. There are  
186 obviously no available standards for these oligomers, and their quantification is therefore a  
187 difficult task. In this work, we propose to give an estimation of their mass proportion in the  
188 hydrosoluble fraction by difference.

189 Hydrosoluble compounds contained in the serum were first monitored by CZE using direct UV  
190 detection. Figure 1 shows the analysis of latex 1 (100 times diluted in water), its serum and  
191 Dowfax 2A1 raw material (used as a surfactant during the synthesis), using UV detection at  
192 200 nm in a 100 mM Li borate buffer, pH 9.2. The electropherograms are presented in mobility  
193 scale, helping the identification of the peaks observed in the latex and serum. At 200 nm, the  
194 latex particles were detected at  $\mu_{ep} \sim -35$  TU and were absent in the serum, as expected. Residual  
195 acrylic acid (AA) was only detected in the serum at  $\mu_{ep} \sim -32$  TU. Dowfax 2A1 was detected as  
196 a distribution of different species according to the number of carbons ( $n$ ) in the alkyl chain of  
197 the surfactant with  $\mu_{ep}$  ranging from -23 to -36 TU, and with a major peak migrating at  $\sim -24$   
198 TU. The chemical structure of Dowfax 2A1 is displayed in the inset of Figure 1, showing two  
199 aromatic cycles, two sulfonate groups and one alkyl chain. The higher  $n$  is, the lower the  
200 effective electrophoretic mobility is (in absolute value). In the latex sample, residual  
201 Dowfax2A1 surfactant could be observed with similar peak distribution as in Dowfax 2A1 raw  
202 material. Surprisingly, the distribution of Dowfax 2A1 surfactant was very different in serum  
203 with an enrichment of low molar mass Dowfax 2A1 molecules (see peaks 1 to 9 in the upper  
204 trace of Figure 1). This means that the sedimentation of the latex particles during centrifugation

205 tends to extract Dowfax 2A1 surfactant of higher molar mass (more hydrophobic components  
206 with smaller  $\mu_{ep}$ ) from the aqueous phase. This extraction only happens during latex  
207 sedimentation since Dowfax 2A1 distribution in latex is similar to that of Dowfax 2A1 raw  
208 material. It is worth noting that this Dowfax 2A1 extraction during particles sedimentation was  
209 observed for all the serum samples (1-5) as shown in Figure S1 (supporting information).

210 To quantify the Dowfax 2A1 surfactant, we studied its distribution. Starting from  $n=13$  for  
211 the main peak ( $\mu_{ep} \sim -24$  TU), other peaks detected in the serum were assigned to lower  $n$  value  
212 following a linear  $1/\mu_{ep}=f(n)$  correlation, as displayed in the inset of Figure S2 in supporting  
213 information. The linearity of this correlation allows us to guess the exact number of carbons in  
214 the alkyl chain compared to the  $n=13$  peak. Such linear correlation was typically observed for  
215 end-charged (macro)molecules [46]. Using this relationship, it is then possible to get the  
216 surfactant distribution according to  $n$  in Dowfax 2A1 raw material and in serum. These  
217 distributions (Figure S2-A in supporting information) are obtained from the electropherograms  
218 by changing the variables from migration time to effective mobility, and finally, from effective  
219 mobility to the  $n$  variable following the general scheme recently described [47] (see supporting  
220 information for calculation details). From the chemical structure of Dowfax 2A1, one can  
221 assume that the response coefficient at 200 nm is proportional to Dowfax 2A1 molar  
222 concentration regardless the value of  $n$  in the alkyl chain. Therefore, distributions given in  
223 Figure S2-A are molar concentration sensitive distributions. From these distributions, one can  
224 determine the number- and the weight-average carbons number ( $\langle n \rangle_n$  and  $\langle n \rangle_w$ , respectively)  
225 for Dowfax 2A1 in the serum and in the raw material. The weight-average carbons number  
226  $\langle n \rangle_w=11.7$  obtained for Dowfax 2A1 raw material was in good agreement with an average of  
227 12 carbons obtained by NMR (see Figure S2-B), and was larger than the  $\langle n \rangle_w=9.9$  obtained  
228 for Dowfax 2A1 in serum. By external calibration using the Dowfax 2A1 raw material, it has

229 been possible to estimate the mass concentration of residual Dowfax 2A1 in serum 1 (10.8 g.L<sup>-1</sup>)  
230 <sup>1</sup>), representing ~47% in mass percentage of the serum dry extract (see Table 1).

231 AA was quantified in the serum 1 by external calibration at 0.11 g.L<sup>-1</sup> corresponding to 0.5%  
232 (% m/m) of serum dry extract. The serum content in buffering agent was estimated at 4 g.L<sup>-1</sup>  
233 (17.5% of the serum dry extract) assuming that the buffering agent stays in the aqueous phase  
234 after centrifugation due to high hydrophilicity.

235 Other ions which may be found as residuals or as degradation compounds are not detected in  
236 direct UV detection. These ions such as ammonium persulfate (used as initiator), sulfate  
237 (resulting from persulfate degradation) and chloride ions (resulting from VDC degradation)  
238 could be detected using indirect UV detection (electropherograms are presented in section 3.2).  
239 Their quantification by external calibration leads to 21% of ammonium sulfate, 3% of  
240 ammonium persulfate and 5% of hydrochloric acid; all estimated as mass percentage of the dry  
241 extract of serum 1 (see Table 1). Knowing the quantity of all hydrosoluble compounds except  
242 the oligomers, the oligomers content in serum dry extract could be estimated by difference at  
243 ~6% in serum 1 dry extract. The presence of oligomers was next investigated by indirect UV  
244 detection.

245

### 246 **3.2. Oligomers analysis by indirect UV detection (IUV) in surfactant free polymerization** 247 **samples.**

248 The detection of oligomers has been first investigated on five specific oligomer samples  
249 obtained by polymerization using the same chemical composition in VDC/MA/AA monomers  
250 as for the latexes, but without surfactant to enhance the production of oligomers in water phase.  
251 The AA amount was kept constant in order to investigate the influence of the ratio VDC / MA  
252 on the synthesis of oligomers. To cover a large range of  $\mu_{ep}$ , and to minimize the  
253 electromigration distortion phenomena (EMD), two different BGE were used; based on two

254 different co-ions (chromophores or probe ions). For low mobility species (-20 to -35 TU), a  
255 BGE composed of 6 mM sorbic acid (monocharged) was selected (detection at 254 nm). For  
256 high mobility species (-35 to -75 TU), 6 mM pyromellitic acid (four charges) was chosen. In  
257 both cases, arginine counter-ion was used to buffer the BGE at pH ~9 to ensure deprotonation  
258 of weak acid (carboxylic) moieties. Brij 35 was added in sorbate BGE for reasons explained in  
259 section 3.4. (Serums analysis by indirect UV detection).

260 Figure 2 displays the electropherograms obtained for the 5 oligomer solutions of different  
261 VDC/MA/AA chemical compositions. Figure 2A covers the  $\mu_{ep}$  region between -20 and -35 TU  
262 where 9 oligomer peaks were detected in sorbate BGE. In Figure 2B, 5 other oligomers (peaks  
263 10 to 14) could be identified in the pyromellitate BGE. It should be noted that the  
264 electropherograms in Figure 2 were obtained for different dilution ratios as indicated on the  
265 graph. Residual sulfate, persulfate and chloride ions were also identified in this region of highly  
266 mobile species.

267 Regarding the quantity of oligomers present in the five samples, the sum of the time-corrected  
268 peak area of peaks 1 to 9 (corrected by the dilution factor of the injected sample given in Figure  
269 2) is presented in Figure 3 (black symbols) as a function of oligomers with the VDC content  
270 increasing from oligomer 1 to 5. Clearly, the amount of oligomers decreases by one order of  
271 magnitude with increasing mass proportion in VDC. This can be explained by the high  
272 hydrophobicity of VDC (0.25% m/m solubility at 20.5 °C and 0.21% m/m at 55 °C; [48])  
273 compared to MA (5% m/m solubility at 60 °C; [49]). When the amount of VDC increases in  
274 the mixture of monomers, the global amount of monomers solubilized in water decreases.  
275 Moreover, the decrease of VDC initial content increases the hydrophilicity (and water  
276 solubility) of the oligomers. As illustrated in Figure S3 in supporting information, the increasing  
277 opacity of the oligomers solutions is due to the increasing VDC initial content which generates  
278 much hydrophobic oligomers creating more and more particles by homogeneous nucleation.

279 Qualitative comparison of the oligomer distribution between the 5 samples was performed by  
280 plotting the ratio of time-corrected area of peak 9 to the sum of the time-corrected area of peaks  
281 1-9 as a function of the VDC initial content (red symbols in Figure 3). The relative proportion  
282 of peak 9 in the mixtures is clearly increasing with increasing initial VDC content and this  
283 illustrates the change in oligomers distribution when changing the initial monomers chemical  
284 composition.

### 285 **3.3. Characterization of oligomers using effective mobility modeling**

286 To get a better insight on oligomers characteristics, we plotted in Figure 4 the effective mobility  
287 of a set of about 30 different and variously charged organic molecules taken from the literature  
288 [50, 51] according to the variable:

$$289 \quad x = \frac{\ln(1+z)}{M^{0.43}} \quad (2)$$

290 where  $z$  is the effective charge number of the molecule (taking into account the dissociation  
291 state of the solute) and  $M$  is the molar mass, following the semi-empirical dependence proposed  
292 by Grossman et al. [50]. To allow the comparison between the data derived from the literature  
293 and the data obtained for the studied oligomers in this work, all the mobility values were  
294 corrected for the ionic strength effect to a value of 3.7 mM (corresponding to the ionic strength  
295 used by Grossman et al. [50]) and at 25°C. The effective mobility values with the  
296 aforementioned corrections are given in Table S1 in supporting information, including data  
297 from the literature and from this work. The set of data from the literature covers a wide range  
298 of charge numbers from 1 to 8 and molar masses from 132 to 4541 g.mol<sup>-1</sup>. Using the linear  
299 relationship displayed in Figure 4, the  $x$  values of oligomers (peaks 1-9 in Figure 2A) were  
300 obtained and gathered in Table 2. These 9 oligomers are distributed according to 3 different  
301 groups corresponding to different ranges of electrophoretic mobility (see Figure 2A). From the  
302  $x$  values, the molar masses were calculated assuming an oligomer charge number ( $z$ ) from -1 to  
303 -3 (see Table 2). It is interesting to notice that the difference in molar mass between groups

304  $\Delta M_r(\text{I}; \text{II})$  and  $\Delta M_r(\text{II}; \text{III})$  are in the same order of the molar masses of the neutral monomers  
305 ( $M_{MA} = 86 \text{ g}\cdot\text{mol}^{-1}$  and  $M_{VDC} = 97 \text{ g}\cdot\text{mol}^{-1}$ ) in the case of  $z = -2$ ; while  $\Delta M_r$  between two  
306 successive groups would be too low to correspond to a monomer in the case of  $z = -1$  ( $\Delta M_r \sim 35$ );  
307 and too high in the case of  $z = -3$  ( $\Delta M_r \sim 175$ ). Therefore, we can conclude from the semi-  
308 empirical electrophoretic mobility modeling that the oligomers (peaks 1-9) are most likely  
309 doubly charged oligomers, varying by one monomer, VDC or MA, between two successive  
310 groups. The two chemical groups that can bring the charges to the oligomers may be a sulfate  
311 moiety coming from the initiation polymerization step, and/or an acrylic acid group  
312 incorporated in the chain. Setting  $z = -2$ , the estimated molar masses of the 9 oligomers (peaks  
313 1 to 9) can be derived from  $x$  values of Table 2 between 300 and 550  $\text{g}\cdot\text{mol}^{-1}$ . Putative chemical  
314 structures associated to the 9 peaks for  $z = -2$  are proposed in Table 2.

315 The two charges of the first putative structure in Table 2 are attributed to a sulfate moiety  
316 coming from the initiation polymerization step, and to an acrylic acid group incorporated in the  
317 chain for oligomers initiated in the aqueous phase that terminated by transfer (to monomer) or  
318 by recombination with oligomers generated by H-abstraction. For the second putative structure  
319 in Table 2, they are attributed to two sulfate moieties for oligomers without acrylic acid, that  
320 terminated by recombination, and for the third structure, to two acrylic acid for oligomers  
321 generated by H-abstraction that terminated by recombination. The different chemical pathways  
322 leading to the different putative structures are given in Scheme S1 in SI.

323 Of course, such approach cannot afford formal structural determination of these oligomers;  
324 and the proposed structures should be considered as possible structures. However, using this  
325 general and relatively simple approach based on electrophoretic mobility modeling permitted  
326 to get important information on the oligomer characteristics. For instance, the degree of  
327 polymerization of the putative structures varies from 4 to 6 for oligomers in group 1, from 3 to  
328 5 for oligomers in group 2 and from 3 to 4 for oligomers in group 3. These values are in very

329 good agreement with the z-mer values reported in literature for emulsion polymerization in the  
330 case of heterogeneous nucleation [2]. The simplicity of the proposed approach should be  
331 considered since peak assignment based on CE-MS coupling would not be possible using the  
332 optimized BGE presented in this work due to compatibility reasons (non-volatility).

### 333 **3.4. Serums analysis by indirect UV detection (IUV)**

334 The experimental conditions optimized on the analysis of the surfactant-free polymerization  
335 samples were applied to serums analysis. Figure 5A shows the electropherograms obtained in  
336 sorbic acid/arginine buffer/Brij 35 for 5 serums of different VDC/MA/AA compositions. Brij  
337 35 was used to avoid any interference between the oligomers and the residual Dowfax 2A1 by  
338 reducing the effective mobility of Dowfax 2A1 surfactant which interacts with the neutral Brij  
339 micelles. Comparing to Figure 2A (surfactant-free polymerization), in addition to the  
340 previously mentioned 9 peaks (peaks 1 to 9), a new peak is observed between peaks 6 and 7.  
341 This new peak, denoted by \*, could belong to a new oligomer formed during latexes synthesis  
342 in presence of Dowfax 2A1 surfactant. Furthermore, serums analysis in pyromellitic acid buffer  
343 (Figure 5B) shows only 2 oligomers peaks (10 and 14), while peaks 11-13 previously observed  
344 in Figure 2B are not observed here. The missing oligomers could have been preferentially  
345 adsorbed by micelles or existing particles and finally completely extracted from the serum [52].

346 Other peaks observed after oligomer 14, belong to residual inorganic ions: sulfate, persulfate  
347 and chloride. The quantity of these ions was estimated as previously discussed in section 3.1.,  
348 and the corresponding values are given in Table 1 for serum 1.

349 A qualitative comparison of the oligomers distributions in the different serums is displayed  
350 in Figure 3 (inset) via the time-corrected peak area of peak 9 relative to peaks 1-9. The  
351 proportion of peak 9 is increasing with increasing VDC content in the initial monomer mixture.  
352 These results are similar to our observations for oligomers samples analysis and confirm that  
353 oligomers distribution in serum samples is changing according to the initial monomers chemical



354 composition. On the other hand, all serum samples were analyzed at the same dilution (1/50)  
355 and the sum of the time-corrected peak area of 1-9 peaks is similar for all serums. Contrary to  
356 our observation for surfactant-free polymerization samples, no significant difference in  
357 oligomers quantity between serums was observed. This phenomenon could be attributed to the  
358 mechanism of particles nucleation which is different in presence of Dowfax 2A1. A micellar  
359 nucleation occurred when Dowfax 2A1 was used whereas the nucleation was heterogeneous in  
360 surfactant-free polymerization. The oligomers were adsorbed by micelles and by the resulting  
361 particles in the five experiments (latexes). As the surfactant concentration was kept constant,  
362 the number of formed particles, and so the surface accessible to the oligomers, was identical in  
363 all cases.

### 364 **3.5. Study of latex electrophoretic behavior in its serum**

365 To characterize the latex in electrophoretic conditions which are the closest to the conditions  
366 of fabrication / application, CZE of the latex was performed using its own serum as BGE. These  
367 conditions were developed to mimic the medium in which the latex is being used. Figure 6  
368 displays the electropherograms obtained for 3 latexes (3, 4 and 5) analyzed by CZE in their  
369 corresponding serums. The electrophoretic mobility was determined for each latex in its serum  
370 and the corresponding values are -58.5, -54.7 and -52.2 TU for latex 3, 4 and 5, respectively.  
371 The heterogeneity of the electrophoretic mobility distributions can reflect both charge and size  
372 dispersities of the latex sample. From the average  $\mu_{ep}$  values, combined to the hydrodynamic  
373 radius ( $R_h$ ) determined by DLS, zeta potential ( $\zeta$ ) were determined by means of O'Brien-White-  
374 Ohshima (OWO) modeling [32], assuming that the latexes are dense spherical objects which  
375 charged in surface. For the calculation using the OWO modeling, the ionic strength of the serum  
376 was evaluated at ~120 mM by taking the NaCl concentration leading to the same current  
377 intensity in the same experimental conditions (capillary dimensions, voltage, temperature). This  
378 is a rough estimation, but it is difficult to provide a better evaluation. Dimensionless ionic drag

379 coefficients of sodium and chloride ions were used in the OWO modelling, as a first  
 380 approximation. For details about the method of  $\zeta$  determination, one can refer to references [32,  
 381 43]. From  $\zeta$  values, surface charge density ( $\sigma$ ) and effective charge number ( $z_{eff}$ ) were calculated  
 382 from the following equations (see Table 3 for the numerical values) [53, 43]:

$$383 \quad \sigma = \frac{2\varepsilon_0\varepsilon_r\kappa k_B T}{ze} \sinh\left(\frac{ze\zeta}{2k_B T}\right) \left[ 1 + \frac{1}{\kappa R_h} \frac{2}{\cosh^2(ze\zeta/4k_B T)} + \frac{1}{(\kappa R_h)^2} \frac{8 \ln[\cosh(ze\zeta/4k_B T)]}{\sinh^2(ze\zeta/2k_B T)} \right]^{1/2} \quad (3)$$

$$384 \quad z_{eff} = \frac{4\pi\sigma R_h^2}{e} \quad (4)$$

385 where  $k_B$  is the Boltzmann constant ( $1.38 \cdot 10^{-23} \text{ J K}^{-1}$ ),  $T$  is the absolute temperature (K),  $\kappa$  is  
 386 Debye-Hückel parameter,  $e$  is the elementary electric charge,  $\varepsilon_r$  is the relative electric  
 387 permittivity,  $\varepsilon_0$  is the electric permittivity of vacuum,  $z$  is the charge number of the electrolyte  
 388 ions (considered as a 1:1 electrolyte here). The numerical values of  $\sigma$  indicate a difference in  
 389 surface charge density up to about 20% between latexes in their suspensions due to the  
 390 differences in their monomers initial compositions.

#### 391 4. Conclusion

392 In this work, a quantitative estimation of the different species constituting the hydrosoluble  
 393 fraction (or serum) of poly(vinylidene chloride) latexes was performed using direct and indirect  
 394 UV detection in CZE. Up to 6% m/m was found for oligomer content in the serum dry extract.  
 395 Since oligomers are not detected in direct UV detection, this estimation was established by  
 396 difference after the quantification of the other species contained in the serum. A large part of  
 397 the hydrosoluble fraction (about 47% m/m) is constituted by residual Dowfax 2A1 surfactant,  
 398 of which the distribution is very different from the Dowfax 2A1 raw material. The latex  
 399 particles sedimentation by centrifugation tends to extract the large molar mass Dowfax 2A1  
 400 surfactant from the aqueous phase. To visualize oligomers, indirect UV detection was  
 401 implemented with two different chromophores (or probe ions). Quantitative and qualitative

402 differences were observed in the oligomers distributions depending on the monomers initial  
403 composition of latexes (or of the surfactant-free polymerizations). Electrophoretic mobility  
404 modeling allowed us to propose putative chemical structure based on di-charged oligomers with  
405 molar masses comprised between 300 and 550 g.mol<sup>-1</sup>. Finally, latexes were characterized,  
406 regarding their zeta potential and effective charge, by CZE in experimental conditions close to  
407 their real environment using their own serum as BGE.

408

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412 **Author Contributions**

413 The manuscript was written through contributions of all authors. All authors have given  
414 approval to the final version of the manuscript.

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549  
550

551 FIGURE CAPTIONS

552 Figure 1. Mobility scale electropherograms for latex 1, its serum and Dowfax 2A1 raw material,  
553 each peak is assigned by the number of carbon atoms in the alkyl chain ( $n = 0-13$ ). The inset  
554 shows the Dowfax 2A1 structure. BGE: 100 mM Li borate buffer, pH 9.2. Experimental  
555 conditions: Fused silica capillary 50 cm (41.5 cm to the detector)  $\times$  50  $\mu$ m I.D.  $\times$  375  $\mu$ m O.D.  
556 Separation voltage: +10 kV with 10 mbar co-pressure. Hydrodynamic injection: 50 mbar, 5 s.  
557 Temperature: 25  $^{\circ}$ C. AA stands for acrylic acid.

558 Figure 2. Mobility scale electropherograms for oligomers of different VDC/MA/AA  
559 compositions with VDC content increasing from oligomer 1 to 5. (A) Electropherograms in the  
560 range of -20 and -35 TU obtained in BGE 6 mM sorbic acid / 12 mM arginine / 5 mM Brij 35,  
561 pH 8.9. (B) Electropherograms, in the mobility range of -45 and -75 TU, obtained in BGE 6  
562 mM pyromellitic acid / 48 mM arginine, pH 9.4. Experimental conditions: HPC coated capillary  
563 50 cm (41.5 cm to the UV detector)  $\times$  50  $\mu$ m I.D.  $\times$  375  $\mu$ m O.D. Separation voltage: -30 kV.  
564 Hydrodynamic injection: 50 mbar, 5 s. Temperature: 25  $^{\circ}$ C. Samples were prepared by dilution  
565 of the stock solutions with water. Dilutions are indicated on each electropherogram. Oligomers  
566 groups I to III are indicated on graph 2A.

567 Figure 3. Quantitative (left) and qualitative (right) comparison between different oligomer  
568 distributions in surfactant free polymerization samples ( $\blacksquare$ ,  $\bullet$ ) or in serum displayed in the inset  
569 ( $\blacktriangledown$ ). ( $\blacksquare$ ) Sum of the time-corrected peak area of peaks 1-9 in surfactant free polymerization  
570 samples. ( $\bullet$ ) Relative time-corrected peak area of peak 9 in surfactant free polymerization  
571 samples. Relative time-corrected peak area of peak 9 in serums of emulsion polymerization  
572 samples ( $\blacktriangledown$ ).

573 Figure 4. Relationship between the electrophoretic effective mobility  $\mu_{ep}$  and the  $x$  parameter  
574 (Eq. 2) for variously charged organic molecules (peptides) taken from the literature [48,49] and

575 for the oligomers of this work. Numerical values used to plot this figure are given in supporting  
576 information (Table S1).

577 Figure 5. Mobility scale electropherograms for serums of different VDC/MA/AA compositions  
578 with VDC content increasing from serum 1 to 5. BGE: (A) 6 mM sorbic acid / 12 mM arginine  
579 / 5 mM Brij 35, pH 8.9, (B) 6 mM pyromellitic acid / 48 mM arginine, pH 9.4. Experimental  
580 conditions: HPC coated capillary 50 cm (41.5 cm to the UV detector) × 50 μm I.D. × 375 μm  
581 O.D. Separation voltage: -30 kV. Hydrodynamic injection: 50 mbar, 5 s. Temperature: 25 °C.  
582 All samples were prepared by 50 fold dilution of the stock solutions with water. AA stands for  
583 acrylic acid.

584 Figure 6. Mobility scale electropherograms for latexes 3, 4 and 5 analyzed in BGE composed  
585 of their serums 3, 4 and 5, respectively. Experimental conditions: fused silica capillary 50 cm  
586 (41.5 cm to the UV detector) × 50 μm I.D. × 375 μm O.D. Separation voltage: -10 kV.  
587 Hydrodynamic injection: 50 mbar, 5 s. Temperature: 25 °C. Samples were prepared by dilution  
588 of the latex suspension in its own serum. Dilution factors are indicated on each  
589 electropherogram.



Figure1

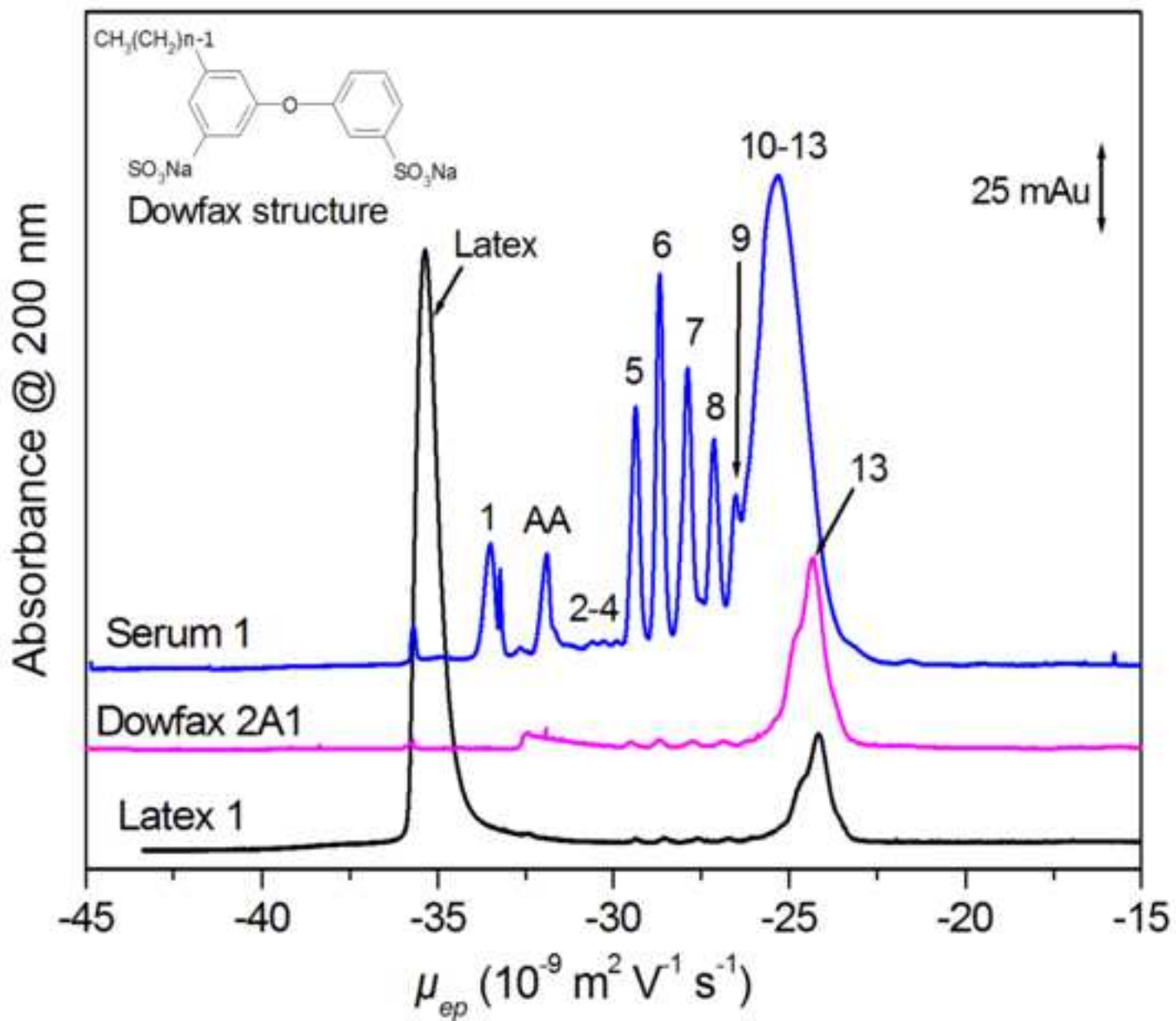


Figure2A

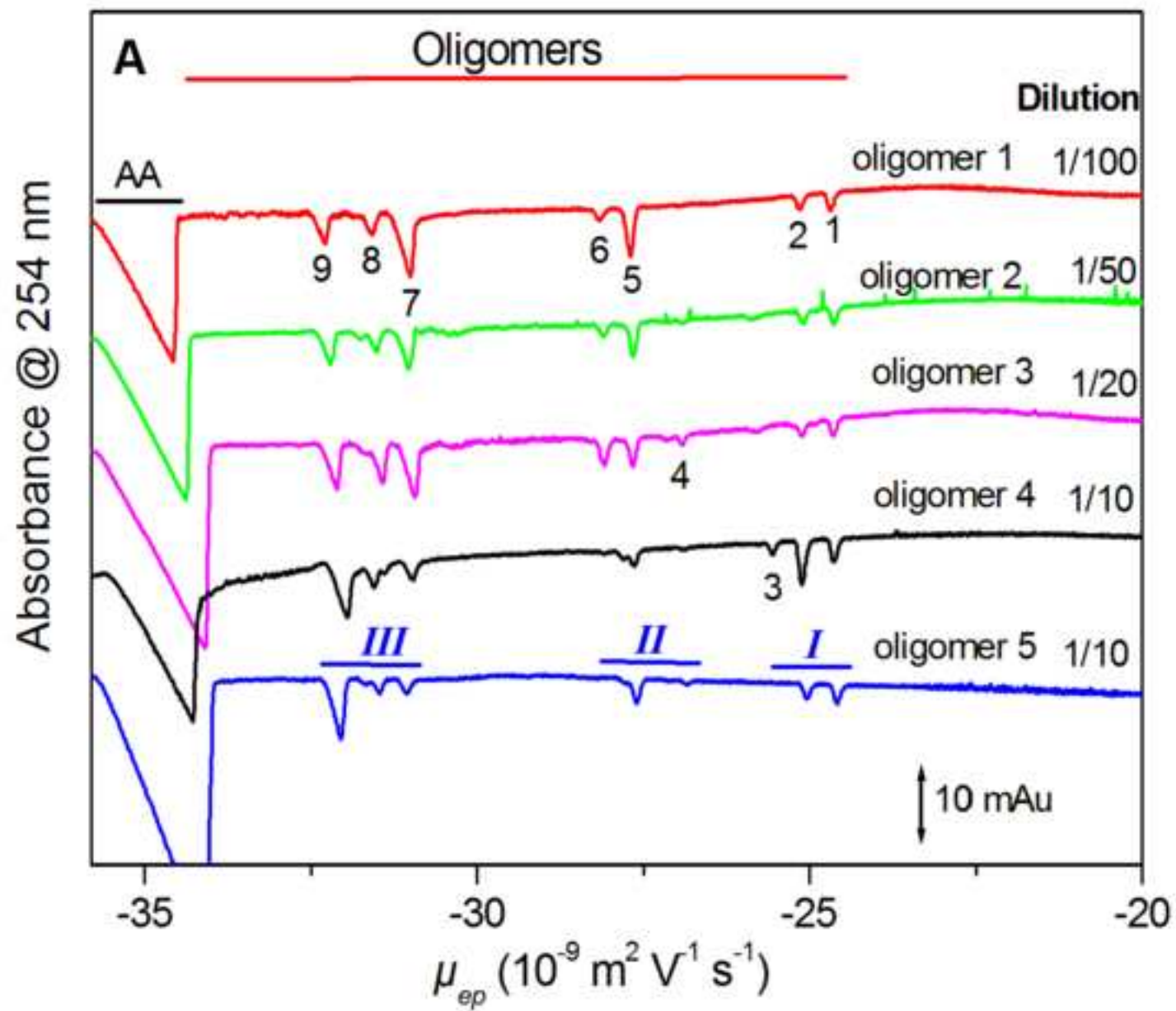


Figure2B

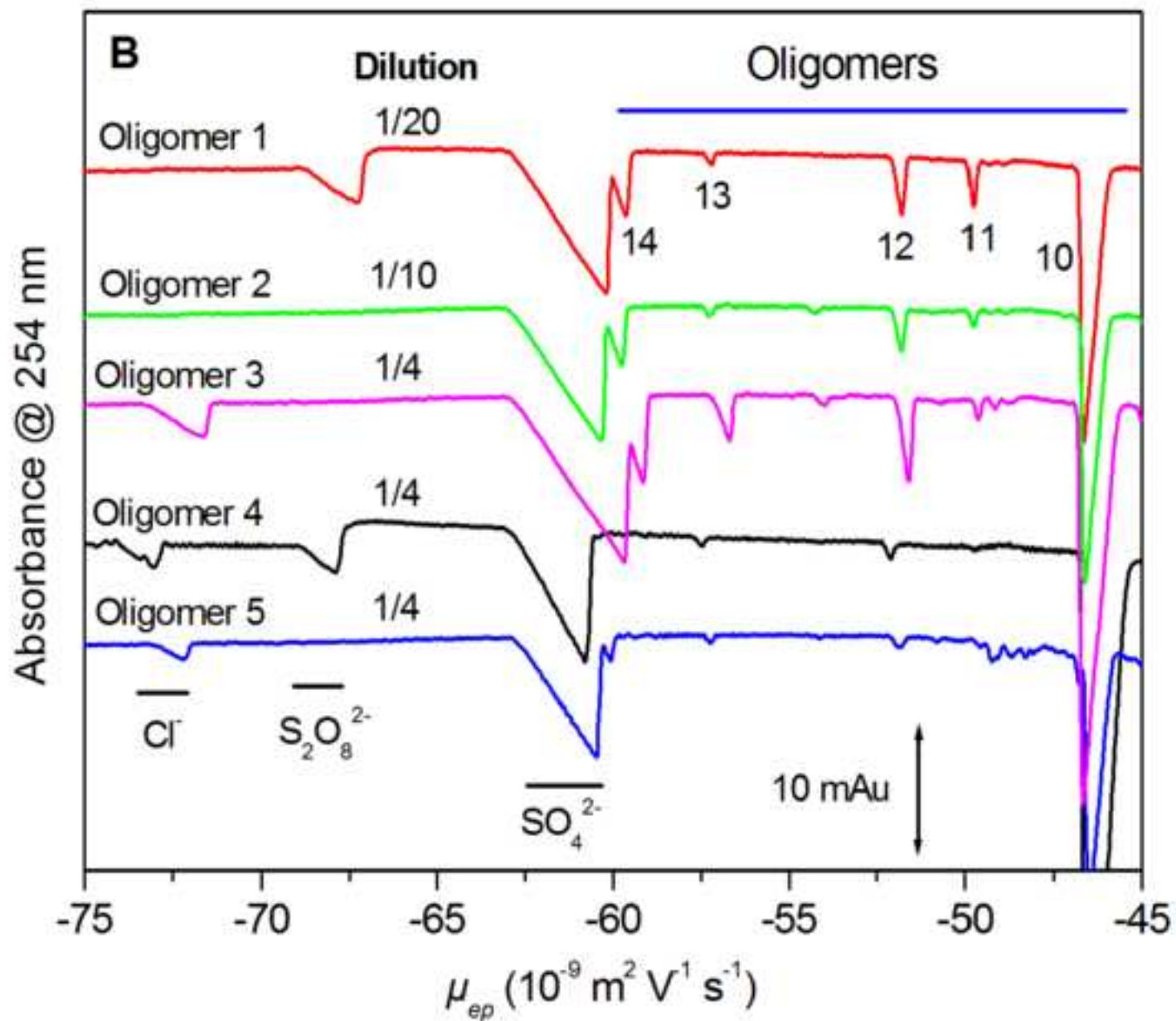


Figure3

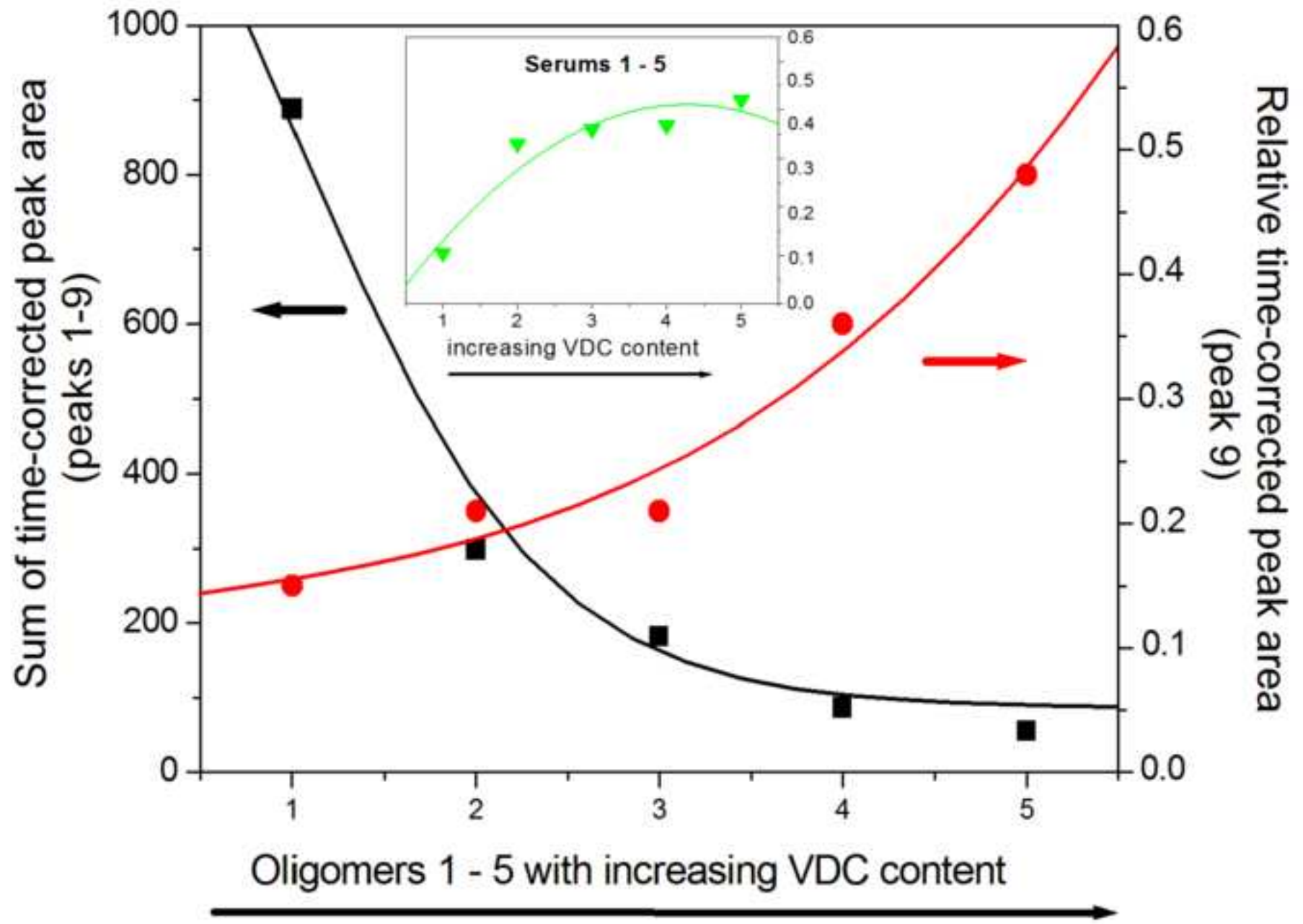


Figure4

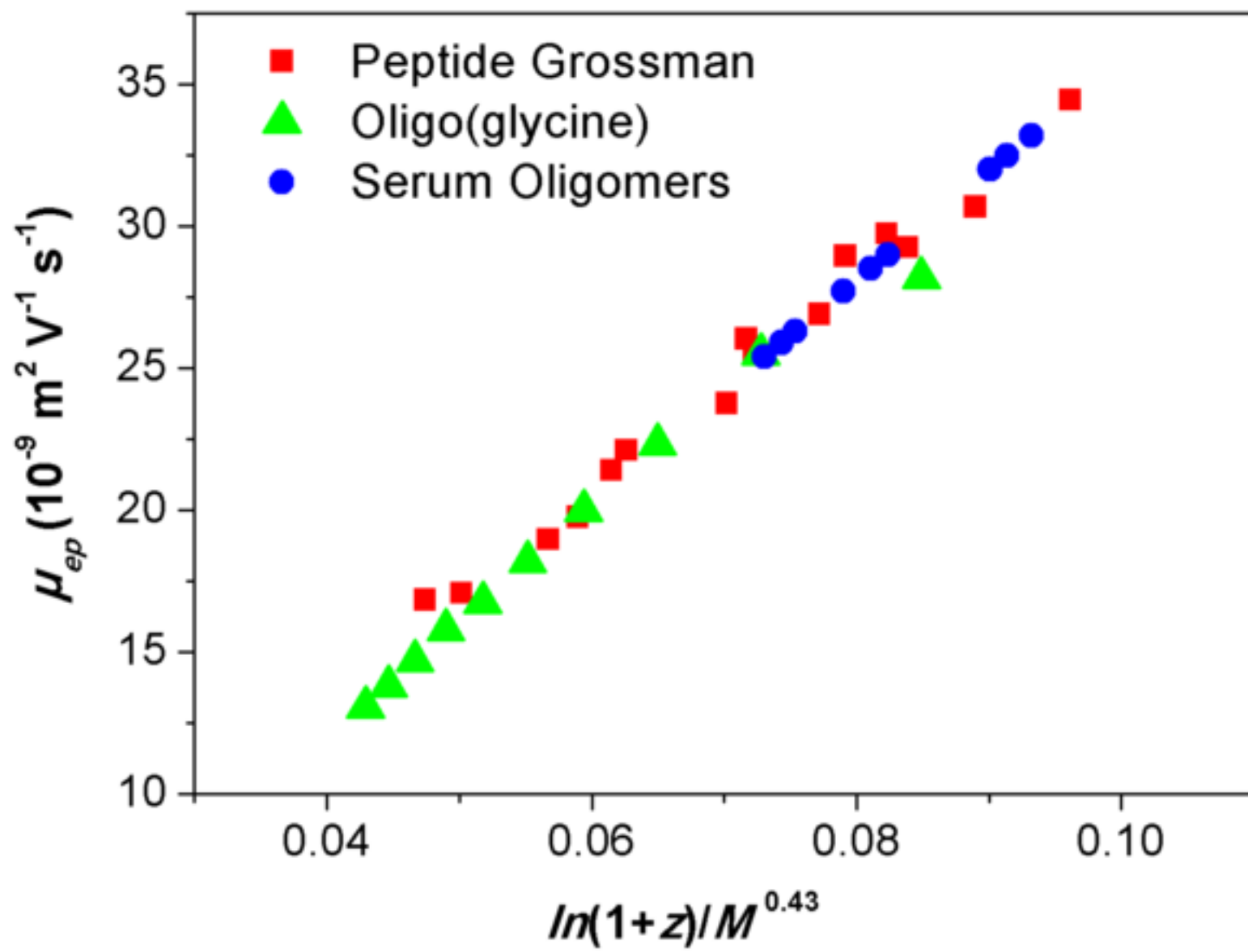


Figure5A

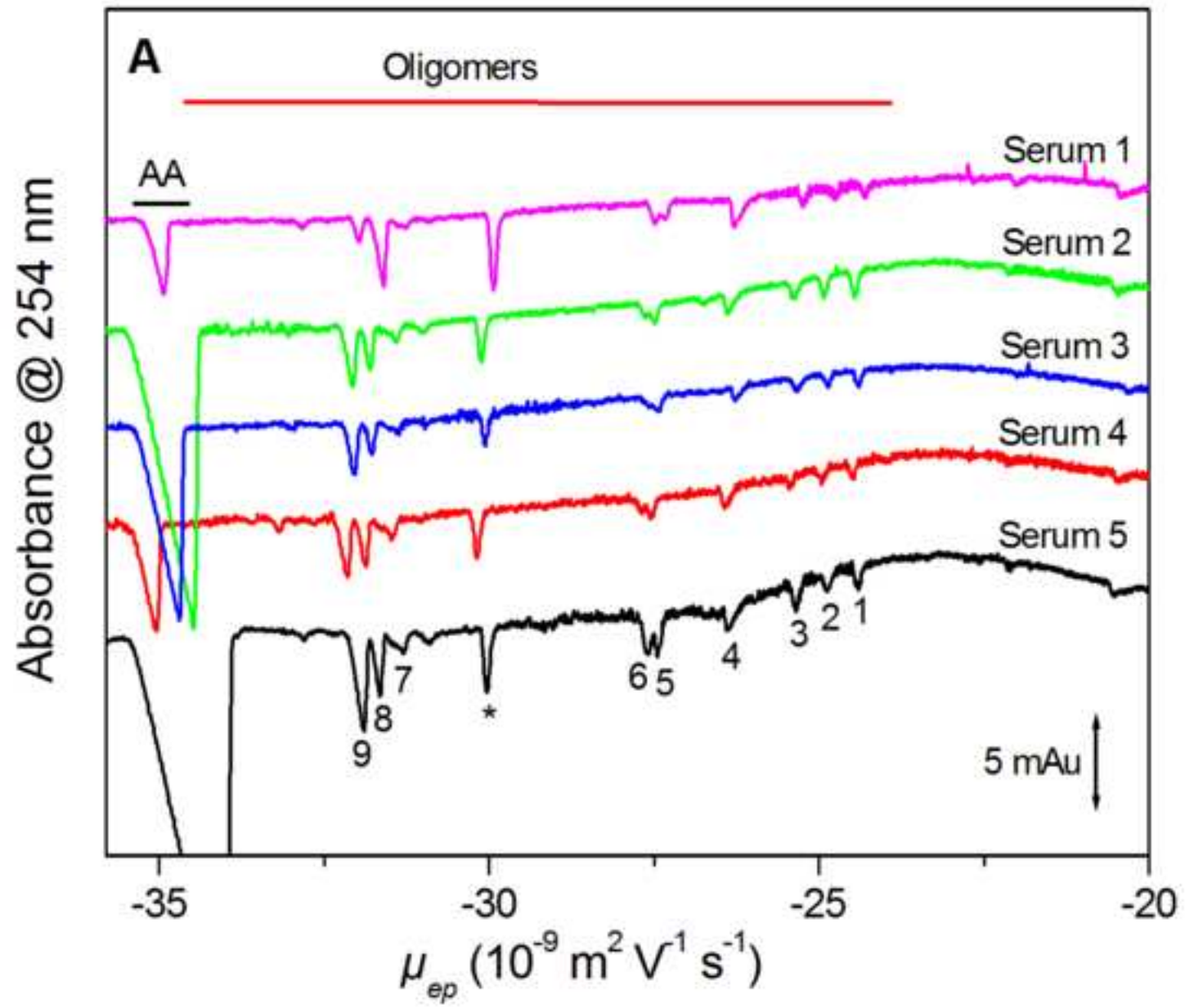


Figure5B

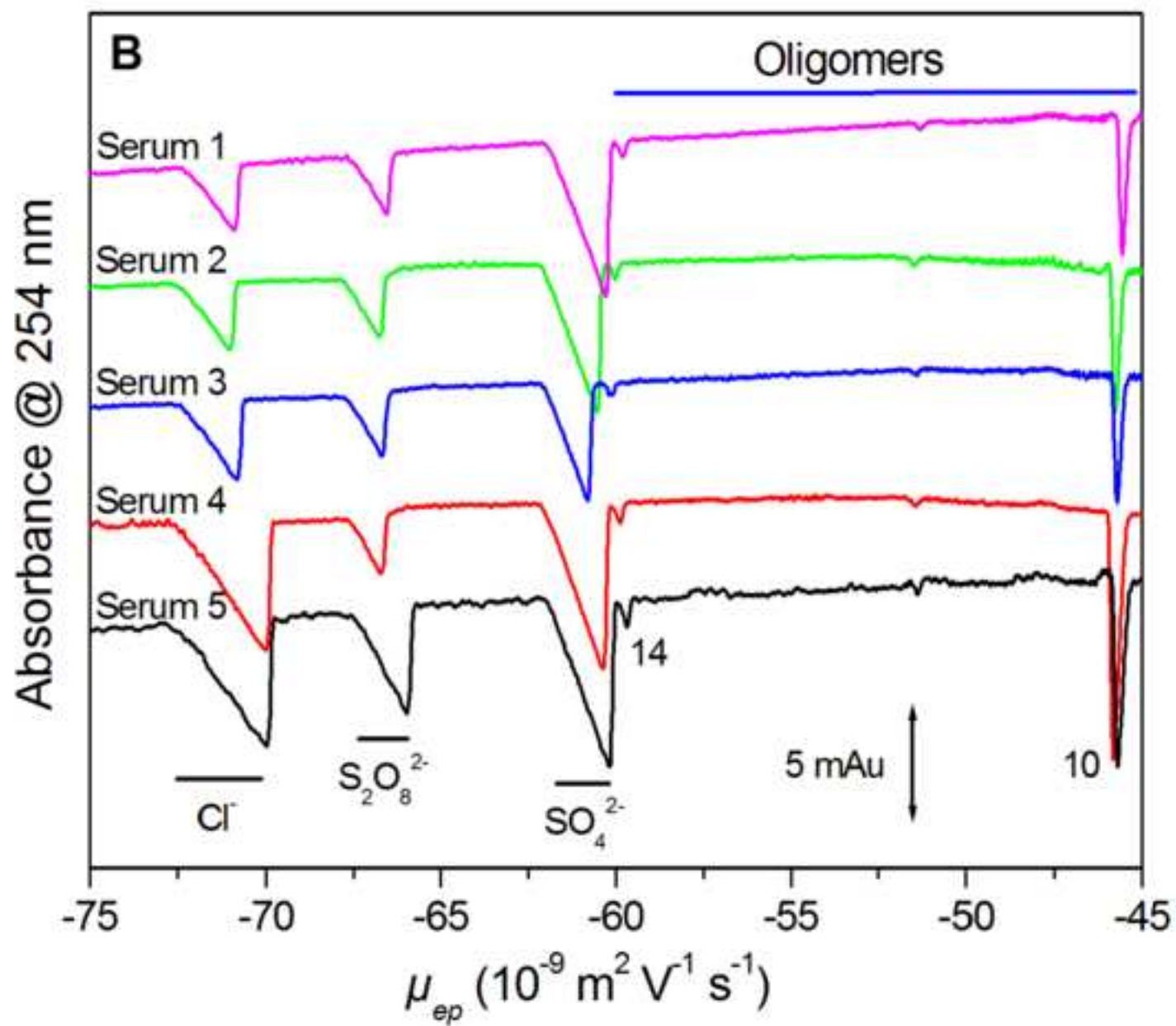
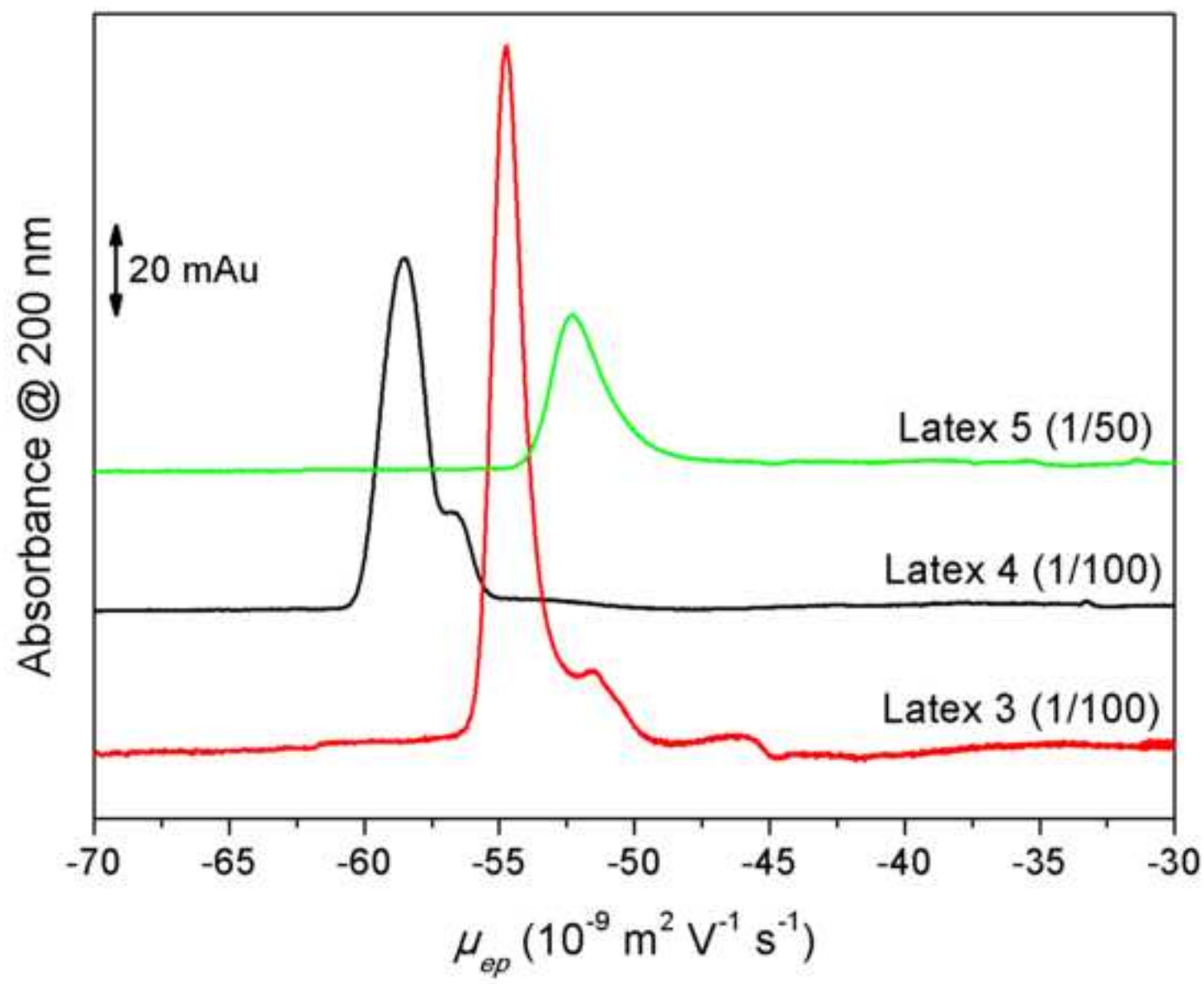


Figure6



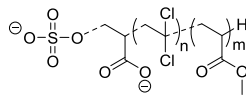
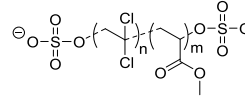
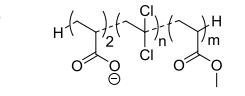


1 **Table 1.** Estimation of the quantity of hydrosoluble oligomers in serum 1 containing 23 g.L<sup>-1</sup> of dry extract (% m/m). Mass  
 2 concentrations ( $C_m$ ) and mass percentage (% m/m) are presented for the different components of the serum: buffering agent, sulfate  
 3 ( $\text{SO}_4^{2-}$ ), persulfate ( $\text{S}_2\text{O}_8^{2-}$ ), chloride (Cl), acrylic acid (AA) and Dowfax 2A1. Oligomers quantity was estimated by difference.

	$C_m$ (g.L <sup>-1</sup> )	% m/m <sup>a</sup>	RSD <sup>e</sup>
<b>Buffering agent<sup>b</sup></b>	4	17.5	N/A
<b>SO<sub>4</sub><sup>2-</sup><sup>c</sup></b>	4.8	21	1.5%
<b>S<sub>2</sub>O<sub>8</sub><sup>2-</sup><sup>c</sup></b>	0.7	3	1.1%
<b>Cl<sup>d</sup></b>	1.1	5	1.0%
<b>AA<sup>d</sup></b>	0.11	0.5	0.2%
<b>Dowfax 2A1 in serum 1</b>	10.8	47	3.1%
<b>Oligomers in serum 1</b>	1.5	6	N/A

4 <sup>a</sup> Mass percentage of the serum dry extract. <sup>b</sup> Quantity estimated assuming that the introduced quantity (4 g/L) of the buffering agent  
 5 remains in aqueous phase. <sup>c</sup> Quantity estimated as ammonium salts by CE using external calibration. <sup>d</sup> Mass estimated as HCl and as  
 6 CH<sub>2</sub>=CHCOOH for AA by CE using external calibration; AA stands for acrylic acid. <sup>e</sup> RSD relative standard deviation determined on 3  
 7 repetitions; N/A stands for not applicable.

**Table 2.**  $x$  values for the water soluble oligomers determined from the  $\mu_{ep} = f(\ln(1+z)/M^{0.43})$  correlation displayed in Figure 4 and the corresponding predicted molar masses  $M_r$  according to the possible charge number  $z$  (from -1 to -3). Putative chemical structures with the corresponding exact molar masses proposed for  $z = -2$  ( $n$  (resp.  $m$ ) is the number of VDC monomers (resp. MA monomers) in the oligomer). The three groups of oligomers (denoted I, II and III) correspond to different groups of peaks (from peak 1 to peak 9) having different effective mobility ranges.

Oligomer	$x$	$M_r$			Putative chemical structure ( $z=-2$ )			
		( $z = -1$ )	( $z = -2$ )	( $z = -3$ )				
Group I	Peak 1	0.0730	187	547	939	(3; 1; 544), (4; 0; 555)	(1; 3; 547)	-
	Peak 2	0.0743	180	525	902	(1; 3; 522), (2; 2; 533)	(0; 4; 536)	(4; 0; 530), (3; 1; 519)
	Peak 3	0.0754	174	508	873	(0; 4; 511)	-	(2; 2; 508), (1; 3; 497)
Group II	Peak 4	0.0790	156	456	783	(3; 0; 458), (2; 1; 447)	(1; 2; 461), (0; 3; 450)	-
	Peak 5	0.0811	147	429	737	(0; 3; 425), (1; 2; 436)	-	(3; 0; 433), (2; 1; 422)
	Peak 6	0.0824	142	414	711	-	-	(1; 2; 411), (0; 3; 400)
Group III	Peak 7	0.0901	115	336	576	(0; 2; 339)	-	(2; 0; 336), (1; 1; 325)
	Peak 8	0.0914	111	325	558	-	-	(1; 1; 325)
	Peak 9	0.0932	106	310	533	-	-	(0; 2; 314)

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2 **Table 3.** Characterization of latexes 3, 4 and 5 in their own serum (used as background electrolyte, BGE).

<b>Sample</b>	<b>BGE<sup>a</sup></b>	<b><math>\mu_{ep}^b</math></b>	<b><math>R_h^c</math></b>	<b><math>\zeta_{owo}^d</math></b>	<b><math>\sigma^e</math></b>	<b><math>z_{eff}(10^{+4})^f</math></b>
<b>Latex 3</b>	Serum 3	-54.7	67	-0.075	-0.0849	-2.99
<b>Latex 4</b>	Serum 4	-58.5	88	-0.080	-0.0943	-5.74
<b>Latex 5</b>	Serum 5	-52.2	55	-0.072	-0.0797	-1.89

3 <sup>a</sup> Serums prepared by latex centrifugation as mentioned in section "serum preparation" in the experimental part. <sup>b</sup> effective mobility in  
4  $10^{-9} \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$ . <sup>c</sup> hydrodynamic radius in nm, determined by DLS. <sup>d</sup> zeta potential in V, determined using O'Brien-White-Ohshima  
5 modeling [32] taking an ionic strength of 120 mM and ionic drag coefficients of sodium and chloride ions in OWO modelling. <sup>e</sup> surface  
6 charge density in  $(\text{C m}^{-2})$  calculated using equation (3). <sup>f</sup> effective charge number calculated using equation (4). Experimental conditions as  
7 in Figure 6.

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