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Colloidal stability of dextran-modified latex particles toward adsorption of concanavalin A

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Abstract The colloidal stability of the dextran-modified poly(methyl methacrylate) (PMMA) latex particles toward adsorption of a carbohydrate-binding protein, concanavalin A (Con A), is primarily controlled by the charge neutralization mechanism. Formation of a crosslinked network structure via the specific affinity interactions between the dimeric Con A molecules and the dextran molecules anchored onto different latex particles may also have an impact on the coagulation kinetics. Judging from the data of coagulation kinetics, the colloidal stability of the latex particles toward added Con A in the decreasing order is: latex particles without dextran modification > latex particles with a dextran content of 2.15% > latex particles with a dextran content of 1.24% based on total polymer weight (PMMA + grafted dextran). The coagulation mechanisms involved in the adsorption of Con A onto the latex particles have been proposed to explain these experimental data. Charge neutralization of the negatively charged latex particles by adsorption of the positively charged Con A is the predominant destabilization mechanism. The ratio of the number of dextran active sites to that of Con A molecules plays an important role in the formation of the crosslinked network structure. The electrolytes in water cause a reduction in the electrostatic repulsion force among the interactive latex particles, but this ionic strength effect is not significant in comparison with charge neutralization.

Key words Colloidal stability – dextran-modified latex particles – concanavalin A – electrostatic/steric stabilization – charge neutralization

Introduction

Submicron latex particles have been used to purify proteins from a crude biological mixture by either electrostatic interactions or specific ligand–protein interactions because of the extremely large particle surface area provided by these polymeric supports [1–13]. In our previous work [14], stable poly(methyl methracrylate) latex particles were prepared by using dextran as the protective colloid. Dextran can be chemically coupled onto the latex particle surfaces by the grafting reaction, as shown by the color development with the phenol–sulfuric acid reaction [15]. These dextran-modified latex particles may find potential application in affinity purification of carbohydrate-binding proteins (lectins) such as concanavalin A (Con A). The protein Con A shows an equal or better specific affinity for carbohydrates such as dextran in comparison with antibodies for antigens [16]. According to the work of Edelman et al. [17], Con A exhibits a dimeric (pH = 2.0–5.8) or tetrameric (pH > 5.8) structure. The Con A species may thus specifically bind to the surface dextran active sites which are chemically incorporated onto different latex particles. This will lead to a crosslinked network structure. Furthermore, the isoelectric point (pI) of Con A is 7.1 [18] and, therefore, the net charge of the Con A molecules in a pH 5 phosphate solution should be positive. Adsorption of Con A onto the dextran-modified latex particle surfaces is expected to take place due to the electrostatic attraction force between the positively charged Con A species and the latex particles carrying negative charges. Such a self-promoting adsorption process [19] can cause charge neutralization, reduce the particle surface charge density, and destabilize the dextran-modified latex particles. The counterions Na^+, Ca^{2+}, and Mn^{2+} associated with the Con A solution (see the Experimental section) will compress the electric double layer of the latex particles carrying negative charges (derived from the persulfate initiator). This in turn can reduce the repulsive force among the interactive latex particles and, thereby, decrease the stability of these particles significantly according to DLVO theory [20, 21]. All these factors will contribute to the destabilization of the dextran-modified latex particles and, thereby, induce the selective precipitation of the resultant large flocs.

The coagulation rate and the resultant structure of flocs may have an important influence on the affinity adsorption of Con A onto the dextran-modified latex particles. For example, the number of effective binding sites on the dextran-modified latex particle surfaces may be greatly reduced due to the steric hindrance effect provided by the crosslinked network structure as the selective precipitation process proceeds. This may result in a decrease in the binding capacity of these dextran-modified latex particles. On the other hand, formation of large enough flocs may facilitate precipitation of the dextran–Con A complex out of the crude extract by gravitational or centrifugal force. An optimal condition may thus exist in the selective precipitation of Con A induced by the dextran-modified latex particles. Therefore, it is crucial to gain a better understanding of the fundamental aspects of the colloidal stability of these dextran-modified latex particles toward affinity adsorption of Con A in order to assure a successful process development.

Experiments of coagulation kinetics [22–25] were originally designed for determination of the colloidal stability of the electrostatically stabilized latex particles toward added electrolytes (e.g., NaCl). The stability of the negatively charged latex particles decreases rapidly with increasing concentration of the counterion Na^+. This is due to the fact that the enhanced ionic strength of the aqueous solution can greatly compress the electric double layer of the latex particles and, hence, decrease the electrostatic stabilization effect [19, 20]. The objective of this project was to use the technique of coagulation kinetics to gain a better understanding of the very complicated crosslinking system of the dextran-modified latex particles/Con A.

Experimental

The chemicals used in this work include the dextran-modified poly(methyl methacrylate) (PMMA) latex particles D20 and D75 and the D0 PMMA latex particles stabilized only by the surface SO_4^- groups obtained from ref. [14] ; dextran with a molecular weight of approximate 5×10^5 g/mol (Fluka Biochemika); sulfuric acid (Shimakyu's Pure Chemicals); phenol (Nacalai Tesque Inc.); sodium chloride (Riedel-de Haen); calcium chloride (J.T. Baker); manganous chloride (J.T. Baker); sodium phosphate, monobasic monohydrate (J.T. Baker); concanavalin A (Con A) (Type III, Sigma); deionized water (Barnsted, Nanopure Ultrapure Water System, specific conductance $< 0.057\ \mu$S/cm).

The dextran content (C^*(Dextran)) of the dextran-modified emulsion polymers was determined by measuring the absorbance at 485 nm (Shimadzu, UV-160A) after color development with the phenol–sulfuric acid reaction [15]. The parameter C^*(Dextran) represents the weight percentage of dextran based on total polymer weight (PMMA + grafted dextran). First, 1 ml of the dextran-modified latex (solid content = 0.5%) was mixed with 0.5 ml phenol (5%) and 3 ml pure sulfuric acid. The reaction mixture was stirred for 10 min at 25 °C, followed by measuring the absorbance at 485 nm. The calibration curve (absorbance = 0.03456 C^*(Dextran) − 0.008504) was established by a series of standards with a volume of 1 ml, a solid content of 0.5%, and prescribed amounts of D0 emulsion polymer and dextran. The experiment using the latex sample with [Dextran] = 0% was taken as the reference (zero point).

Before the experiments of coagulation kinetics were carried out, the latex product was separated into the supernatant phase and the precipitate phase by centrifugation at 11 000 rpm for 15 min (Beckman, J2-21). The clear supernatant was withdrawn, followed by redispersion of the precipitate in fresh deionized water using a mini ultrasonic cleaner (Delta DG-1). This procedure was repeated at least three times to remove the free dextran molecules in water. The particle size data determined by the dynamic light scattering method show that the dextran-modified latex particles are very stable toward at least five cycles of centrifugation–redispersion [14]. A latex sample with a total solid content of 0.02% was prepared by using a pH 5 phosphate solution comprising 0.15 M NaCl, 0.1 mM Ca^{2+}, and 0.1 mM Mn^{2+}. The latex sample with a volume of 0.6 ml was then mixed rapidly with an equal volume of the pH 5 phosphate solution comprising a prescribed quantity of Con A (0.47–22.98 μM), 0.15 M NaCl, 0.1 mM Ca^{2+}, and 0.1 mM Mn^{2+} to initiate the affinity precipitation of Con A. The divalent cations Ca^{2+} and Mn^{2+} were used to ensure the complete dissolution of Con A in water throughout this work, unless otherwise stated. The absorbance of the latex sample was monitored by a spectrophotometer (Shimadzu UV-160A) at 540 nm for determination of the coagulation kinetics and the critical flocculation concentration of the D0, D20, and D75 latices toward added Con A (CFC(Con A)). Twelve minutes after the start of the coagulation kinetics experiments, the zeta potential (ζ) of the D0 latex particles containing various concentrations of Con A (C(Con A) = 0, 0.26, 1.95, 5.49, and 12.38 μM) was determined by Zetamaster (Malvern). Five measurements were made for each latex sample and the average of these five measurements was reported as the ζ of the latex sample.

Results and discussion

Latices D20 and D75 have similar particle sizes (d_w) and particle size distributions (d_w/d_n) but different levels of dextran modification. The parameters d_w and d_n are the weight-average and number-average particle diameters, respectively. For comparison, the PMMA latex product D0, which has a comparable particle size and is stabilized only by the surface SO_4^- groups originating from the persulfate initiator, was also included in this work. The recipe for preparing the D0 latex product is exactly the same as that for the D20 or D75 latex product except that no dextran was incorporated into the D0 latex particles. Some physical properties of these latex products are summarized in Table 1. The parameters [Dextran] and CCC(NaCl) represent the amount of dextran (wt% based on total monomer) used in the latex synthesis work and the critical coagulation concentration of the latex particles at pH 5 toward added NaCl. Also included in this table is the C^*(Dextran) data for the dextran-modified emulsion polymers determined in this work (see the Experimental section). The larger the value of C^*(Dextran), the greater is the amount of dextran grafted onto the latex particle surfaces. Furthermore, the D20 latex particles show similar particle size (d_w) and polydispersity index (d_w/d_n) to those of D75. Thus, the density of dextran on the D75 latex particle surfaces should be greater than that on the D20 latex particle surfaces. The critical coagulation concentration of the D0, D20, and D75 latices at pH 5 toward added NaCl (CCC(NaCl)) are 0.175, 0.305 and 0.880 M, respectively. This is simply because the D0 latex particles are stabilized only by the electrostatic repulsion force, whereas both the D20 and D75 latex particles are protected more effectively by the synergetic electrostatic and steric stabilization mechanisms.

Table 1 Some physical properties of the dextran-modified latex products

	[Dextran] [%]	d_w [a] [nm]	d_w/d_n [a]	C^* (Dextran) [%]	CCC(NaCl) [b] [M]
D0	0.0	207	1.007	0.00	0.175
D20	2.0	175	1.016	1.24	0.305
D75	7.5	181	1.016	2.15	0.880

[a] Particle size data based on TEM.
[b] Critical coagulation concentration of NaCl at pH 5.

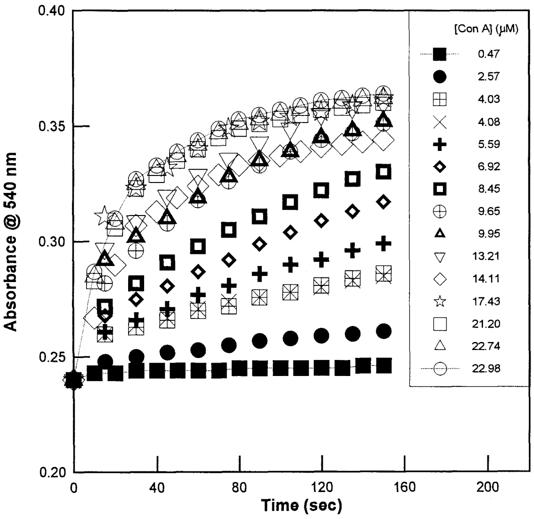

Fig. 1 Typical absorbance versus time profiles for the dextran-modified latex D75 at pH 5: C(Con A) (μM): 0.47 (■), 2.57 (●), 4.03 (⊞) 4.08 (×), 5.59 (✚), 6.92 (◆), 8.45 (▣),9.65 (⊗), 9.95 (▲), 13.21 (▽), 14.11 (◇), 17.43 (☆), 21.20 (□), 22.74 (△), 22.98 (○)

The typical absorbance (A) at 540 nm versus time (t) profiles with various levels of Con A (C(Con A) = 0.47–22.98 μM) for the dextran-modified D75 latex particles in a pH 5 phosphate solution are shown in Fig. 1. Both the D0 and D20 latices also show similar A versus t profiles. A general feature of the coagulation kinetics data is that at constant C(Con A) the value of A increases with increasing t. This trend indicates the scenario that the dimension of the flocculated latex particles continues to build up as the precipitation process proceeds. Furthermore, at constant t the value of A increases with increasing C(Con A), but the difference diminishes as C(Con A) approaches the range of 17–23 M (see the ☆, □, △, and ○ data points in Fig. 1). According to Fuchs [26], the stability ratio (W) is defined as the ratio K_r/K_s, where K_r and K_s are the rapid flocculation rate constant and slow flocculation rate constant, respectively. For example, the value of W for the D75 latex sample at

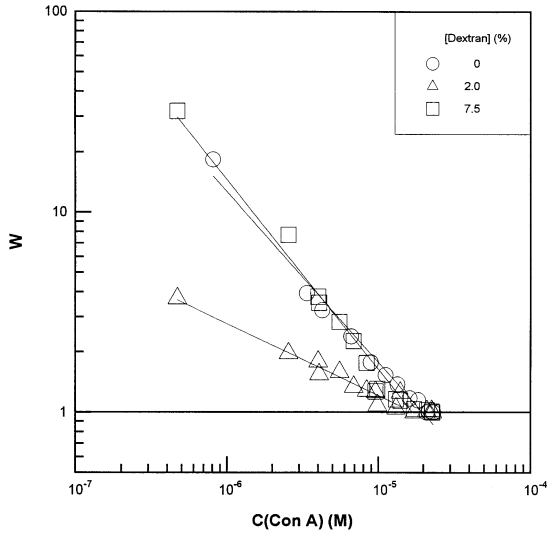

Fig. 2 Stability ratio versus Con A concentration profiles for the latex sample at pH 5: D0 (○), D20 (△), D75 (□)

Table 2 Colloidal stability data for the D0, D20, and D75 latices in a pH 5 phosphate solution obtained from the experiments of coagulation kinetics

	CFC(Con A) [μM]	CFC(Con A) / C*(Dextran) [μM]	$d(\log W)$ / $d(\log C(\text{Con A}))$ [1/M]
D0	18.6	—	− 0.882
D20	16.4	1322	− 0.359
D75	17.1	795	− 1.011

C(Con A) = 6.92 μM can be estimated as the ratio of the asymptotic slope of the A versus t curve at $t = 0$ (e.g., the initial slope as C(Con A) → 22.98 μM in Fig. 1) to the slope of the A versus t curve at $t = 0$ (e.g., the initial slope at C(Con A) = 6.92 μM in Fig. 1). This is because K_r or K_s is proportional to the initial slope of the A versus t curve. The log W versus log C(Con A) profiles for the D0, D20 and D75 latices in a pH 5 phosphate solution are shown in Fig. 2. The discontinuous point in the log W versus log C(Con A) profile is then identified as the critical flocculation concentration of the dextran-modified latex particles toward added Con A (CFC(Con A)). The resultant CFC(Con A) data for these latices are summarized in Table 2.

It is shown in Tables 1 and 2 that the CFC(Con A) data are relatively insensitive to changes in C*(Dextran) (0–2.15%) and these data are about four orders of magnitude smaller than those of CCC(NaCl). This result implies that Con A is much more effective in destabilizing both the latex sample without dextran modification (D0) and the dextran-modified latex sample (D20 or D75) than NaCl. Note that the value of CFC(Con A) for the D20 or D75 latex product is only slightly lower than that for the D0 latex product. This result then leads to the postulate that formation of a crosslinked network structure by the affinity interactions between the dimeric Con A species and the dextran active sites grafted onto different latex particles indeed enhances the coagulation rate, but this effect is not as important as other destabilization factors. The predominant destabilization factor may be the charge neutralization of these negatively charged dextran-modified latex particles induced by adsorption of the positively charged Con A molecules.

To verify this point, the ζ data for a series of D0 latex samples with various levels of C(Con A) were determined and the result is summarized in Table 3. The negative sign in front of the symbol ζ indicates that the latex particles carry negative charges. The absolute value of ζ drops rapidly from 61.5 to 27.4 mV when deionized water is replaced by a pH 5 phosphate solution comprising 0.15 M NaCl, 0.1 mM Ca^{2+}, and 0.1 mM Mn^{2+}. Such a change in ζ represents the influence of the counterions Na^+, Ca^{2+}, and Mn^{2+} on the colloidal stability. No precipitate was observed for the latex sample, but the average latex particle size increased from 207 to 323 nm (an average of three measurements determined by the dynamic light scattering method; Otsuka, Photal LPA-3000/3100). This signaled the start of limited flocculation among the interactive latex particles induced by compression of the electric double layer of the particles by the counterions present in the aqueous phase. Thus, the latex particles exposed to such an aqueous environment were on the verge of instability because the electrolyte concentration approached the value of CCC(NaCl) (0.175 M). The absolute value of ζ continues to decrease from 27.4 to 0.4 mV and, consequently, the latex particles become unstable when C(Con A) increases from 0 to 12.38 μM. Note that the ζ data become more scattered when C(Con A) increases from 0 to 12.38 μM. The latex particles may even carry positive charges due to the excessive adsorption of Con A molecules onto the latex particles ($\zeta = -1.5 - +0.7$ mV) when C(Con A) is equal to 12.38 μM. In this case, quantitative determination of the ionic strength effect on the colloidal stability of the complicated system of Con A/D0 latex particles with various extents of dextran modification is not straightforward. This is because the system comprises two extremely different populations of colloidal particles: the D0 latex particles (207 nm in diameter) surrounded by an electric double layer rich in positively charged counterions and the Con A molecules (the molecular weight $\sim 5.3 \times 10^4$ g/mol and the dimension of one subunit $\sim 42 \times 40 \times 39$ Å [17]) surrounded with an atmosphere rich in negatively charged counterions. Obviously, this scenario cannot be described by the conventional DLVO

Table 3 Zeta potential data for a series of D0 latex samples with various concentrations of Con A

C(Con A) [μM]	$0^{a)}$	$0^{b)}$	$0.26^{b)}$	$1.95^{b)}$	$5.49^{b)}$	$12.38^{b)}$
$-\zeta$ [mV]	61.5 ± 1.5	27.4 ± 0.7	19.7 ± 0.8	9.3 ± 1.4	2.2 ± 0.9	0.4 ± 1.1

$^{a)}$ Deionized water.
$^{b)}$ pH 5 phosphate solution (0.15 M NaCl, 0.1 mM Ca^{2+}, and 0.1 mM Mn^{2+}).

theory. This subject is beyond the scope of this work. These ζ data support the above speculation that the coagulation kinetics is primarily controlled by the effect of charge neutralization of the latex particles provided by Con A. Although the ζ of the D20 or D75 latex particles in the presence of salts and/or Con A have not been measured in this work, these dextran-modified particles are expected to be less sensitive to the ionic strength effect due to the synergistic electrostatic and steric stabilization mechanisms.

It is also interesting to note that at very low values of C(Con A) (e.g., 0.47 μM) the value of W for the D20 latex particles is about one order of magnitude smaller than that for the D75 latex particles, as shown in Fig. 2. The D20 latex particles with a lower C^*(Dextran) (1.24%) are expected to be more stable than the D75 latex particles with a higher C^*(Dextran) (2.15%) due to the reduced extent of affinity adsorption of Con A onto the dextran-modified latex particles with a decrease in C^*(Dextran). The value of W then approaches unity for both the D20 and D75 latices when C(Con A) becomes high enough (C(Con A) $\rightarrow$ 17 μM). In addition, the absolute value of the least-squares best-fitted slope of the $\log W$ versus $\log C$(Con A) line for the D20 latex product is much smaller than that for the D75 latex product (see Fig. 2 and the $d(\log W)/d(\log C(\text{Con A}))$ data in Table 2). As a matter of fact, the slope of the log W versus log C(Con A) line for the D75 latex particles is quite close to that for the D0 latex particles (see Fig. 2 and Table 2).

Figures 3–5 show the $(A - A_0)/A_0$ data as a function of C(Con A) at various adsorption times (30–150 s) for the D0, D20, and D75 lattices in a pH 5 phosphate solution, respectively. The parameters A_0 and A are the absorbance of the mixture of the latex particles and Con A at 540 nm at time equal to zero and t, respectively. The ratio $(A - A_0)/A_0$ represents the degree of coagulation occurring in the course of adsorption of Con A onto the latex particles. The larger the ratio $(A - A_0)/A_0$, the greater is the degree of coagulation (i.e., the larger is the resultant flocs). For the D0 latex particles, the ratio $(A - A_0)/A_0$ increases significantly with increasing C(Con A), as shown in Fig. 3. This trend indicates that the colloid stability of the D0 latex particles decreases rapidly as more Con A is used in the coagulation experiment. At very low values of C(Con A) (e.g., C(Con A) $< 4\,\mu$M), the ratio $(A - A_0)/A_0$ is very small (e.g., $(A - A_0)/A_0 < 0.1$). In addition, at constant C(Con A), the vertical span of the $(A - A_0)/A_0$ data (~ 0.02) with t being increased from 30 to 150 s is relatively narrow (see the bottom left corner in Fig. 3). At constant C(Con A), the larger the span of the $(A - A_0)/A_0$ data, the

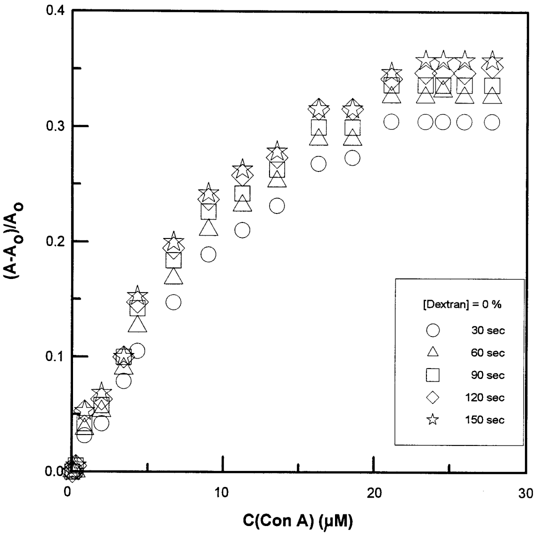

Fig. 3 $(A - A_0)/A_0$ versus Con A concentration profiles for the D0 latex at pH 5 at various absorption times (s): 30 (○), 60 (△), 90 (□), 120 (◇), 150 (☆)

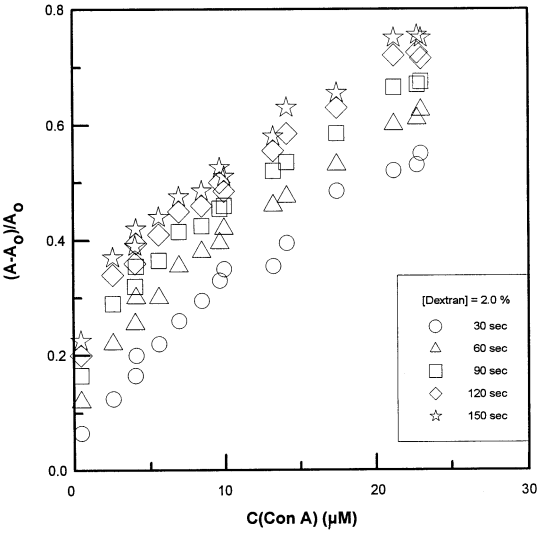

Fig. 4 $(A - A_0)/A_0$ versus Con A concentration profiles for the D20 latex at pH 5 at various absorption times (s): 30 (○), 60 (△), 90 (□), 120 (◇), 150 (☆)

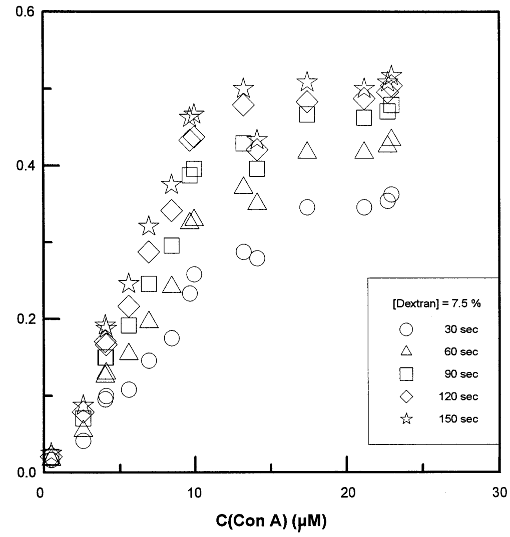

Fig. 5 $(A - A_0)/A_0$ versus Con A concentration profiles for the D75 latex at pH 5 at various absorption times (s): 30 (○), 60 (△), 90 (□), 120 (◇), 150 (☆)

less stable is the colloidal system (i.e., the more significant is the change in the dimension of flocs) when t increases from 30 to 150 s. In this case, C(Con A) is not high enough to reduce the colloidal stability of the latex particles significantly. For example, the absolute value of ζ is greater than 10 mV when C(Con A) is lower than 2 μM (see Table 3). On the other hand, the ratio $(A - A_0)/A_0$ becomes significant (e.g., $(A - A_0)/A_0 > 0.3$) and the span of the $(A - A_0)/A_0$ data ($\sim$0.05) is relatively broad when C(Con A) is greater than 20 μM (see the top right corner in Fig. 3). These experimental data suggest that the D0 latex particles become unstable as a result of the compression of the electric double layer and the subsequent charge neutralization of the latex particles by the adsorbed Con A molecules (see path (a) in Fig. 6).

Figures 3 and 4 show that the $(A - A_0)/A_0$ versus C(Con A) profiles for the D0 latex particles is different from those for the D20 latex particles. It is shown in Fig. 4 that the span of the $(A - A_0)/A_0$ data ($\sim$0.21) is much broader for the D20 latex product in comparison with the D0 latex product. This is presumably due to the scenario that the crosslinking reaction between the dimeric Con A molecules and the dextran-modified latex particles comes into play in the experiments of coagulation kinetics. Furthermore, the span of the $(A - A_0)/A_0$ data is quite uniform over the range of C(Con A) investigated in this work. This result implies that the Con A species is still effective in inducing the formation of a crosslinked network structures even when C(Con A) is very low (see the bottom left corner in Fig. 4). The destabilization mechanism involved in the adsorption of Con A onto the D20 latex particles is shown schematically by path (b) in Fig. 6. On the other hand, Figs. 3 and 5 show that the $(A - A_0)/A_0$ versus C(Con A) profiles for the D75 latex particles are similar to those for the D0 latex particles. For the D75 latex particles at very low values of C(Con A) (e.g., C(Con A) < 5 μM), however, the ratio $(A - A_0)/A_0$ is very small (e.g., $(A - A_0)/A_0 < 0.1$) and the span of the $(A - A_0)/A_0$ data ($\sim$0.06) is relatively narrow (see the bottom left corner in Fig. 5). It is then postulated that the colloidal stability for the D75 latex particles with a higher degree of dextran modification at C(Con A) < 5 μM is achieved by the increased probability of forming affinity bonds between the dimeric Con A molecules and the dextran molecules on the same latex particle surface due to the very high ratio of dextran to Con A. This event may alleviate the crosslinking reaction and, thereby, make the colloidal system more stable toward affinity adsorption of Con A onto the D75 latex particles (see path (c) in Fig. 6). The influence of the crosslinking reaction among the interactive latex particles increases rapidly when C(Con A) is above 5 μM (the span of the $(A - A_0)/A_0$ data is about

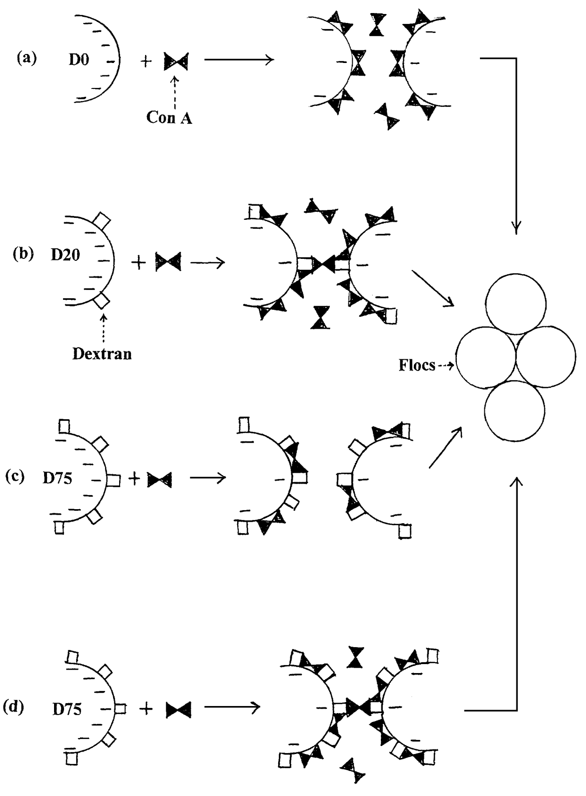

Fig. 6 A schematic model of the destabilization mechanisms involved in the adsorption of the positively charged Con A onto the negatively charged latex particles. Destabilization mechanisms: (a) charge neutralization for D0, (b) charge neutralization + crosslinking for D20, (c) charge neutralization for D75 when C(Con A)≪, and (d) charge neutralization + crosslinking for D75 when C(Con A)≫

0.18). This is because the ratio of dextran to Con A decreases with increasing *C*(Con A). As a result, the dimeric Con A species specifically adsorbed on one latex particle can compete effectively with others for the dextran molecules on another latex particle (see path (d) in Fig. 6). The calculated values of CFC(Con A)/C^*(Dextran) for the D20 and D75 latices in a pH 5 phosphate solution are 1322 and 795 μM, respectively (see Table 2). This is reasonable because the dimeric Con A species is very effective in inducing the formation of a crosslinked network structure at *C*(Con A) $\sim$ 17 μM and D75 latex particles with a higher degree of dextran modification should require a smaller amount of Con A to push the colloidal system toward the condition of fast flocculation (i.e., $W = 1$).

In conclusion, the colloidal stability of the latex particles toward added Con A in the decreasing order is: the D0 latex particles without dextran modification > the D75 latex particles with C^*(Dextran) = 2.15% > the D20 latex particles with C^*(Dextran) = 1.24%, based on the data of coagulation kinetics presented in this paper. The experimental data show that the latex stability decreases rapidly with increasing *C*(Con A). The decreased colloidal stability is primarily caused by charge neutralization of the negatively charged latex particles by adsorption of the positively charged Con A molecules in a pH 5 phosphate solution. For the D20 latex particles, formation of a crosslinked network structure via the affinity interactions between the dimeric Con A molecules and the dextran molecules belonging to different latex particles also plays an important role in the coagulation kinetics. However, this factor becomes important for the D75 latex particles only when *C*(Con A) is greater than 5 μM due to the formation of affinity bonds between the dimeric Con A molecules and the dextran molecules on the same latex particle surface. The ratio of the number of dextran molecules to Con A molecules plays an important role in the formation of the crosslinked network structure. The influence of compression of the electric double layer of the latex particles by the counterions in the aqueous phase is rather limited. This ionic strength effect, however, is not significant as compared to charge neutralization.

The negatively charged D0 latex particles can be used to concentrate the target protein (e.g., Con A in this work) from a crude extract. The dextran-modified D20 or D75 latex particles then can be employed in a subsequent step to purify Con A via affinity interactions from an intermediate product containing Con A and other positively charged proteins. In addition to the data of coagulation kinetics presented in this work, isothermal equilibrium adsorption experiments [27] may also help gain a better understanding of the coagulation mechanisms involved in the adsorption of Con A onto these latex particles with various extents of dextran modification. This will be the subject of a forthcoming paper.

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