Question 1 (6p)

Colloidal dispersions are generally referred to as stable when there is no aggregation and no significant sedimentation/creaming. Give three examples of colloid or solution properties (natural or engineered) that contribute to making dispersions stable.

Some examples: Small size, makes diffusion faster. Density close to solvent, makes buoyancy balance gravity. High surface charge (zeta potential), increases double layer repulsion. Low ionic strength, gives less screening of the repulsion.

Note: Using polymers is a valid answer but then you must explain that they are bound to the colloids and SOLVATED so that they repel each other. (Polymers may just as well decrease stability.) Also, several people wrote that adding ions will IMPROVE stability, which made me a little sad…

Mean score: 2.88

Question 2

The picture shows a water-absorbing polymer gel (as demonstrated on the lecture).

A (2p)

Describe the microstructure of the polymer inside the ”balls” (not its chemical formula) and state roughly the volume fraction of water inside.

The polymer chains are cross linked by covalent bonds and forms a single network. The volume fraction of water is at least around 99%.

B (2p)

How would you describe the material in terms of its rheology? (Two words are sufficient.)

Elastic solid. (Not viscoelastic.)

Note: It seems some people did not know what rheology means! This is the very core of defining soft matter. We teachers must do a better job here…

Mean score: 2.12

Question 3 (4p)

Polyurethanes are used as materials in many applications. The simplest monomer is:

$-CO-NH-C_6H_4-CH_2-C_6H_4-NH-CO-O-CH_2-CH_2-O-$

Assuming the monomer length is 2 nm and the Kuhn length 4 nm, estimate the end-to-end distance in a heated polyurethane melt when the average molecular weight is 100 kg/mol.

The monomer has 17 C, 2 N, 4 O and 16 H so the weight is 312 g/mol. This gives N = 321. Assuming the random walk model holds for the melt we get $R = [abN]^{1/2} = 51$ nm. (Using the Flory radius is not correct.)

Mean score: 3.2

Question 4 (6p)

The Flory-Huggins theory of a binary mixture be summarized as:

$$\Delta F_{\mathrm{mix}} = \Delta U_{\mathrm{mix}} - T\Delta S_{\mathrm{mix}} = k_{\mathrm{B}}T\left[\frac{\Phi_{\mathrm{A}}}{N_{\mathrm{A}}}\log(\Phi_{\mathrm{A}}) + \frac{\Phi_{\mathrm{B}}}{N_{\mathrm{B}}}\log(\Phi_{\mathrm{B}}) + \chi\Phi_{\mathrm{A}}\Phi_{\mathrm{B}}\right]$$

Use the model to derive the critical value of χ below which all mixtures are stable for the case of a polymer with degree of polymerization N in a solvent. The solvent molecules can be assumed equal in size to a monomer.

First note that we have $N_{\mathrm{A}} = N$, $N_{\mathrm{B}} = 1$, $\Phi_{\mathrm{A}} = \Phi$ and $\Phi_{\mathrm{B}} = 1 - \Phi$. The free energy of mixing is then:

$$\frac{\Delta F_{\mathrm{mix}}}{k_{\mathrm{B}}T} = \frac{\Phi}{N}\log(\Phi) + [1-\Phi]\log(1-\Phi) + \Phi[1-\Phi]\chi$$

As in the regular solution model the condition for stability is that the curvature is positive. Deriving twice gives:

$$\frac{\partial^2}{\partial\Phi^2}\left(\frac{\Delta F_{\mathrm{mix}}}{k_{\mathrm{B}}T}\right) = \frac{1}{N\Phi} + \frac{1}{1-\Phi} - 2\chi > 0$$

We know that Φ is always between zero and one. We can form the function:

$$f(\Phi) = \frac{1}{2N\Phi} + \frac{1}{2-2\Phi}$$

The condition is that $\chi < f(\Phi)$ always. It is clear that for $\Phi = 0$ and $\Phi = 1$, $f(\Phi) \to \infty$. We derive and search for a minimum:

$$-\frac{1}{2N\Phi^2}+\frac{1}{2[1-\Phi]^2}=0$$

This second degree equation has one solution between $\Phi = 0$ and $\Phi = 1$:

$$\Phi=\frac{N^{1/2}-1}{N-1}$$

So for this value of Φ we have the mimimum of $f(\Phi)$ and inserting gives the critical value of χ:

$$\chi<\frac{N-1}{2N\left[N^{1/2}-1\right]}+\frac{N-1}{2\left[N-N^{1/2}\right]}$$

Note that when $N \to 1$ we get $\chi < 2$ as in the regular solution model. (Actually the final expression can be simplified algebraically as some students showed.)

Mean score: 2.28

Helpful constants and data

Boltzmann's constant: 1.381×10^{-23} JK^{-1}

Avogadro's number: 6.022×10^{23} mol^{-1}

Permittivity of free space: 8.854×10^{-12} $m^{-3}kg^{-1}s^{4}A^{2}$

Planck's constant: 6.626×10^{-34} $m^{2}kgs^{-1}$

Speed of light in vacuum: 2.998×10^{8} ms^{-1}

Kelvin temperature scale: 0 °C = 273.15 K

Elementary charge: 1.602×10^{-19} C

Properties of water at room temperature

- Density: 1.0×10^{3} kgm^{-3}
- Dynamic viscosity: 1.0×10^{-3} Pas
- Relative permittivity (static field): 80
- Refractive index (at 589 nm): 1.333
- Interfacial energy (against air): 7.2×10^{-2} Jm^{-2}

B = Solids Hg = Liquids Kr = Gases Pm = Not found in nature

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H 1.00794																	2 He 4.002602
3 Li 6.941	4 Be 9.012182											5 B 10.811	C 12.0107	7 N 14.00674	8 O 15.9994	9 F 18.9984032	10 Ne 20.1797
11 Na 22.989770	12 Mg 24.3050											13 Al 26.581538	14 Si 28.0855	15 P 30.973761	16 S 32.066	17 Cl 35.4527	18 Ar 39.948
19 K 39.0983	20 Ca 40.078	21 Sc 44.955910	22 Ti 47.867	23 V 50.9415	24 Cr 51.9961	25 Mn 54.938049	26 Fe 55.845	27 Co 58.933200	28 Ni 58.6534	29 Cu 63.545	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.92160	34 Se 78.96	35 Br 79.504	36 Kr 83.80
37 Rb 85.4678	38 Sr 87.62	39 Y 88.90585	40 Zr 91.224	41 Nb 92.90638	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.90550	46 Pd 106.42	47 Ag 196.56655	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.90447	54 Xe 131.29
55 Cs 132.90545	56 Ba 137.327	71 Lu 174.967	72 Hf 178.49	73 Ta 180.94.79	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.078	79 Au 196.56655	80 Hg 200.59	81 Tl 204.3833	82 Pb 207.2	83 Bi 208.58038	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	103 Lr (262)	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 Ds (269)	111 Rg (272)	112 Cn (277)	113 Uut (277)	114 Uuq (277)	115 Uup (277)	116 Uuh (277)		118 Uuo (277)

57 La 138.9055	58 Ce 140.116	59 Pr 140.50765	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.92534	66 Dy 162.50	67 Ho 164.93032	68 Er 167.26	69 Tm 168.93421	70 Yb 173.04
89 Ac 232.0381	90 Th 232.0381	91 Pa 231.035888	92 U 238.0289	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)