

Solutions to Additional Questions for Exam Preparation

1. Nematic Liquid Crystals

- a. The melting transition temperature from a crystal into the nematic phase, T_m , increases if:
- the aliphatic chain is shortened. Long aliphatic chains hamper packing, lowering T_m .
 - electronegative atoms are added, as they increase the strength of Van-der-Waals interactions.
 - a phenol ring or other unit that forms strong intermolecular forces is added.
- b. The transition temperatures can be quantified using **differential scanning calorimetry** (DSC). The operating principle is as follows: You have an empty pan that serves as a reference and a pan filled with a known amount of your sample. Both pans are heated, with the goal of keeping the temperature the same between both pans. You measure the amount of energy needed to increase the temperature of the sample pan relative to the energy needed to increase the temperature of the reference pan. The difference in energy allows to determine the difference in the specific heat capacity. If there is a phase transition, the temperature does not increase or decrease until the phase transition is completed. During an endothermic transition, much more energy is required to increase the temperature of the sample compared to the energy needed to increase the temperature of the reference. This is seen as a peak in the energy that is input into the sample at the phase transition temperature. If the phase transition is exothermic, the sample will heat without any energy input. This will again display as a peak at the transition temperature (albeit with the opposite sign).

2. Cholesteric Liquid Crystals

The pitch distance of cholesteric liquid crystals determines the wavelength of the reflected light. By extension, determining the color of the liquid crystal. The pitch distance changes with temperature, so the color of the liquid crystal changes with temperature.

Limitations:

- They can only be used in the nematic range.
- Mesogen choice is limited as the molecules used must be chiral.

3. Liquid Crystal Display

Because the mesogens of nematic liquid crystals rotate around the axis perpendicular to the plane if they are oriented parallel to the plane, it must be a twisted nematic liquid crystal. Therefore, to determine the critical field needed to switch such a crystal, we can use:

$$E_{\text{crit}} = \frac{2\pi}{d} \sqrt{\frac{\pi}{\Delta\epsilon}} [K_1 + \frac{1}{4}(K_3 - 2K_2)]^{\frac{1}{2}}$$

Using the given values, we find:

- a. $E_{\text{crit}} = \frac{2\pi}{100 \times 10^{-9} \text{ m}} \sqrt{\frac{\pi}{(5.4-4.7) \times 8.85 \times 10^{-12} \frac{\text{F}}{\text{m}}}} [5.3 \times 10^{-12} \text{ N} + \frac{1}{4}(7.45 \times 10^{-12} \text{ N} - 2 \times 2.2 \times 10^{-12})]^{\frac{1}{2}} = 110 \text{ MV/m}$
- b. $E_{\text{crit}} = 11 \text{ MV/m}$
- c. $E_{\text{crit}} = 110 \text{ kV/m}$
- d. If the chamber becomes too thick, it is difficult to maintain a good alignment of the mesogens and prevent domain formation.

4. Composition of Micelles

The shape of micelles is defined by the ratio of the volume of the hydrocarbon chain to the product of the area of the head group and the length of the hydrophobic chain:

$$\alpha = v/a_0 I_c$$

Therefore, it is essentially the ratio of the average cross-section of the hydrophobic chain to that of the hydrophilic part of the detergent. The area of the head group is strongly influenced by their electrostatic and steric repulsion. By adding salts, the electrostatic repulsion can be screened such that the average distance between adjacent head groups will be decreased, thus reducing the optimal head group area. If the reduction in a_0 is large enough, micelles will change their shape from spherical to elliptical, to cylinders, to bilayers.

5. Micelle Size

The volume fraction of micelles can be calculated using:

$$\phi = \sum_N N [X_1 e^\alpha]^N e^{-\alpha N^P}$$

For cylindrical micelles, the curvature in the direction of their length is zero such that $P = 0$, resulting in:

$$\phi = \sum_N N [X_1 e^\alpha]^N e^{-\alpha}$$

For concentrations above the CMC, we approximate $X_1 e^\alpha = 1$, resulting in:

$$\phi = \sum_N N e^{-\alpha}$$

The CMC is defined as $\text{CMC} = e^{-\alpha}$. In reality, $X_1 e^\alpha$ is slightly below unity because some molecules also assemble into aggregates. Taking this into account, we find:

$$X_N = N \left(1 - \frac{1}{\sqrt{\phi e^\alpha}}\right)^N \times \text{CMC}$$

As indicated in the slides, we find the maximum at:

$$X_{N,\text{max}} = \sqrt{\phi e^\alpha} = \sqrt{\frac{0.035}{5 \times 10^{-8}}} = 837$$

Therefore, most of the micelles are composed of approximately 840 molecules.

Note: In cylindrical micelles, the ends of the cylinders are energetically costly because some of the hydrophobic regions of the molecules are exposed to water. The energy contribution of the ends towards the total energy of cylindrical micelles decreases with increasing cylinder length. Therefore, as N increases, the contributions of the two ends to the excess energy decreases. The decrease in excess energy must be balanced with the probability for aggregates containing N molecules to form, which decreases with increasing N . Therefore, for cylindrical micelles, there is an $X_{N,\text{max}}$ that is significantly higher than that for spherical micelles, where hydrophobic regions of molecules are never exposed to water.

6. Temperature Dependence

- a. The CMC is defined as:

$$\text{CMC} \approx e^{-\frac{2\pi r l \gamma}{k_B T}}$$

An increase in temperature would increase the solubility of the molecule and thus increase the CMC.

- b. The exchange rate is given by:

$$\tau = \frac{\tau_0}{e^{-\frac{\mu_1^0 - \mu_N^0}{k_B T}}} \approx \frac{55\tau_0}{\text{CMC}}$$

Because the CMC would increase, τ_R would decrease.

- c. It would make the vesicle more fluid. Because the exchange rates would be much faster, the system would be more dynamic and less stable.
- d. To decrease the CMC, one could:
1. add CH_2 groups to the chain, increasing l .
 2. introduce unsaturated bonds to the hydrophobic part of the vesicle to increase r .

7. pH-responsiveness

- a. Poly(acrylic acid) (PAA) has a carboxylic acid group that is deprotonated at $\text{pH} > \text{pK}_a$ and protonated at $\text{pH} < \text{pK}_a$.

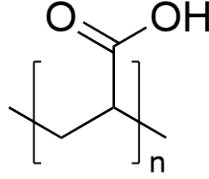


Figure 1: Poly(acrylic acid)

- b. The degree of hydration changes around the pK_a of PAA, which is around 4.2. Therefore, at $\text{pH} < 4.2$, PAA is protonated and collapsed. At $\text{pH} > 4.2$, PAA is deprotonated and swollen.
- c. At high pHs ($\text{pH} > \text{pK}_a$), PAA is deprotonated and therefore hydrated.

8. Viscosity of Entangled Melts

- a. The molar mass between two entanglements can be deduced from the shear modulus using:

$$G = \frac{\rho RT}{M_x}$$

With this, we find:

$$M_x = \frac{\rho RT}{G} = \frac{900 \frac{\text{kg}}{\text{m}^3} \times 8.31 \frac{\text{J}}{\text{K} \times \text{mol}} \times 298 \text{ K}}{1.15 \times 10^6 \text{ Pa}} = 1.9 \frac{\text{kg}}{\text{mol}}$$

- b. For entangled polymers, the diffusion coefficient can be estimated as:

$$D \approx \frac{\langle r^2 \rangle}{6\tau_d}$$

Because the polymer is contained in a melt, the Flory exponent is $\nu = 0.5$ (theta solvent): The intermolecular interactions between the solute molecules and the solvent are the same as those between the solute molecules themselves because the solvent is the solute.

$$D \approx \frac{\langle r^2 \rangle}{6\tau_d} = \frac{\langle R_g^2 \rangle}{\tau_d} = \frac{Na^2}{6\tau_d}$$

We calculate the degree of polymerization using:

$$N = \frac{M_{W,\text{poly}}}{M_{W,\text{r.u.}}} = \frac{100000 \frac{\text{g}}{\text{mol}}}{54 \frac{\text{g}}{\text{mol}}} = 1582$$

With this, we find:

$$D \times 6\tau_d = Na^2 = 1582 \times 0.65^2 \text{ nm}^2 = 782 \text{ nm}^2$$

To determine τ_d , we use η_0 by approximating:

$$\eta_0 \approx G\tau_d$$

$$\tau_d \approx \frac{\eta_0}{G} = \frac{3.86 \times 10^{-3} \times \exp\left(\frac{1404}{298-128}\right) \times 1852^{3.4} \text{ Pa}\cdot\text{s}}{1150000 \text{ Pa}} = \frac{1.9 \times 10^{12} \text{ Pa}\cdot\text{s}}{1150000 \text{ Pa}} = 1.7 \times 10^6 \text{ s}$$

$$D \approx \frac{Na^2}{6\tau_d} = \frac{782 \text{ nm}^2}{6 \times 1.7 \times 10^6 \text{ s}} = 7.8 \times 10^{-23} \frac{\text{m}^2}{\text{s}}$$

- c. This diffusion coefficient is very low. Reasons for the low diffusion coefficient include the high molecular weight and the entanglements of the polymers.

9. Crosslink Density of an Elastomer

- a. To calculate the molecular weight between crosslinks, which we can use to determine the crosslinking density, we (once again) use the relation between the shear modulus and the molecular weight between crosslinks:

$$G = \frac{\rho RT}{M_x}$$

To determine G , we assume the relationship between stress and strain to be linear at small strains with the slope being equal to G . Taking the difference between points 4 and 1 (other points at low strains may also be used) we obtain:

$$\sigma = \epsilon G$$

$$G = \frac{\Delta\sigma}{\Delta\epsilon} = \frac{0.327 \text{ MPa}}{0.433} = 0.755 \text{ MPa}$$

From this, we obtain:

$$\frac{\rho}{M_x} = \frac{G}{RT} = \frac{7.55 \times 10^5 \text{ Pa}}{8.31 \frac{\text{J}}{\text{K}\cdot\text{mol}} \times 293 \text{ K}} = 310 \frac{\text{mol}}{\text{m}^3} = 0.186 \frac{\text{bonds}}{\text{nm}^3}$$

b. Using the prediction of rubber elasticity, we obtain:

$$\tau = \frac{\rho}{M_x} k_B T \left[(1 + \epsilon) - \frac{1}{(1 + \epsilon)^2} \right]$$

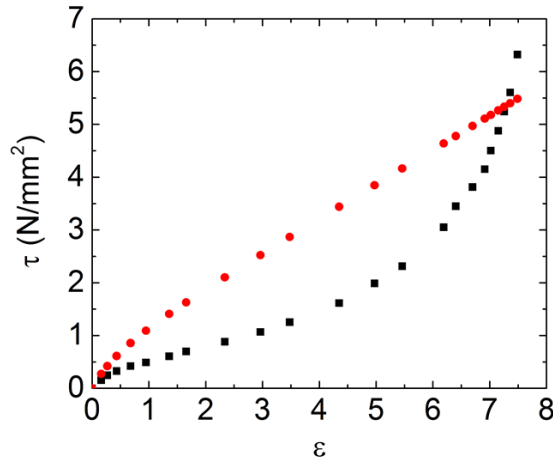


Figure 2: The measured data points (black squares) and the calculated ones (red circles) for the shear stress as a function of the strain

We see that there is only a reasonable agreement at very low strains. As soon as the material starts to yield (flattening of the black curve), we observe a significant discrepancy. The discrepancy could come from inhomogeneous crosslink-distributions or hardening effects at higher strains.

10. Thermosets

- a. Resins (material precursors) are heated to initiate a crosslinking reaction where covalent bonds are formed. This crosslinking is irreversible. Therefore, it is important that the material is shaped before the crosslinking reaction starts or during the early stages of the reaction.
- b. Examples of thermosets include:
 - poly(urethanes) - commonly used as insulating foams
 - poly(imides) - commonly used as medical tubings, insulating films, or cable cladding

11. Self-Healing Hydrogels

- a. The hydrogel should be crosslinked using ionic bonds because they form reversibly, thereby imparting self-healing properties to the hydrogel.
- b. One should increase the relaxation time of the hydrogel. This can be done by choosing a chelator-ion pair with a higher complexation constant. Alternatively, larger crosslinking agents that can bind more chelators per crosslinking agent can be employed. For example, if ions are replaced by nanoparticles, relaxation times are significantly increased because it takes longer to simultaneously break multiple bonds (which is required for the hydrogel to

flow) than it takes to break a single bond or, as is the case for conventional chelators, to simultaneously break two bonds.

- c. The relaxation time is the time over which a hydrogel relaxes stress and is directly related to the dissipation time of the ion-chelator pair used to crosslink hydrogels. Weak ionic bonds have short relaxation times, strong ionic bonds have long relaxation times.
- d. The relaxation time is coupled to the transition from a gel to a sol behavior. **Oscillatory rheology** can be used to determine G' and G'' as a function of shear rate. The shear rate where $G' \approx G''$ is the inverse time scale where a sol transitions into a gel.

In oscillatory rheology, a sinusoidal stress is applied and the material's response is measured. If the material is perfectly elastic, there is no lag between the application of stress and the response. If the material is viscoelastic, there is a delay between the stress application and the material response caused by the viscous nature of the material (i.e. the energy dissipation). By analyzing the delay in the material response, δ , one can determine the ratio between the loss and the storage modulus, and by knowing the shear rate at which δ is measured, G' and G'' can be deduced with the following equations:

$$\tan \delta = \frac{G''}{G'}$$

$$\sigma = \sigma'_0 \sin(\omega t) + \sigma''_0 \cos(\omega t)$$

$$G' = \frac{\sigma'_0}{\gamma_0}$$

$$G'' = \frac{\sigma''_0}{\gamma_0}$$

12. Nanoparticles in Solution

- a. To determine if these particles sediment over time, we calculate their sedimentation length:

$$I_{\text{sed}} = \frac{k_B T}{m^* g} = \frac{k_B T}{\frac{4}{3} \pi r^3 \Delta \rho g} = \frac{1.38 \times 10^{-23} \frac{\text{J}}{\text{K}} \times 298 \text{ K}}{\frac{4}{3} \pi \times (100 \times 10^{-9} \text{ m})^3 \times (2650 - 1000) \frac{\text{kg}}{\text{m}^3} \times 9.8 \frac{\text{N}}{\text{kg}}}$$

$$= 6.1 \times 10^{-5} \text{ m}$$

This sedimentation length is longer than the particle diameter so sedimentation can be neglected.

To estimate the time needed for particles to reach the end of the pipe, we determine the mean end-to-end distance a particle diffuses during a time t , which can be described in 3D as:

$$\langle r^2 \rangle = 6Dt$$

Using this equation, we can calculate the time needed to diffuse a distance r .

$$t = \frac{\langle r^2 \rangle}{6D}$$

The Stokes-Einstein equation is used to obtain the diffusion coefficient:

$$D = \frac{k_B T}{6\pi\eta r} = \frac{1.38 \times 10^{-23} \frac{\text{J}}{\text{K}} \times 298 \text{ K}}{6\pi \times 0.001 \text{ Pa}\cdot\text{s} \times 100 \times 10^{-9} \text{ m}} = 2.2 \times 10^{-12} \frac{\text{m}^2}{\text{s}}$$

Which is used to finally obtain:

$$\begin{aligned} t &= \frac{\langle r^2 \rangle}{6D} = \frac{0.3^2 \text{ m}^2}{6 \times 2.2 \times 10^{-12} \frac{\text{m}^2}{\text{s}}} \\ &= 6.9 \times 10^9 \text{ s} \approx 1.91 \times 10^9 \text{ h} \approx 8 \times 10^4 \text{ d} \approx 218 \text{ years} \end{aligned}$$

In the absence of any forced flow, these particles will, within the lifetime of a pipe, never reach the end of the pipe.

- b. To determine if the particles are Brownian, we calculate the sedimentation length:

$$\begin{aligned} I_{\text{sed}} &= \frac{k_B T}{m^* g} = \frac{k_B T}{\frac{4}{3}\pi r^3 \Delta\rho g} = \frac{1.38 \times 10^{-23} \frac{\text{J}}{\text{K}} \times 298 \text{ K}}{\frac{4}{3}\pi \times (1 \times 10^{-9} \text{ m})^3 \times (2650 - 1000) \frac{\text{kg}}{\text{m}^3} \times 9.8 \frac{\text{N}}{\text{kg}}} \\ &= 60.7 \text{ m} \end{aligned}$$

Even in this case, sedimentation can be neglected.

We calculate the diffusion coefficient using the Stokes-Einstein equation:

$$D = \frac{k_B T}{6\pi\eta r} = \frac{1.38 \times 10^{-23} \frac{\text{J}}{\text{K}} \times 298 \text{ K}}{6\pi \times 0.001 \text{ Pa}\cdot\text{s} \times 1 \times 10^{-9} \text{ m}} = 2.2 \times 10^{-10} \frac{\text{m}^2}{\text{s}}$$

to obtain:

$$\begin{aligned} t &= \frac{\langle r^2 \rangle}{6D} = \frac{0.3^2 \text{ m}^2}{6 \times 2.2 \times 10^{-10} \frac{\text{m}^2}{\text{s}}} \\ &= 6.9 \times 10^7 \text{ s} \approx 1.91 \times 10^4 \text{ h} \approx 800 \text{ d} \approx 2.2 \text{ years} \end{aligned}$$

- c. The sedimentation velocity can be determined by equating the gravitational force and the drag force, resulting in:

$$\begin{aligned} v_{\text{sed}} &= \frac{2r^2 \Delta\rho g}{9\eta} = \frac{2(100 \times 10^{-9} \text{ m})^2 \times (2650 - 1000) \frac{\text{kg}}{\text{m}^3} \times 9.8 \frac{\text{N}}{\text{kg}}}{9 \times 0.001 \text{ Pa}\cdot\text{s}} \\ &= 3.6 \times 10^{-8} \frac{\text{m}}{\text{s}} \end{aligned}$$

Using this sedimentation velocity, we can calculate the time needed to sediment 0.3 m as:

$$t = \frac{I}{v_{\text{sed}}} = \frac{0.3 \text{ m}}{3.6 \times 10^{-8} \frac{\text{m}}{\text{s}}} = 8.4 \times 10^6 \text{ s} \approx 2.3 \times 10^3 \text{ h} \approx 97 \text{ d}$$

d. Using the same equations, we obtain:

$$v_{\text{sed}} = \frac{2r^2 \Delta \rho g}{9\eta} = \frac{2(1 \times 10^{-9} \text{ m})^2 \times (2650 - 1000) \frac{\text{kg}}{\text{m}^3} \times 9.8 \frac{\text{N}}{\text{kg}}}{9 \times 0.001 \text{ Pa}\cdot\text{s}}$$

$$= 3.6 \times 10^{-12} \frac{\text{m}}{\text{s}}$$

and

$$t = \frac{I}{v_{\text{sed}}} = \frac{0.3 \text{ m}}{3.6 \times 10^{-12} \frac{\text{m}}{\text{s}}} = 8.4 \times 10^{10} \text{ s} \approx 2.3 \times 10^7 \text{ h} \approx 9.7 \times 10^5 \text{ d} \approx 2.7 \times 10^3 \text{ years}$$

This time is much longer than that determined in (b) for Brownian motion. As such, these small particles will not sediment within a reasonable observation time. The time it takes for these particles to reach the bottom of the tube will be equal to 2.2 years, as determined in (b).

13. Surface Area

The volume of a cube with 1 cm long edges is

$$V_1 = (1 \times 10^{-2} \text{ m})^3 = 10^{-6} \text{ m}^3$$

A cube has a surface area of

$$A_1 = 6 \times (1 \times 10^{-2} \text{ m})^2 = 6 \times 10^{-4} \text{ m}^2$$

The total surface energy of this cube is

$$E = \gamma A = 0.07 \frac{\text{J}}{\text{m}^2} \times 6 \times 10^{-4} \text{ m}^2 = 4.2 \times 10^{-5} \text{ J} = 6 \times 10^{-4} k_B T$$

- a. The volume of a 1 μm sized cube is 10^{-18} m^3 . Therefore, the initial cube can be cut into 10^{12} smaller cubes with individual surface areas equal to $A_2 = 6 \times (1 \times 10^{-6} \text{ m})^2 = 6 \times 10^{-12} \text{ m}^2$. The total surface area of 10^{12} cubes is therefore 6 m^2 , and we find:

$$E = \gamma A = 0.07 \frac{\text{J}}{\text{m}^2} \times 6 \text{ m}^2 = 0.42 \text{ J} = 6 \times 10^{20} k_B T$$

Notice that cutting a cube with an edge size of 1 cm into cubes with edge sizes of 1 μm increases the surface energy by four orders of magnitude.

- b. The volume of a 100 nm sized cube is 10^{-21} m^3 . Therefore, the initial cube can be cut into 10^{15} smaller cubes with individual surface areas equal to $A_2 = 6 \times (1 \times 10^{-7} \text{ m})^2 = 6 \times 10^{-14} \text{ m}^2$. The total surface area of 10^{15} cubes is therefore 60 m^2 , and we find:

$$E = \gamma A = 0.07 \frac{\text{J}}{\text{m}^2} \times 60 \text{ m}^2 = 4.2 \text{ J} = 1 \times 10^{21} k_B T$$

- c. The volume of a 1 nm sized cube is 10^{-27} m^3 . Therefore, the initial cube can be cut into 10^{21} smaller cubes with individual surface areas equal to $A_2 = 6 \times (1 \times 10^{-9} \text{ m})^2 = 6 \times 10^{-18} \text{ m}^2$. The total surface area of 10^{21} cubes is therefore 6000 m^2 , and we find:

$$E = \gamma A = 0.07 \frac{\text{J}}{\text{m}^2} \times 60 \text{ m}^2 = 420 \text{ J} = 1 \times 10^{23} k_B T$$

Cutting a larger volume into smaller pieces strongly increases the surface energy of the system. Smaller particles may reduce the total energy through the formation of aggregates. In all cases here, the surface energies are much higher than the thermal energy so once particles or cubes come into contact with one another, they will, under realistic experimental conditions, never come apart again.

14. Electrostatic Stabilization

- a. The Debye screening length is defined as

$$\frac{1}{\kappa} = \sqrt{\frac{\epsilon_0 \epsilon_r k_B T}{e^2 \sum_i c_i z_i^2}}$$

KCl is a monovalent salt, so the Debye screening length can be calculated as:

$$\text{i. } \frac{1}{\kappa} = \sqrt{\frac{8.85 \times 10^{-12} \frac{\text{F}}{\text{m}} \times 80 \times 1.38 \times 10^{-23} \frac{\text{J}}{\text{K}} \times 293 \text{K}}{(1.6 \times 10^{-19} \text{ C})^2 \times 2 \times 1 \frac{\text{mol} \times 6.02 \times 10^{23}}{10^{-3} \text{ m}^3 \times \text{mol}} \times 1^2}} = 0.3 \text{ nm}$$

$$\text{ii. } \frac{1}{\kappa} = \sqrt{\frac{8.85 \times 10^{-12} \frac{\text{F}}{\text{m}} \times 80 \times 1.38 \times 10^{-23} \frac{\text{J}}{\text{K}} \times 293 \text{K}}{(1.6 \times 10^{-19} \text{ C})^2 \times 2 \times 0.01 \frac{\text{mol} \times 6.02 \times 10^{23}}{10^{-3} \text{ m}^3 \times \text{mol}} \times 1^2}} = 3 \text{ nm}$$

$$\text{iii. } \frac{1}{\kappa} = \sqrt{\frac{8.85 \times 10^{-12} \frac{\text{F}}{\text{m}} \times 80 \times 1.38 \times 10^{-23} \frac{\text{J}}{\text{K}} \times 293 \text{K}}{(1.6 \times 10^{-19} \text{ C})^2 \times 2 \times 10^{-4} \frac{\text{mol} \times 6.02 \times 10^{23}}{10^{-3} \text{ m}^3 \times \text{mol}} \times 1^2}} = 30 \text{ nm}$$

- iv. For CaCl_2 , we must consider that the concentration of Cl^- is twice that of Ca^{2+} , therefore $z_{\text{Cl}} = 1$ whereas $z_{\text{Ca}} = 2$. With this we obtain:

$$\frac{1}{\kappa} = \sqrt{\frac{8.85 \times 10^{-12} \frac{\text{F}}{\text{m}} \times 80 \times 1.38 \times 10^{-23} \frac{\text{J}}{\text{K}} \times 293 \text{K}}{(1.6 \times 10^{-19} \text{ C})^2 \times (1 \times 2^2 + 2 \times 1^2) \times \frac{\text{mol} \times 6.02 \times 10^{23}}{10^{-3} \text{ m}^3 \times \text{mol}}} = 0.18 \text{ nm}$$

- b. Like KCl, NaCl is a monovalent salt, as such we find:

$$\frac{1}{\kappa} = \sqrt{\frac{8.85 \times 10^{-12} \frac{\text{F}}{\text{m}} \times 55 \times 1.38 \times 10^{-23} \frac{\text{J}}{\text{K}} \times 353 \text{K}}{(1.6 \times 10^{-19} \text{ C})^2 \times 2 \times 1 \times \frac{\text{mol} \times 6.02 \times 10^{23}}{10^{-3} \text{ m}^3 \times \text{mol}}} = 0.27 \text{ nm}$$

15. Stabilization of Emulsions

Emulsions can be stabilized with **surfactants** or **nanoparticles**.

Surfactants are typically more mobile than nanoparticles and adsorb faster at the liquid-liquid interfaces. Therefore, they are preferred in processes where emulsion drops can come in contact with each other shortly after they have been formed. However, they adsorb reversibly which can compromise the long-term stability of the emulsions.

Nanoparticles are larger than surfactants so they diffuse slower, taking longer to move to the interface. Additionally, they will only rest at the interface if their surface chemistry is designed to have some affinity to both phases. However, if this is the case, and once the particles are successfully adsorbed, the energy required to remove them is very high. Therefore, very few nanoparticles will leave the interface. This makes nanoparticle stabilized emulsions, so-called Pickering emulsions, very stable even if stored for prolonged times at elevated temperatures and increased ionic strength.

16. Surfactants

Surfactants are molecules that lower the surface or interfacial tension. They are usually amphiphilic, meaning they contain hydrophobic and hydrophilic parts. They are for example used in emulsions to prevent coalescence of drops. They are also used to lower the interfacial tension of fluids to, for example, change their flow properties in channels.

17. Adsorption of Surfactants

The adsorption kinetics of surfactants at the drop surface can be measured using the pendant drop method. This method analyzes the shape of the drop. The equilibrium shape is determined by the balance of the gravitational force that pulls the drop down and the surface tension force that pulls the drop towards the needle. By analyzing the shape of the drop and knowing its volume and density, and thus its weight, the surface tension can be determined. In general, the lower the surface tension, the more deformed the drop is. To measure the adsorption kinetics of surfactants, the drop shape is measured as a function of time. Hence, by acquiring time-lapse images of the pendant drop, the evolution of the interfacial tension with time can be extracted.

18. Stabilization of Vinaigrette

Vinaigrette is an oil-in-water emulsion. The surfactant should be soluble in the continuous phase, which in this case is water. Therefore, the HLB value should be above 10. Food grade surfactants are typically nonionic. Therefore, the surfactant should be a food grade, nonionic surfactant, such as a Pluronics or Span, with an HLB value above 10.