Soft Matter exercise, Chapter 10: Particles

1. Nanoparticles in solution

a. How long will it take for a 200-nm diameter SiO_2 particle added to one side of a 30 cm long horizontal pipe filled with water to diffuse to the other end?
b. How long will it take if the SiO_2 particle is 2 nm in diameter?
c. How long will it take for 200-nm diameter particles added to the top of a vertical 30 cm long pipe that is filled with water to sediment to the bottom of the tube?
d. How long will it take if the SiO_2 particle is 2 nm in diameter?

Assume the temperature to be 20°C, the density of water to be 1 g/cm^3 and that of SiO_2 to be 2.65 g/cm^3. The viscosity of water at 25°C is 1 mPas. Assume the gravitational acceleration to be 9.8 m/s^2.

2. Characterization of nanoparticles

Dynamic light scattering can be used to determine the particle size from the diffusion constant. You measure the velocity of a poly(styrene) particle dispersed in water to be 2 mm/s at 25°C. Estimate the size of the particle, assuming it is spherical. Assume the density of polystyrene to be 1.04 g/cm^3, the viscosity of water is 1 mPas.

3. Surface area

Starting with a cube of solid that is 1 cm along each edge. What is the total surface area when the solid is divided into cubes whose edges are

a. 1 μm
b. 100 nm
c. 1 nm long.

In each case, calculate the surface energy per particle assuming a surface energy of 70 mJ/m^2 and compare it to the thermal energy at room temperature.

4. Nanoparticle stability

a. Why do nanoparticles tend to aggregate?
b. What can you do to prevent aggregation?
c. You want to intravenously inject iron oxide nanoparticles into humans to enhance the contrast on magnetic resonance images that are used to determine if a patient has cancer. How would you ensure that these nanoparticles do not clog blood vessels?

5. Electrostatic stabilization

a. Calculate the Debye screening length at 20°C for solutions containing
   i. 1 M KCl
   ii. 0.01 M KCl
   iii. 10^{-4} M KCl
   iv. 1 M $CaCl_2$.
b. What is the Debye length of an aqueous solution containing 1 M NaCl at 80°C?

Assume ε_r of water at 20°C to be 80 and ε_r of water at 80°C to be 55.

6. Effective volume fraction

Calculate the effective volume fraction of a suspension of 100 nm diameter SiO_2 particles that are electrostatically stabilized and dispersed at 10 vol% in an aqueous solution containing

a. 0.005 M NaCl
b. 0.1 M NaCl
c. 1 M NaCl

To calculate the effective volume, take the volume of a sphere whose radius is the radius of the SiO_2 particle plus the Debye screening length. Assume the temperature to be 20°C and ε_r of water at 20°C to be 80.

7. Steric stabilization

You should stabilize 20 nm diameter gold nanoparticles by adsorbing poly(ethylene glycol) (PEG) with a molecular weight of 2000 g/mol. Assume the length of an ethylene glycol repeat unit to be 0.36 nm. To ensure that proteins do not adsorb at the nanoparticle surface, the steric layer should be at least 9 nm thick. Assume PEG is dissolved in a theta solvent and the angle between two bonds is 109°.

a. What should be the packing density of PEG on the gold nanoparticle surface to achieve this thickness?
b. If you adsorb PEG chains at this packing density, do they come in contact with their nearest neighbors? How does that influence their conformation?
c. How would you bind the PEG to the surface of gold nanoparticles?

8. Colloidal stability

You prepare a dispersion of colloidal particles that is stable. However, when you add smaller particles, you observe sedimentation. Explain this phenomenon.

9. Colloidal crystals

a. What is a colloidal crystal?
b. How can a colloidal crystal be made?
c. What volume fraction do 100 nm diameter spherical particles occupy if they are arranged in a close-packed, face-centered cubic structure?