BITS-Pilani K K Birla Goa Campus

Semester I 2022-23

Mid-semester examination

PHY F416 Soft Condensed Matter Elective course

Time: 90 mins Date: 05.11.2021 Full marks: 60 Type: Closed book/notes

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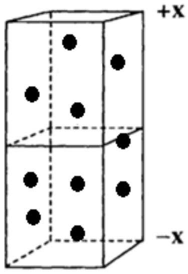
(There are total 4 pages in the question paper. Please read the entire question carefully (don't miss any questions if it is on the next page!) before answering. Be careful about radius and diameter, and unit conversions. Some useful constants are provided at the end of the question paper. Good luck!)

Important: You can choose either choose question 2 or question 3.

1. **Diffusion of colloids:**
Consider a column of spherical colloidal particles in water sedimenting under gravity as shown in the figure. Each colloidal particle has a volume V, radius a, density ρ_2 and the diffusion constant D at temperature T. The density of water is ρ_1. Gravity is in the *negative* x direction.



(a) At a given height inside the suspension, (shown in the figure as a plane) where concentration of the colloidal particles is c, write the diffusion flux J_{diff} according to Fick's first law and the flux due to sedimentation J_{sed}. (1+1=2)

(b) At equilibrium, find the relation between the two fluxes (with the correct signs). (1)

(c) What is the sedimentation velocity v at the steady state when diffusion is ignored? Consider η as the viscosity of water. (2)

(d) At equilibrium, find a relation between two concentrations c_1 and c_2 at two given heights x_1 and x_2 using the information from (a),(b) and (c). (3)

(e) From this, define the gravitational height of the colloidal particles (1).

(f) The density of 1 μm diameter silica particles suspended in water is 2.65 g/cm^3. What would be the gravitational height of the particles, taking the density of water at 25°C to be 1 g/cm^3? (4)

(g) Calculate the sedimentation velocity v due to gravitational falling for the same colloidal particles in water at 25°C (Viscosity of water at 25°C is η = 8.9 x 10^{-4} P-s and density is 1 g/cm^3). (3)

(Total marks = 16)

2. Colloids and Amphiphiles: (*optional with Q3*.)

(a) What is a Photonic crystal? Give one example of a naturally occurring and one example of an artificially made photonic crystal. (2+1+1=4)

(b) Consider two samples:

i) A colloidal solution in which volume fraction of colloids was initially 40% and then it was slowly increased to 75%.

ii) ii) A surfactant solution in water where the concentration of the surfactant molecules is increased from 10% to 90%. Describe in general what kind of structural rearrangement one will observe for each of the two cases. (A general overview is sufficient without getting into the details for the specific surfactant molecule or colloid.) (2+2 =4)

(c) Draw the structure of a vesicle and a bilayer (clearly show the arrangement of the amphiphile molecules). (1)

(d) Define what is the 'Peclet number' and write the equation for it. You can derive it by considering the relevant timescales in the Peclet number. (2)

(e) What would happen to a colloidal solution containing spherical silica colloidal particles of 1 µm radius at 25°C if it is subjected to a shear rate of: a) 2 × 10^{-2} s^{-1} and b) 0.60 s^{-1}? Take water viscosity η = 8.9 x 10^{-4} P-s at 25°C (Hint: Calculate the Peclet number). (2+2=4)

(Total marks = 15)

3. On viscoelastic materials: (*optional with Q2*.)

(a) What is the difference between a 'rheopectic' and a 'shear thickening' material? State with one example in each case and plot the typical shear stress vs shear rate plots for both. (4)

(b) Explain the Kelvin-Voigt model for viscoelastic materials with a schematic diagram and set up the stress-strain equation. Assume σ to be the stress, ϵ to be the strain, $\dot{\epsilon}$ as the strain rate, E as the shear modulus and η as the viscosity. (2)

(c) In the Kelvin-Voigt model let a constant stress σ_0 be applied. Let the initial strain $\epsilon(0) = 0$. By solving the equation that you got in part (b), derive the expression for the strain $\epsilon(t)$ at time t and the creep compliance $J(t)$. (2+2=4)

(d) What happens when the stress is removed suddenly? Derive the expression for the strain at a later time t considering the initial strain when the unloading starts is ϵ_{start}. Explain with a plot for strain vs time. (2+2=4)

(e) What kind of viscoelastic material should be a good choice for paints and why? (1)

(Total marks =15)

4. On forces and interactions:

(a) What are the three types of interactions that constitute the Vander Waals forces between two molecules? Give a brief explanation of these three interactions along with their variation with r (the distance between the two molecules). Also give one example for each case. (2+2+2=6).

(b) Describe what is the contact mode and non-contact mode of an AFM. Plot a typical force-distance plot for an AFM and show which parts are relevant to the contact or non-contact modes. (2+2+1=5)

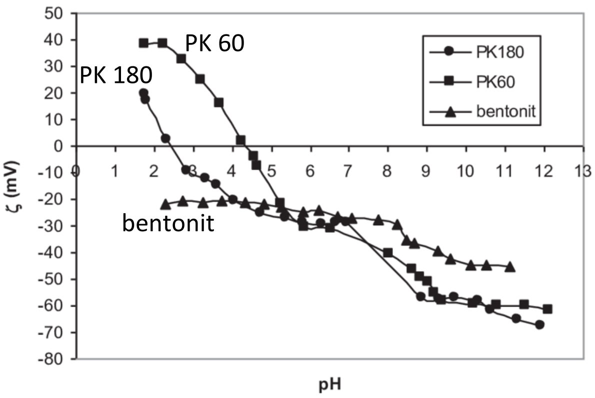
(c) Spiderman weighs 60 Kg and his hands and feet are covered with microscopic appendages (resembling the spatula of a gecko-feet). The tips of these appendages are spherical with radius 1 μm. Consider a typical interatomic distance of 1.5 Å and a Hamaker constant of 10^{-20} J. The Vander Waals interaction energy between a sphere and a planar surface is given as $W = -\frac{AR}{6D}$. If the total area of the hands and feet of the spiderman is 0.016 m^2, find the areal density (no of appendages/unit area) that spiderman will need to support his own weight and hang from the ceiling. (4)

(Total marks =15)

5. On stability of colloidal dispersions and emulsions:

(a) What are the two major ways of stabilizing a colloidal dispersion? Explain. (2)

(b) Look at the following graph of pH vs Zeta potential:



What is the approximate *range of pH values* at which each of the three materials i) PK180 ii) PK60 and iii) bentonite will form stable colloidal suspensions? Also write the approximate *Isoelectric points* (write 'not applicable' if it is not possible to determine). (3)

(c) On i) a clear schematic diagram combined with ii) a plot for electric potential vs distance from the particle surface, show what the following are for a negatively charged colloidal particle dispersed in a solution containing ions: a) Slipping plane b) Stern Layer c) Electric double layer d) Surface potential e) Stern potential c) Zeta potential. (3)

(d) Considering 3D diffusion, calculate the time taken by a spherical virus of radius 25 nm to diffuse a distance equal to its own diameter (50 nm) at 298 K. (Viscosity of water = 8.9 x 10^{-4} Pa-s.) (4)

(e) In mayonnaise, an oil phase exists within a water phase containing vinegar and lemon juice. How is mayonnaise stabilized, that is what prevents the oil and water phase from separating out? (2)

(Total marks =14)

INFORMATION:

1. Boltzmann constant $k_B = 1.38$ x 10^{-23} m^2 kg s^{-2} K^{-1}
2. Avogadro number N_A = 6.023 x 10^{23}.
3. 1 m = 10^6 µm = 10^9 nm = 10^{10} Å.
4. 1 g/cm^3 = 1000 Kg/m^3.
