IMPERIAL COLLEGE LONDON

M.Eng EXAMINATION IN CHEMICAL ENGINEERING 2021

PART III, IV

and

M.Sc. in ADVANCED CHEMICAL ENGINEERING

For Internal Students of Imperial College London

This paper is also taken for the relevant examination
for the Associateship

Colloid and Interface Science

Thursday 20th May 2021: 10.00 – 11.30

Answer **ALL** questions

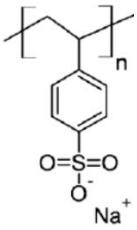
Question 1 carries **40 marks**
Question 2 carries **30 marks**
Question 3 carries **30 marks**

**THIS EXAMINATION PAPER HAS FIVE PAGES IN TOTAL
WHICH INCLUDES THIS COVER SHEET**

TURN OVER FOR QUESTIONS

Question 1 **40 marks**

Figure 1 below shows the interaction force as a function of separation between two silica spheres immersed in a solution of the negatively charged polymer sodium polystyrene sulfonate (NaPSS) $C_2H_3C_6H_5SO_4$ Na,for different polymer molar masses and concentrations. The structure of the polymer is given below.



In Figure 1 the symbols are experimental data and the lines are calculations based on double layer and depletion theories.

(i) What is the physical origin of the double layer interaction? **5 marks**

(ii) What is the physical origin of the depletion interaction? **5 marks**

(iii) Why are the interactions oscillatory in nature? **5 marks**

(iv) Why are there more oscillations at higher polymer concentrations, i.e. at 48.5 mM compared to 4.8 mM? **5 marks**

(v) Why is the frequency of oscillation greater at higher polymer concentration i.e. at 48.5 mM compared to 4.8 mM? **5 marks**

(vi) Why is the magnitude of the oscillations larger at higher polymer concentrations, i.e. at 48.5 mM compared to 4.8 mM? **5 marks**

(vii) Why is the magnitude of oscillation lower for the lower molar mass sodium polystyrene sulfonate shown in Figure 1e compared to the other molar mass polymers in Figure 1a and 1d? **5 marks**

(viii) At large forces, above 100pN, the force decays roughly exponentially with distance (linear on the semilogarithmic plots), why is this? **5 marks**

Question 1 continues

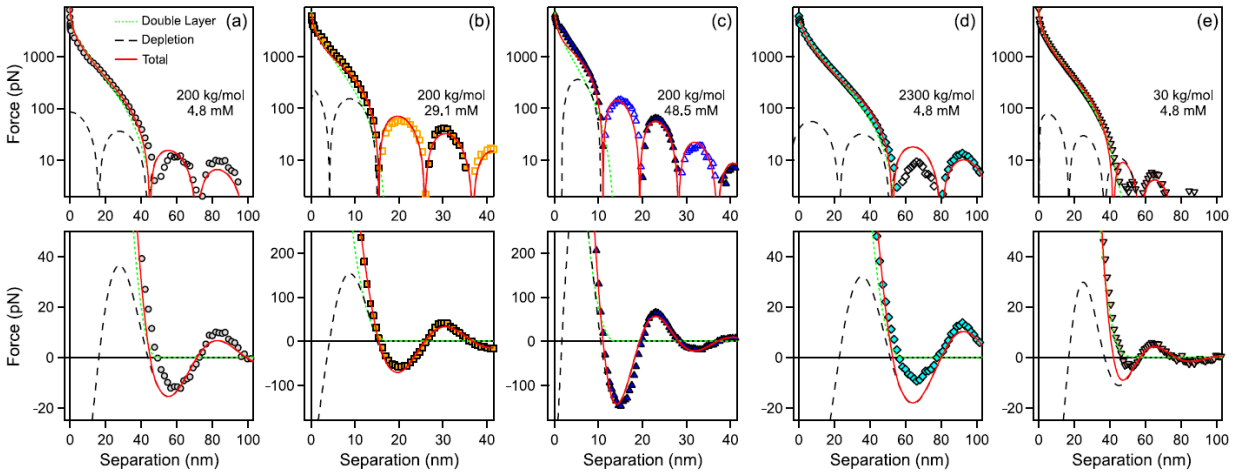


Figure 1 Forces between silica particles in solutions of NaPSS. Experimental data are compared with calculations based on an electrical double layer theory and a damped oscillatory depletion force. The concentration indicated corresponds to the monomer concentration of the polyelectrolyte, i.e the concentration of $C_2H_3C_6H_5SO_4Na$ *. The semilogarithmic representations plot the magnitude of the force, whilst the linear force plots reveals that the force goes attractive (negative). (a)–(c) Variation in polyelectrolyte concentration and (a),(d),(e) variation in molecular mass.*

End of Question 1

Question 2 **30 marks**

(i) Calculate the interfacial tension between water and carbon tetrachloride at $25^{O}C$ given that the surface tension of water is $72mN.m^{-1}$ and carbon tetrachloride is $45mN.m^{-1}$

5 marks

(ii) Calculate the height by which a column of water will rise up in a 1 mm radius capillary, assuming that the wetting is perfect, *i.e.* contact angle = 0 and the density of water is $1000kg.m^{-3}$.

5 marks

(iii) In the above example (i.e. part (ii)) what would happen if the contact angle was 120^{O}

5 marks

(iv) Pair each of the following 4 potassium chloride concentrations with the thickness of double layer, and explain your selections.

Potassium Chloride Concentration ($mol.dm^{-3}$)	**Electrical double layer thickness, nm**
1.0	2.56
0.1	25.6
0.01	0.256
0.0001	0.811

5 marks

(v) How do surfactants in solution act as a cleaner?

5 marks

(vi) An emulsion droplet has a -240 mV surface potential in a given salt solution and the thickness of the double layer is 10 nm. Calculate the potential a distance of 10 nm from the droplet. State any assumptions you make

5 marks

End of Question 2

Question 3 **30 marks**

(i) Outline how you would remove crude oil from production water so that the water is no longer contaminated? A **hydro-cyclone** would not remove sufficient crude oil and bacterial degradation is not an option as the volume of water is too large.

10 marks

(ii) The Young–Dupre equation is used to relate the contact angle (θ) of a liquid droplet on a surface to the surface tension of the liquid (γ_{lv}), the surface energy of the substrate/air (γ_{sv}) interface, and surface energy between the substrate and contacting liquid (γ_{sl});

$$\gamma_{SV} - \gamma_{Sl} = \gamma_{lV} cos\theta$$

Assuming that the liquid is water and the surface quartz, which is **negatively** charged, what would happen to the contact angle if :

(a) An anionic surfactant was added to the water above its cmc?
(b) A nonionic surfactant was added to the water above its cmc?
(c) A cationic surfactant was added to the water above its cmc?
(d) In practice it is very hard to measure γ_{sv} and γ_{sl} so manipulate the above relation such that only are included measurable parameters are included.

20 marks

End of Paper