IMPERIAL COLLEGE LONDON

M.Eng EXAMINATION IN CHEMICAL ENGINEERING 2017

PART III and 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

Colloids and Interface Science

Wednesday 24th May 2017: 10:00-11:30

Answer **ALL** questions

Question 1 carries 40 marks
Question 2 carries 40 marks
Question 3 carries 20 marks

This examination is an **OPEN** note examination, which means that you can bring into the examination any **written material APART FROM TEXT BOOKS**

THIS EXAMINATION PAPER HAS SEVEN PAGES IN TOTAL
WHICH INCLUDES THIS COVER SHEET

Before starting, please make sure that the paper is complete. Ask the invigilator for a replacement if your copy is faulty

TURN OVER FOR QUESTIONS

Question 1 **[40 marks]**

a) The forces between two sapphire (Al_2O_3) surfaces in 10^{-3} mol dm^{-3} NaCl solutions are shown as a function of pH in figure 1

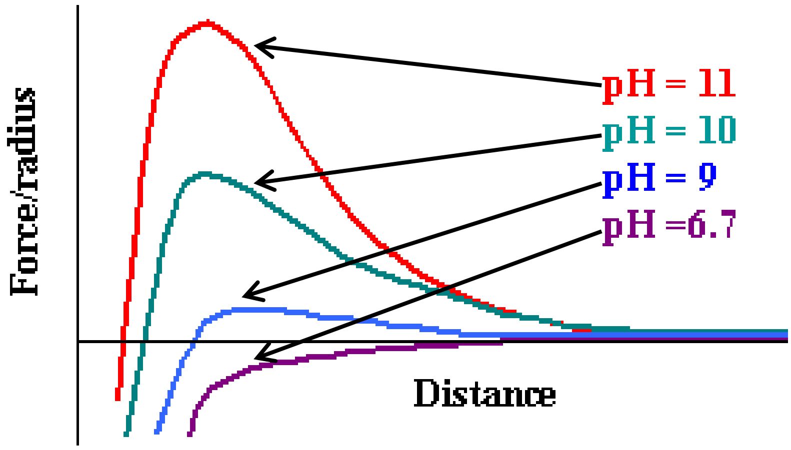

Figure 1

(i) Give a qualitative explanation of the changes that occur.

[4 marks]

(ii) At which pH would the alumina dispersion be most stable against aggregation?

[2 marks]

(iii) Suggest another way by which the particles of alumina could be stabilised and describe the mechanism by which it works

[4 marks]

Question 1 continues

b) When decane is placed in a quartz vessel, the decane wets the walls of the vessel (contact angle = 0) , as shown in Figure 2.

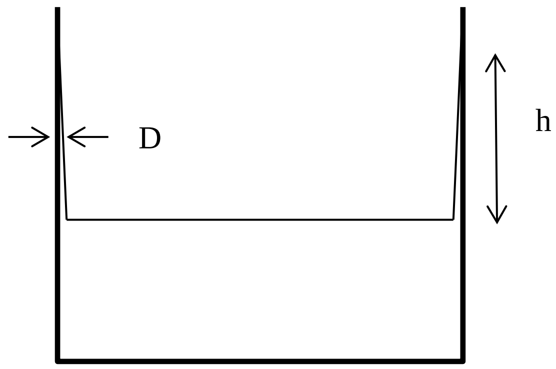

Figure 2

The energy per unit area, U_{VdeW}, of a film of decane of thickness, D, due to van der Waals interactions is given by

$$U_{VdeW} = -A/12\pi D^2$$

where the Hamaker constant $A = -7\times10^{-21}$ J.

The gravitational potential energy per unit area, U_G, of the film at a height, h, above the liquid surface is given by

$$U_G = \rho g h D$$

where ρ is the density of the liquid and $g = 9.81$ m s^{-2} is the acceleration due to gravity.

(i) Sketch the form of (i) U_{VdeW}, (ii) U_G and (iii) $U_{VdeW} + U_G$ as a function of D.

[8 marks]

(ii) Evaluate the equilibrium thickness of the film at h = 10 mm, (0.01m). (Take the density of decane, ρ to be 730 kg m^3.)

[7 marks]

Question 1 continues

c) In 1965, Lyklema and Mysels measured the equilibrium thickness of soap bubbles, and found it to be 73 nm, when the bubble was stabilised by 10^{-3} mol dm^{-3} sodium dodecylsulfate and the hydrostatic pressure on the surface of the film was 66 N m^{2}. In this experiment the thickness satisfies the condition of equilibrium between the hydrostatic pressure and the force of repulsion between the double layers on the adjacent faces of the film, *F*, which can be described by

$$F = 64 k_B T n_\infty \gamma^2 \exp(-\kappa D)$$

Where $\gamma = \tanh\left(\frac{ze\psi_0}{4k_B T}\right)$

In these equations k_B is Boltzmann's constant, 1.38×10^{-23} J K^{-1}, e is the charge on a single electron, 1.6×10^{-19} Coulombs T, is the absolute temperature, n_∞ is the number of ions in a cubic metre of solvent at an infinite distance away from the surface (*i.e. in the bulk),* κ is the Debye Huckel coefficient, ψ_0 is the surface potential and D is the separation between the two soap films in the bubble.

(i) Assuming that the adsorption of the surfactant at the air water interface gives a very high surface potential (of order 250mV), estimate the thickness of the soap film predicted by this model (**note you do not need to know a precise value for the surface potential**), state any assumptions that you make.

[9 marks]

(ii) What would be the effect of adding 10^{-2} mol dm^{-3} sodium chloride to the surfactant solution on the thickness of the bubble film?

[6 marks]

[END OF QUESTION 1]

Question 2 **[40 marks]**

(a) After an underwater oil spill, natural biodegradation is faster if the oil forms small droplets on the surface of the sea, rather than spreading to form a film. Crude oil is a mixture of hydrocarbons, and its spreading behaviour can be different depending on composition.

We wish to determine whether pentane and hexadecane spread upon water to form a film, or form isolated droplets. You may assume that water interacts with alkanes exclusively through dispersion interactions.

The surface tension of water is 71.8 mN m^{-1}; the dispersion contribution to the surface tension of water is 21.8 mN m^{-1}. The surface tension of pentane is 16.1 mN m^{-1}, and the surface tension of hexadecane is 27.5 mN m^{-1}.

(i) Quantify the dispersion contributions to the surface tensions of pentane and hexadecane. Justify your answer.

[3 marks]

(ii) State whether the Fowkes equation is applicable to the system under consideration. Justify your answer based on the physico-chemical properties of the three liquids.

[3 marks]

(iii) Calculate the interfacial tensions of pentane with water, and of hexadecane with water.

[6 marks]

(iv) Determine whether pentane and hexadecane spread on water.

[8 marks]

(v) Discuss the relevance of your findings to oil spill remediation.

[3 marks]

(b) Self-cleaning coatings are widely used in the construction, automotive, and aerospace industries. The coating is designed so that a certain liquid (l) phase,

Question 2 continues

in the presence of its vapour (v) does not spread on the solid (s) surface, but instead it forms droplets that roll off the surface.

(i) List the properties of a self-cleaning car coating, assuming that the liquid phase is mostly water. In your answer you should focus on self-cleaning performance, and may include also other possible consumer requirements.

[6 marks]

(ii) Calculate the Young's contact angle for the liquid-solid-vapour system, assuming the following values of interfacial tensions:

$$\gamma_{lv} = 52 \text{ mN m}^{-1},\ \gamma_{sv} = 29 \text{ mN.m}^{-1},\ \gamma_{ls} = 67 \text{ mN.m}^{-1}.$$

Comment on the value of contact angle that you have obtained

[3 marks]

(iii) Determine whether it is more advantageous to exploit the Wenzel state or the Cassie-Baxter state to obtain self-cleaning properties, assuming that the roughness factor is $R_w = 1.3$, that the surface fractions are $f_1 = f_2 = 0.5$, and that the surface tension of the vapour phase is zero. **[8 marks]**

[END OF QUESTION 2]

Question 3 **[20 marks]**

(a) You are given a choice between Silicon (bang gap = 1.14 eV), PCDTBT, Poly[N-90 -heptadecanyl-2,7-carbazole-alt-5,5-(40 ,70 -di-2-thienyl-20 ,10 ,30 -benzothiadiazole)] (band gap = 1.80 eV) and $SrTiO_3$:Nb (band gap = 3.2 eV).

(i) Which one would you use to make a transparent solar cell and why?

[4 marks]

(ii) What are the advantages of a transparent solar cell?

[3 marks]

(iii) What are the disadvantages?

[3 marks]

(b) Imagine that you are in charge of integrating as many solar cells into a high rise office building in the sunny city of Sydney, Australia. The outer surfaces of the office building are mostly glass windows, while the roof is made of flat concrete and is mostly empty. The company's employees have complained about the harsh light coming through the windows, and they hinted that a rooftop bar would greatly improve productivity.

(i) What **type or types** of solar cells would you use, where would you put them and why?

[10 marks]

[END OF QUESTION 3]