Birla Institute of Technology and Science Pilani, K K Birla Goa Campus
FIRST SEMESTER 2019-2020
ME F423 Microfluidics & its applications
Comprehensive Exam (Closed Book)
DATE: 09/12/2019 Time: 2:00 P.M. – 05:00 PM Maximum Marks: 80

Instructions

a) Write all steps and mention all **assumptions** involved while answering the problems.
b) Answer each **main** question on a **new page**.
c) Use of **schematics** is encouraged

Q. 1. Answer the following questions in **brief** with appropriate **reasoning** **[2 x8]**

a) Photolithography & Soft-lithography is frequently employed for microchannel fabrication. How will you fabricate microchannels using this technique? (Mention important steps only)

b) Mention two differences between micro-scale flow and macro-scale flow dynamics.

c) Droplets in the dripping regime are formed due to the competition between the viscous forces and surface tension forces, refer figure 1. Using this information, find the control parameters for diameter of the droplet.

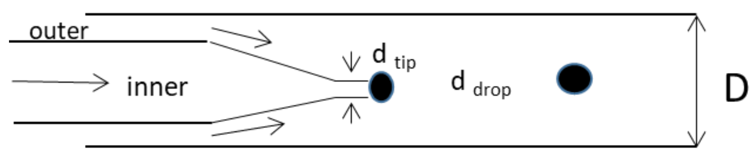

Figure 1

d) Represent the phenomenon of electro-wetting on a di-electric (EWOD) using a schematic diagram and mention one of its applications.

e) Nitrogen gas flows through a microchannel 10 μm in diameter, the diameter of the molecule is 3 x10^{-10} m, gas is maintained at a pressure of 300 kPa and temperature of 330 K, find the Knudsen number and determine the flow regime if the mean free path length is given by $\lambda = \frac{1}{\sqrt{2}\left(\pi d^2 n\right)}$ where *d* is diameter of gas molecule and *n* is number density of gas.

f) Represent the phenomenon of negative-Dielectrophoresis (n-DEP) using a schematic. What will be the sign of Clausius-Mossotti factor for n-DEP.

g) List at least four assumptions made while deriving the Boltzmann distribution in the electric double layer.

h) Capillary length dictates the behaviour of the menisci. Find the capillary length for water, given that the surface tension of water is 72 mJ/m^2.

Q.2 a) Driving flows in microchannels without use of pump is beneficial, capillarity is one such method. Refer the schematic shown in Figure 2, a flow being driven in a horizontal rectangular microchannel. Using Hagen-Poiseuille equation for rectangular microchannel, Young-Laplace equation and continuity principles show that distance '*s*' traversed by the fluid is proportional to square root of time. [Hint: The Young–Laplace pressure in a flat channel with equal contact angles at top plate and bottom plate and h<<w] **[8]**

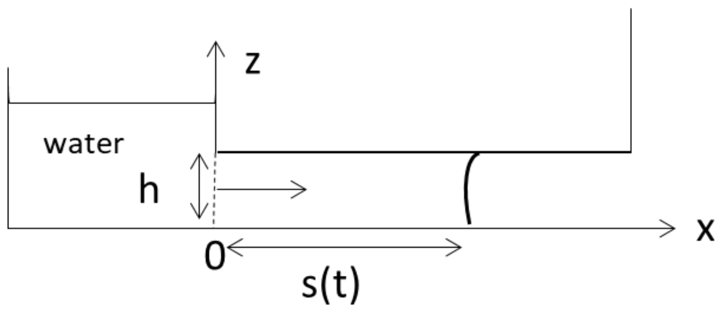

Figure 2

b) Provide two example of mixing using passive micromixers and explain the phenomenon "Tears of Wine". **[6]**

Q3. a) What is understood by the term slip boundary condition? Using the Maxwell's first order slip model and Newton's slip velocity obtain an expression for slip length. **[4]**

b) Air flows through two parallel plates separated by a distance of 40 µm, the length of the channel is 5 cm and a pressure difference of 50 kPa is maintained. Momentum accommodation coefficient is 0.8, and the mean free path length of air is 5 µm. Assume viscosity and density of air as 20 x 10^{-6} Pa-sec and 1.2 kg/m^3. Using 1^{st} order slip boundary condition, find the slip velocity and flow rate of air per unit width. Also find the flow rate per unit width for the 'no-slip' case. **[10]**

Q4. a) Explain the physics behind the formation of an Electric Double layer (Additionally, use schematics and potential distribution diagram for the explanation). Using the Poisson's equation and the Boltzmann distribution obtain the Poisson-Boltzmann equation. Further show the dependency of Debye length on number density (concentration) using the P-B equation obtained.

Note the Boltzmann distribution is given by: $n = n_o e^{-\frac{ze\psi}{k_B T}}$ **[10]**

(b) Consider flow of an electrolyte as shown in figure 3, the fluid flows in the microchannel under the influence of electrical field and pressure. Write the momentum equation for this case under the assumption of low Re and fully developed flow conditions. Simplify the momentum equation obtained using the Poisson's equation. Using appropriate boundary conditions determine an expression for the velocity profile. **[10]**

The Poisson's equation is given by: $\nabla^2\psi = -\frac{\rho_e}{\varepsilon}$

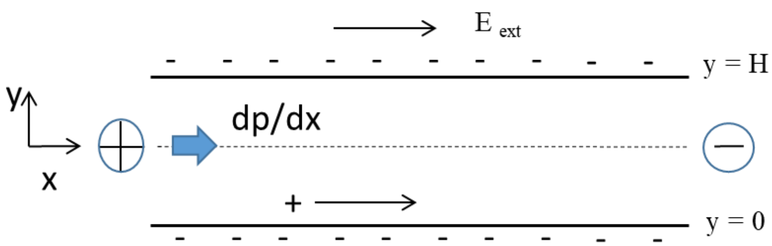

Figure 3

Q5. (a) Electro-osmotic force is sum of electric body force and osmotic force. The electric body force is given by $F_E = \varepsilon \nabla\phi \nabla^2 \phi$ and the osmotic force can be obtained by using the Navier-Stokes equation in the y-direction, refer figure 4. Find the osmotic force and hence show that the total electro-osmotic force is $\rho_e E_{ext}$. [Note: ϕ is total potential, ϕ_o is the applied potential and ψ is potential due to EDL]. Now, use the momentum equation in x-direction (refer figure 3, fully developed and low Re) including the electro-osmotic body force term but no pressure gradient to evaluate the Helmholtz –Smoluchowski velocity scale. **[10]**

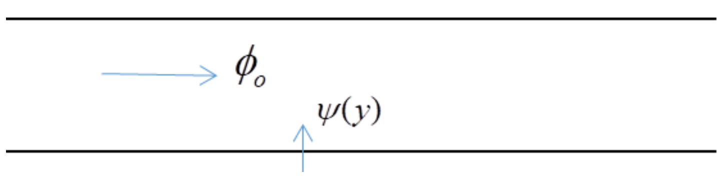

Figure 4

b) Consider two spherical protein strands, the human protein strand has a charge of 1 x 10^{-8} Coulomb and radius of 0.2 nm, the mouse protein strand has a charge of 2 x10^{-8} Coulomb and radius of 0.4 nm. Both the strands are kept inside de-ionized water medium, μ= 1mPa-s and are subjected to a field of 1 V/m. Find the ratio of electrophoretic velocity of the human protein and mouse protein. (Note: assume the case when $R \ll \lambda$). **[6]**