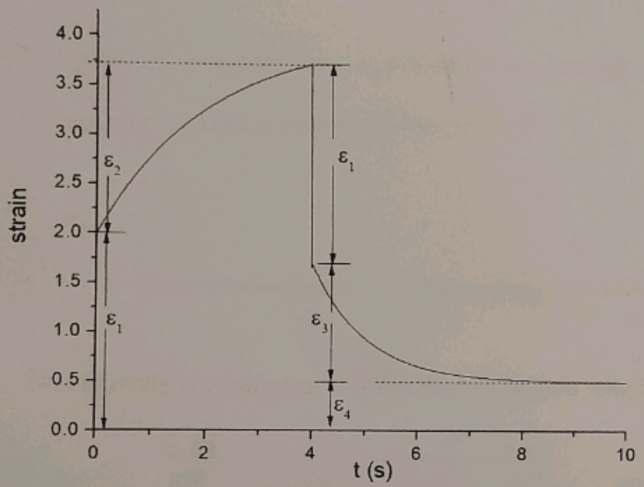
# Indian Institute of Technology Kharagpur
End-Autumn Semester 2024 – 2025

Date of Examination: Session: Duration 3 hrs Full Marks **140**
Subject Number: CH61017 Subject: Rheology of Complex Fluids
Department: Chemical Engineering

Specific Instructions: Assume and write any assumption and data that you feel are missing.
**Graph paper: one log-log plot, one semi-log plot and one linear-scale plot.**

**Q1.** Explain that why Dynamic light scattering techniques is recommended only for dilute suspensions of particles/polymers? (5)

**Q2.** Figure below shows strain evolution during a creep-recovery test of an Electrorheological fluids.




a) Plot the instantaneous elastic strain ($\varepsilon_1$) as a function of electric field intensity qualitatively, and explain? (3+3)
b) Plot the strain-time curve during creep for different electric field intensities in the same plot qualitatively, and explain? (3+3)
c) Suggest a model to capture the above shown strain evolution during creep-recovery test. Kindly also mention that which component/components of your model will be dependent on electric field and why? (7+3)
d) Solve the above model and obtain the strain as a function of time during creep (over time 0 to $t_1$) and during recovery ($t>t_1$). Choose your own model parameters. (8)

**Q3.** The radius of gyration of a polymer is defined as the radius of circle encompassing the polymer in random coil configuration, as shown below. This radius of gyration provides insight on polymer-solvent interaction.

In table-1, the data of normalized autocorrelation function ($g_2(\tau) = 1 + b * \exp(-Dq^2\tau)$) obtained from Dynamic Light Scattering measurements for two suspensions of the same polymer in solvent-X and solvent-Y. Using the data given in table-1, determine the radius of gyration of polymer in both solvents and then comment and explain that in which solvent polymer is more compatible? Other information: $\lambda$=650 nm, viscosity of both solvent are roughly equal to water-viscosity ($10^{-3}$ Pa.s) .

Stokes-Einstein equation: $D = \frac{k_b T}{6\pi\mu R_h}$, where $k_b = 1.380649 \times 10^{-23}$ joule/K. All DLS measurements done at T=298K. $q = \frac{4\pi}{\lambda} sin\frac{\theta}{2}$, where $\theta = 60°$ is the scattering angle.

(15+10)

Table-1

| | Solvent-X | Solvent-Y |
|---|---|---|
| τ(s) | $g_2(\tau)$ | $g_2(\tau)$ |
| 0.000337 | 1.945132 | 1.994227 |
| 0.000862 | 1.74626 | 1.849345 |
| 0.00146 | 1.570193 | 1.709858 |
| 0.00185 | 1.478413 | 1.631479 |
| 0.002404 | 1.372849 | 1.534785 |
| 0.0027 | 1.326351 | 1.489344 |
| 0.003362 | 1.242275 | 1.401202 |
| 0.00398 | 1.183456 | 1.333307 |
| 0.004501 | 1.145115 | 1.285079 |
| 0.004972 | 1.117399 | 1.247514 |
| 0.005395 | 1.09705 | 1.218015 |
| 0.006795 | 1.051688 | 1.143246 |
| 0.00795 | 1.030737 | 1.101298 |
| 0.008389 | 1.025227 | 1.088798 |

**Q4.** Relaxation modulus decay data for a polymer melt at five different temperatures is given below:

| 80°C | |
|---|---|
| log (t) | G(t) |
| -1.16827 | 100 |
| -0.92308 | 90.68745 |
| -0.61538 | 78.74559 |
| -0.27885 | 76.22112 |
| 0.16827 | 76.22112 |

| 70°C | |
|---|---|
| log (t) | G(t) |
| -1.09135 | 220.97318 |
| -0.625 | 149.46112 |
| -0.22115 | 111.47301 |
| 0.37019 | 85.89387 |
| 0.5 | 81.35368 |

| 60°C | |
|---|---|
| log (t) | G(t) |
| -1.46154 | 450 |
| -1.15865 | 375 |
| -0.77404 | 277.58511 |
| -0.3125 | 200 |
| 0.25481 | 131.19717 |
| 0.80288 | 92.67892 |
| 0.94231 | 89.70777 |

| 50°C | |
|---|---|
| log (t) | G(t) |
| -1.96635 | 900 |
| -1.16346 | 730 |
| -0.86058 | 660 |
| -0.16346 | 499.01449 |
| 0.4375 | 356.35825 |
| 0.91827 | 238.42867 |

| 40°C | |
|---|---|
| log (t) | G(t) |
| -1.45673 | 1102.68847 |
| -1.16346 | 957.48513 |
| -0.50962 | 813.53702 |
| -0.16346 | 745.83284 |
| 0.36538 | 647.62069 |
| 0.84615 | 521.17206 |

**a)** Demonstrate time-temperature superposition by creating a master curve (Consider curve for 40°C as the reference curve). List down the shift factors.

(13+5)

**b)** Report the relaxation modulus value at $10^3$s for 60°C using the master curve. Explain the advantage of time-temperature superposition.

(5 +5)

**Short Answer type questions (answer briefly and precisely in few lines)**

**4)** Why soft glassy materials possess a yield stress? (5)

**5)** Draw a nice schematic of a particle-based Pickering emulsion, and explain the physics . Provide two applications of Pickering emulsion. (5)

**6)** Concentrated polymers suspensions show die-swelling effect. Which rheological property is responsible for such phenomenon? Explain the physics of this phenomenon? (7)

**7)** Explain the glass transition temperature and its significance by citing two real life examples? (5+5)

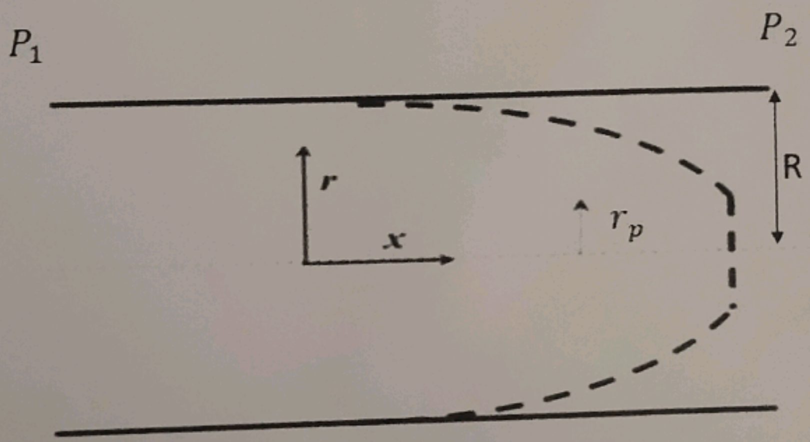
**8)** Describe shear thinning and shear thickening fluids and plot the stress as a function of shear rate qualitatively for both fluids? (5+5)

**9)** Consider a Bingham Fluid, whose constitutive equation is given by

$$\tau = \tau_y + K\dot{\gamma}$$

The typical velocity profile for a pressure driven laminar pipe flow is shown below.

The pressure gradient across pipe is linear $\frac{(P_1-P_2)}{L}$




(a) Derive the expression for the radius of plug zone ($r_p$). (5)

(b) Derive the velocity profile in annular region. (5)

(c) Find out the velocity of central plug. (5)