

## Soft Matter - Exam Preparation

### 1. Nematic Liquid Crystals

- Mention at least two options for increasing the transition temperature of a nematic liquid crystal. Explain on a molecular level why the transition temperature increases.
- How can you quantify the transition temperature? What is the principle behind this measuring technique?

### 2. Cholesteric Liquid Crystals

Why can cholesteric liquid crystals be used as a temperature sensor? What are their limitations?

### 3. Liquid Crystal Display

*N*-(4-Methoxybenzylidene)-4-butylaniline (MBBA) is a light-responsive, nematic liquid crystal with the structure shown in Figure 1. The elastic constants for this material at 22°C are:

$$K_1 = 5.3 \times 10^{-12} \text{ N}$$

$$K_2 = 2.2 \times 10^{-12} \text{ N}$$

$$K_3 = 7.45 \times 10^{-12} \text{ N}$$

The dielectric permittivity in the direction of the ordinary ray is 4.7; that in the direction of the extraordinary ray is 5.4. You use this material to design a liquid crystal display that is bright if there is no electric field and becomes dark if there is an electric field. The mesogens are initially oriented parallel to the chamber surface. Calculate the electric field required to make the display bright if the chamber is:

- 100 nm thick
- 1  $\mu\text{m}$  thick
- 100  $\mu\text{m}$  thick
- What could be a potential difficulty for displays with a chamber that is 100  $\mu\text{m}$  thick?

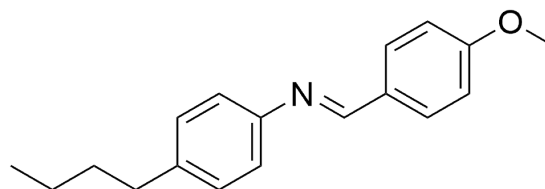


Figure 1: Structure of *N*-(4-Methoxybenzylidene)-4-butylaniline (MBBA)

#### 4. Composition of Micelles

How can the shape of micelles, composed of anionic amphiphiles, be changed without changing the composition of the amphiphiles?

#### 5. Micelle Size

An amphiphile is dispersed in a solution at a concentration of 3.5 vol%, and it forms cylindrical micelles. You measure a CMC of  $5 \times 10^{-8}$ . What is the most probable number of molecules contained in such a micelle?

#### 6. Temperature Dependence of Lyotropic Liquid Crystals

You optimize phospholipid-based vesicles. Imagine that the average temperature on Earth increases by 20°C.

- How would that affect the CMC of the phospholipids?
- How would that affect the exchange rates of amphiphiles contained in vesicles?
- How would that affect the stability of cell membranes?
- What would you change in the composition and/or structure of the phospholipids to obtain similar membrane properties to those you observe with the current phospholipids at room temperature but at 20°C higher temperatures?

#### 7. pH-Responsiveness of Polymers

- Why is poly(acrylic acid) pH responsive?
- Around which pH does the degree of hydration change for poly(acrylic acid)?
- Is poly(acrylic acid) hydrated at very high pHs? Why or why not?

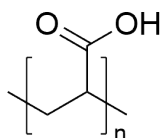


Figure 2: Chemical structure of poly(acrylic acid)

#### 8. Viscosity of Entangled Melts

For an entangled melt of poly(butadiene), the plateau value of the shear modulus at room temperature is  $1.15 \times 10^6$  Pa. Assume the density of poly(butadiene) to be  $900 \text{ kg/m}^3$  and the  $a$  to be  $0.65 \text{ nm}$ . The molar mass of a monomer unit is  $54 \text{ g/mol}$ . The zero shear viscosity,  $\eta_0$ , as a function of the degree of polymerization,  $N$ , and the temperature,  $T$ , may be written as:

$$\eta_0 = 3.86 \times 10^{-3} \times \exp\left(\frac{1404}{T-128}\right) N^{3.4} \text{ Pa.s}$$

- Calculate the relative molecular mass between entanglements,  $M_x$ , using  $G = (\rho RT)/M_x$

- b. Estimate the diffusion coefficient of poly(butadiene) with a relative molecular mass of 100,000 g/mol at 298 K.
- c. Based on the result obtained in (b), judge if this diffusion is fast. Why or why not?

### 9. Crosslink Density of an Elastomer

The data shown in Table 1 gives the experimental relation between stress and strain for a piece of rubber at 20°C.

- a. Use the data of Table 1 at small strains to calculate the density of crosslinks.
- b. Plot the data over the full range of strains, together with the prediction of rubber elasticity, assuming the density of crosslinks you calculated, and discuss possible discrepancies.

| $\epsilon$ | $\sigma$ (MPa) |
|------------|----------------|
| 0          | 0              |
| 0.162      | 0.152          |
| 0.27       | 0.246          |
| 0.433      | 0.327          |
| 0.678      | 0.42           |
| 0.95       | 0.489          |
| 1.358      | 0.605          |
| 1.657      | 0.697          |
| 2.338      | 0.882          |
| 2.964      | 1.067          |
| 3.48       | 1.253          |
| 4.35       | 1.613          |
| 4.973      | 1.986          |
| 5.461      | 2.313          |
| 6.19       | 3.05           |
| 6.403      | 3.448          |
| 6.699      | 3.811          |
| 6.914      | 4.151          |
| 7.019      | 4.503          |
| 7.151      | 4.878          |
| 7.256      | 5.242          |
| 7.361      | 5.605          |
| 7.489      | 6.321          |

Table 1: Stress as a function of strain

### 10. Thermosets

- a. How are thermosets typically processed?
- b. Name an example of a thermoset. Where is this thermoset used?

## 11. Self-Healing Hydrogels

You designed a self-healing hydrogel that contains 80 wt% water.

- a. How would you design the crosslinks of this hydrogel to ensure that it has self-healing properties?
- b. You realize that the hydrogel starts to flow very quickly even if you stress it minimally. This hampers the use of this hydrogel as a damper. You are asked to improve the mechanical properties to ensure that the hydrogel flows only if higher stresses are applied while maintaining the self-healing properties and without significantly changing the elastic modulus. What would you do?
- c. Generally speaking, what is a relaxation time?
- d. How would you characterize the relaxation time? Describe the working principle of this technique.

## 12. Nanoparticles in Solution

- a. How long will it take for a 200-nm diameter  $\text{SiO}_2$  particle added to one side of a 30 cm long horizontal pipe filled with water to diffuse to the other end?
- b. How long will it take if the  $\text{SiO}_2$  particle is 2 nm in diameter?
- c. How long will it take for 200-nm diameter particles added to the top of a vertical 30 cm long pipe that is filled with water to sediment to the bottom of the tube?
- d. How long will it take if the  $\text{SiO}_2$  particle is 2 nm in diameter?

Assume the temperature to be  $20^\circ\text{C}$ , the density of the water to be  $1\text{ g/cm}^3$  and that of  $\text{SiO}_2$  to be  $2.65\text{ g/cm}^3$ . The viscosity of water at  $20^\circ\text{C}$  is  $1\text{ mPa}\cdot\text{s}$ . Assume the gravitational acceleration to be  $9.0\text{ m/s}^2$ .

## 13. Surface Area

Starting with a solid cube that is 1 cm along each edge, what is the total surface area when the solid is divided into cubes whose edges are:

- a.  $1\ \mu\text{m}$
- b. 100 nm
- c. 1 nm

In each case, calculate the surface energy per particle assuming a surface energy of  $0.07\text{ mJ/m}^2$  and compare it to the thermal energy at room temperature.

## 14. Electrostatic Stabilization

- a. Calculate the Debye screening length at  $20^\circ\text{C}$  for aqueous solutions containing:
  - i. 1 M KCl
  - ii. 0.01 M KCl
  - iii.  $10^{-4}$  M KCl
  - iv. 1 M  $\text{CaCl}_2$

(Assume  $\epsilon_r$  of water at  $20^\circ\text{C}$  to be 80.)

- b. What is the Debye length of an aqueous solution containing 1 M NaCl at 80°C? (Assume  $\epsilon_r$  of water at 80°C to be 55.)

### **15. Surfactants**

What are surfactants and where are they used?

### **16. Adsorption of Surfactants**

What technique would you use to measure the adsorption kinetics of surfactants at air-liquid interfaces? What is the underlying principle of this technique?

### **17. Stabilization of Vinaigrette**

What types of surfactants (activity, charge, and composition) would you use to stabilize vinaigrette?