Fluorescence Probing of the Temperature-Induced Phase Transition in a Glycolipid Self-Assembly: Hexagonal ↔ Micellar and Cubic ↔ Lamellar

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**ABSTRACT:** Water-driven self-assembly of lipids displays a variety of liquid crystalline phases that are crucial for membrane functions. Herein, we characterize the temperature-induced phase transitions in two compositions of an aqueous self-assembly system of the octyl β-D-glucoside (βGlcOC₈) system, using steady-state and time-resolved fluorescence measurements. The phase transitions hexagonal ↔ micellar and cubic ↔ lamellar were investigated using tryptophan (Trp) and two of its ester derivatives (Trp-C₄ and Trp-C₆) to probe the polar headgroup region and pyrene to probe the hydrophobic tail region. The polarity of the headgroup region was estimated to be close to that of simple alcohols (methanol and ethanol) for all phases. The pyrene fluorescence indicates that the pyrene molecules are dispersed among the tails of the hydrophobic region, yet remain in close proximity to the polar head groups. Comparing the present results with our previously reported one for βMaltoOC₁₃, increasing the tail length of the hexagonal phase from C₄ to C₁₃ leads to less interaction with pyrene, which is attributed to the more random and wobbling motion of the longer alkyl tail. We measured a reduction (more hydrophobic) in the ratio of the vibronic peak intensities of pyrene (I₂/I₁) for the lamellar phase compared to that of the cubic phase. The higher polarity in the cubic phase can be correlated to the nature of its interface, which curves toward the bulk water. This geometry also explains the slight reduction in polarity of the headgroup region compared to the other phases. Upon the addition of Trp-C₆, the fluorescence lifetime of pyrene is reduced by 25% in the lamellar and cubic phases, whereas the I₂/I₁ value is only slightly reduced. The results reflect the dominant role of dynamic interaction mechanism between the C₄ chain of Trp-C₄ and pyrene. This mechanism may be important for these two phases since they participate in the process of membrane fusion. Both lipid compositions show completely reversible temperature-induced phase transitions, reflecting the thermodynamic equilibrium structures of their mesophases. Probing both regions of the different lipid phases reveals a large degree of heterogeneity and flexibility of the lipid self-assembly. These properties are crucial for carrying out different biological functions such as the ability to accommodate various molecular sizes.

**INTRODUCTION**

Lyotropic mesophases of lipids in water have received much attention from the fundamental point of view as well as for application aspects.¹⁻⁴ Their self-assembly properties are suitable as model systems for understanding specific membrane function in biosystems. When dispersed in water, lipids can display not only the lamellar phase but also a variety of nonlamellar curved liquid crystal phases such as the cubic, the hexagonal, and the ribbon phases.⁵⁻⁹ The transition between these possible phases is a result of an abrupt change in the interface curvature. This transition is believed to be governed by competition between the bending elastic energy of the interface and energies resulting from interfacial separation constraints.¹⁰

Glycolipids (GLs) belong to a large family of molecules known as glycoconjugates.¹¹ They have been extensively studied due to their connection to biological cell membranes. Although GLs are minor components in the cell membranes of prokaryotes and eukaryotes (compared to phospholipids), their widespread occurrence and extensive structural diversity suggest functional importance in cell processes,¹² such as endo- and exocytosis, apoptosis, and molecular recognition at the cell surface specific to the cell type.¹³ Chemically, GLs exhibit surfactant properties due to the dichotomic balance of the carbohydrate headgroup (with one or more monosaccharide units) and the lipophilic alkyl tail.¹² As amphiphilic liquid crystals,¹⁴ they are able to self-assemble in both dry (thermotropic) and solvated (lyotropic) states into many different polymorphic forms such as the lamellar, hexagonal, sponge, and gel phases depending on appropriate conditions.

Phase studies of glycolipids have mostly focused on lyotropic systems because these are closely related to biological membranes. The adhesion property of the sugar headgroups and their interactions with peptides and surface proteins make them suitable targets for nanoparticle vectors.¹⁶ Their importance in biology and industry has encouraged many