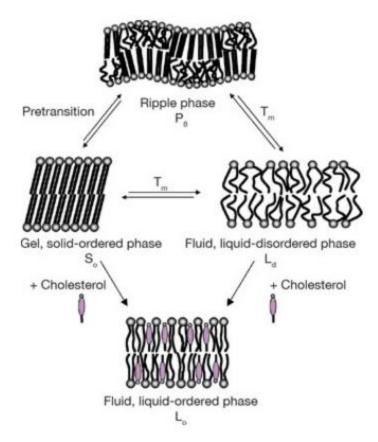


## 3.5: The Ripple Phase

Lipids consist of hydrophilic polar head groups attached to hydrocarbon chains and arrange themselves in bilayers to make biological membrane structures. At lower temperatures, the bilayer is in a  $L_{\beta'}$  'gel' phase and there is a transition to 'fluid' phase,  $L_{\alpha}$ , at higher temperatures due to an increase in mobility of individual lipids in the bilayer. A smectic ripple phase  $P_{\beta'}$  is observed in hydrated lipid bilayers between the  $L_{\beta'}$  and  $L_{\alpha}$  phase. This phase is characterized by corrugations of the membrane surface with well-defined periodicity with an axis parallel to the mean bilayer plane [1]. The molecular origin of ripple-phase formation is traditionally been associated with the lipid headgroup region and hence lipids can be classified into ripple-forming and non-ripple forming lipids based on their headgroups. One of the lipid families belonging to ripple-forming class is phosphatidylcholines and has been studied in extensive detail [1].

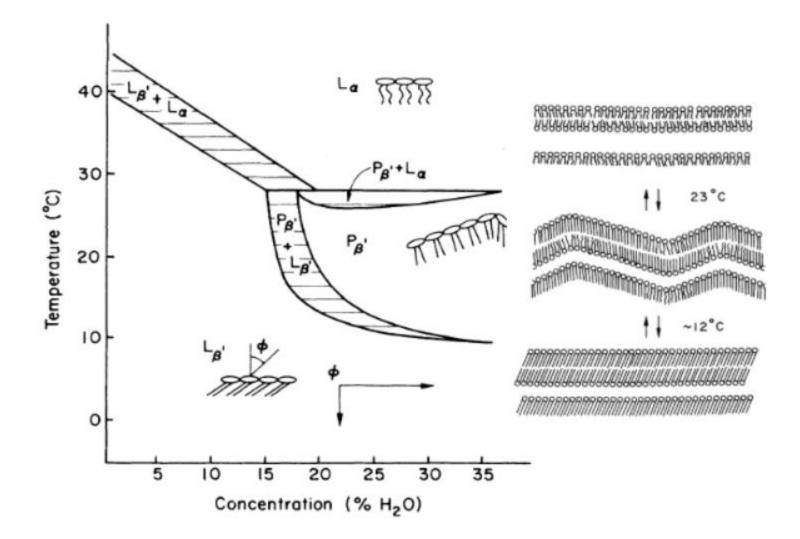


Scheme above shows different physical states adopted by a lipid bilayer in aqueous medium [2]

## Thermodynamics and Existence

The existence of the ripple phase at first sight is paradoxical on thermodynamic grounds since it involves an apparent lowering of symmetry (from  $L_{\beta'}$  to  $P_{\beta'}$ ) on increasing the temperature. Some models suggest that ripples exist because of periodic local spontaneous curvature in the lipid bilayers formed due to electrostatic coupling between water molecules and the polar headgroups or coupling between membrane curvature and molecular tilt. It has also been speculated that ripples form to relieve packing frustrations that arise whenever the relationship between head-group cross sectional area and cross-sectional area of the apolar tails exceeds a certain threshold [1]. However, there is not one conclusive theory to explain ripple phase formation.

## Phase Diagram Depicting Ripple Phase



Experimental phase diagram for (1,2-dimyristoyl-sn-glycero-3-phosphocholine) DMPC, plotted as a function of temperature and hydration. Solid lines indicate first order transitions. Arrows indicate directions of increasing tilt in the  $L_{\beta'}$  phase. The rightmost schematic shows, from top to bottom, the forms of the phases  $L_{\alpha}$ ,  $P_{\beta'}$  and  $L_{\beta'}$  [3]