When Alcohols Break the Rules: Nonmonotonic Forces in Soft Membrane Stacks

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How do small solutes reshape interfacial forces in soft matter? Using lipid multilamellar vesicles, we show that short-chain alcohols drive membrane interactions beyond classical expectations. Combined SAXS and molecular dynamics reveal distinct responses: methanol induces continuous swelling and unbinding, whereas ethanol produces a striking nonmonotonic behavior, with collapse following initial swelling.

These trends violate standard free-energy-minimum descriptions. We show that, in the soft highly fluctuating regime, membrane spacing is governed by the full distribution of fluctuations rather than the free-energy minimum. While this resolves swelling, the ethanol-induced collapse points to additional interfacial stresses linked to solute partitioning and modified fluctuation forces.

These findings highlight how subtle interfacial chemistry can qualitatively reshape collective forces in soft assemblies.