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Specular reflections from fluctuating membranes and interfaces

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We describe the interplay between optical specular reflections and material properties of the fluctuating membranes and interfaces in thermodynamic equilibrium. We focus on the statistical mechanics of two distinct elastic models, fluid membranes with a tension, and capillary-gravity interfaces in two and three dimensions. Our analysis exploits a hydrodynamic model of the statistical mechanics, in which the statistics of specular points is fully characterized by the correlation length, thickness and lateral dimension of the membrane or interface. The correlation lengths of the membranes and capillary interfaces are controlled respectively by the ratio of the surface tension and the bending rigidity or gravity-capillary length scale. By combination of a simple scaling analysis and numerical simulations, we find a simple universal scaling law for the specular density, n_{spec} in d dimensions described by $n_{spec} \propto \ell^{-(d-1)}$, for arbitrary thin fluctuating interfaces, $\ell \to 0$. The specular density diverges for fluctuating interfaces in the limit of vanishing thickness and surprisingly shows no dependance on the correlation length. In contrast, the number of specular reflections from highly bendable fluid membranes grow by decreasing the correlation length.

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