Monopolar charge fluctuation induced forces in 2D nanostructures

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Fluctuation-induced interactions have widespread applications in materials, micro- and nanoscaled devices. The much-studied Casimir and van der Waals interactions are due to vacuum electromagnetic mode fluctuations captured via the dielectric response properties of the objects.[1-4] Such forces are universal, and they are especially prominent at micron distances and below. Fluctuations of many other observables are also possible, which may give rise to different interactions.[5] Fluctuations originating from charge disorder on neutral slabs, in particular, are shown to give an additional contribution to the net interacting force while completely masking the typical Casimir–van der Waals interaction.[6]

Here, we investigate monopolar charge fluctuation induced forces in 2D nanostructures.[7] We present a general theory utilizing the capacitance concept and distinguishing between thermal and quantum mechanical effects through characteristic dependences on distance, temperature, and other factors. Graphene-based systems are taken as templates for which the theory is applied. Here, the fundamental difference of the charge-induced fluctuation forces from the typical Casimir force lies in their origin. While the Casimir force is due to the electromagnetic fluctuation excitations associated with the dielectric response of each plate, the charge-induced effect is due to monopolar charge fluctuations between the plates transferred through a connecting wire, or a metallic substrate (see Figure). Since in many cases nanostructures are characterized by a reduced Casimir force, the nanocapacitors we study offer the possibility of finding regimes where the charge-induced fluctuation interaction can be dominant. Our results are strong evidence that there are different types of dispersive interactions that occur in solid state devices, in particular when lower dimensional materials such as graphene are used.

References

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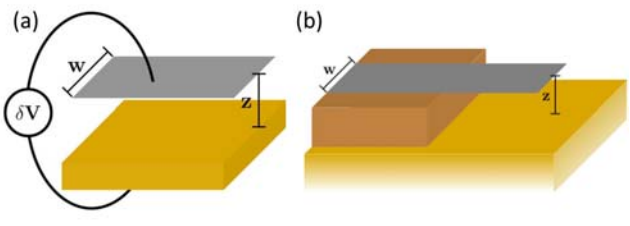
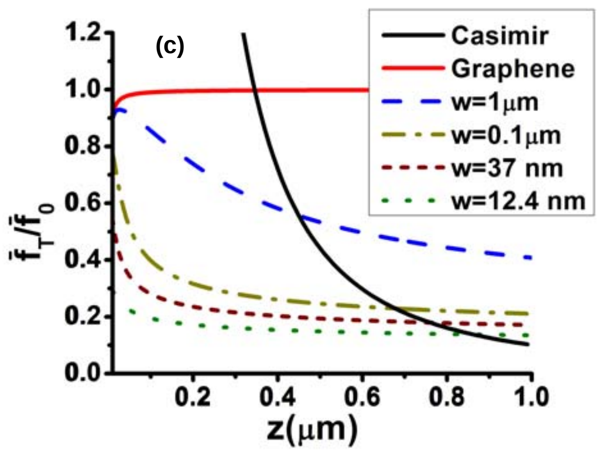
Figures



(a), (b) Metal sheet and carbon nanoribbon systems that exhibit monopolar charge fluctuation forces.



(c) Distance (z-) dependence of the charge fluctuations thermal force normalized by $f_0 = -k_BT/(2Az)$ for graphene nanoribbons of varying width. The area A of all ribbon structures is chosen to be 1 μm^2. The graphene-metal Casimir force at room temperature is also shown.