Long Range Interactions in Cylindrical Structures

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Abstract

We consider the interaction energy due to electromagnetic field fluctuations in various infinitely long cylindrical systems. The structures of interest are a single cylindrical layer with a finite thickness, N concentric infinitely thin shells, and two parallel full cylinders. In all cases, the mode summation method is applied to calculate the zero-point energy. The derived analytical expressions are used to investigate the energy dependence on the cylindrical radial curvature, size of the system, and the dielectric response properties of the involved objects and the medium. Of particular interest is the case of two parallel cylinders, for which we show that the interaction can be changed from attractive to repulsive by a suitable choice of the material composition of the cylinders and the environment. Our studies can serve as a test ground for future, more advanced theories of long ranged interactions in cylindrical systems. The presented results can also be viewed as a model of interactions due electromagnetic field fluctuations between tubular formations, such as nanotubes and nanowires.

Mode Summation Method

\[ E_C = \frac{\hbar}{2} \sum_{\{p\}} (\tilde{\omega}_p - \tilde{\omega}_p) \]

- \( E_C \): zero-point Casimir energy;
- \( \tilde{\omega}_p \): the eigenfrequencies of the system;
- \( \tilde{\omega}_p \): the eigenfrequencies with no boundaries present;
- \( \{p\} = (n, m, k) \): quantum numbers for cylindrical geometry.

Zero-Point Energy of N concentric shells

\[ E_C = \frac{\hbar}{2} \sum_{\{n\}} (\tilde{\omega}_n - \tilde{\omega}_n) \]

- \( N \): number of concentric shells.

Zero-Point Energy of a Cylindrical Layer

In infinitely thick layer, with constant dielectric and magnetic properties \((\varepsilon, \mu)\) imbedded in an infinite medium with constant properties \((\varepsilon_c, \mu_c)\).

- Constant speed of light approximation: \( \varepsilon C = \varepsilon_c C = \varepsilon C \) (dielectric-diamagnetic system)

Zero-Point Energy of two solid parallel cylinders

Two infinitely long solid parallel cylinders, with constant dielectric and magnetic properties \((\varepsilon, \mu)\) imbedded in an infinite medium with properties \((\varepsilon_c, \mu_c)\).

- Constant speed of light approximation: \( \varepsilon C = \varepsilon_c C = \varepsilon C \) (dielectric-diamagnetic system)

Discussions

- Successful in removing divergences for all models and obtained finite results for the zero-point energy.
- Casimir energy as a function of curvature, distance separation and dielectric properties.
- Repulsive interaction for two solid parallel cylinders can be achieved for specific choices of the dielectric constants: \( \varepsilon_1(\varepsilon_2) > \varepsilon_2(\varepsilon_1) \)

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References

2 www.casimir.dur.ac.uk/measurements.htm

Cylindrical Structures

- Concentric metallic cylindrical shells
- Parallel solid cylinders
- Models of different carbon nanotube systems