NEEL INSTITUTE Grenoble

PhD thesis project

Acoustic analog of a quantum effect: the Casimir force

General Context:
In 1948, Hendrik Casimir predicted that quantum fluctuations of the vacuum, so-called zero-point fluctuations, could give rise to an attractive force between objects. Casimir's calculations were idealized - he considered two perfectly conducting parallel mirrors facing each other in the vacuum at absolute-zero temperature. Since then, this prediction has been confirmed experimentally but many questions remain, among which the possibility of achieving a repulsive Casimir force. Although the Casimir effect is deeply rooted in the quantum theory of electrodynamics, there are analogous effects in classical physics. A striking example was discussed in 1836, in P. C. Caussée's L'Album du Marin (The Album of the Mariner). Caussée reported a mysteriously strong attractive force that can arise between two ships floating side by side — a force that can lead to disastrous consequences (Boersma, 1996: see Figures 1 and 3). A physical explanation for this force was offered only recently by Boersma, who suggested that it originates in the radiation pressure force of water waves acting differently on the opposite sides of the ships. Analogous arguments can be employed for the Casimir effect itself by invoking a deficit of virtual photon modes of the vacuum between mirrors.

Fig. 1. Two ships roll heavily on a long swell and there is no more wind to damp their rolling. In this situation a strange force, "une certaine force attractive," will pull the two ships toward each other. From P. C. Caussée: "the Mariners Album," early 19th century.

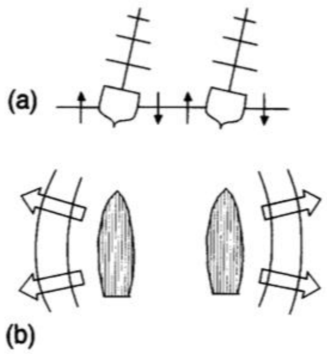

Fig. 3. (a) Two ships at close quarters roll on a long swell. (b) They re-emit the absorbed power as secondary waves.

Historically, the Casimir effect was long considered to be an exotic quantum phenomenon, but now it is starting to take on technological importance. Because of its relatively short range, it has only a very small effect on the dynamics of macroscopic mechanical systems. But the Casimir force plays a major role in modern micro and nanoelectromechanical systems (MEMS and NEMS), where the distances between neighboring surfaces are typically far less than 1 µm. In tiny devices such as these, the Casimir force can cause mechanical elements to collapse onto nearby surfaces, resulting in permanent adhesion - an effect called 'stiction', which often proves to be an important factor in the malfunction of NEMS.

Yet the Casimir force can also be repulsive when modifying the properties of the mirrors.
In recent years, several groups have tried to observe such repulsive forces.
One interesting proposal consists of an elongated object floating above a hole in a plate (Levin, 2010: see Fig.1 (A)), but the acting force has not yet been measured.

Indeed, experimental progress is limited by very severe conditions required by the observation of very tiny effects (the typical Casimir pressure is 10^20 weaker than the atmospheric pressure).

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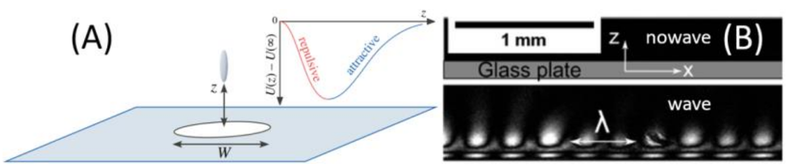

(A) Typical configuration of Casimir repulsive: an object facing a micro-hole. The associated force-distance curve is shown. (extract from [1]). (B) Evanescent acoustic field in the vicinity of a non-pierced plate, obtained via Schlieren imaging.

Subject, available means:
In this thesis, we propose to address the Casimir effect with a hydrodynamic approach based on an acoustical analog of the quantum vacuum. Experimentally, an isotropic random acoustic noise in a liquid is used to mimic the quantum fluctuations of the vacuum Zero-point field (ZPF). The advantages of using an analog approach are manyfold: (i) fluctuation spectra can be fine-tuned and shaped at will to match that of the quantum, (ii) the orders of magnitude of the length-scales and forces are larger than their quantum counterparts, (iii) the experiments do not require heavy instrumentation (when compared with cryogenic and vacuum conditions) and (iv) most parameters can therefore easily be varied, allowing for quick exploration of any effect. Most importantly, the (acoustic) field itself can be probed and even imaged, unlike the vacuum field.

At the lab, two promising experiments have recently been set up. The first is the acoustic version of the historical configuration proposed by Casimir, where two acoustic mirrors are immersed in a fluid insonified by ultrasound radiation and an attractive force arises from the difference in acoustic radiation pressures. The second acoustic setup is the pierced hole configuration described above which aims to achieve a repulsive Casimir force and consequently quantum levitation.
During this thesis both setups will be very carefully examined both experimentally and theoretically, and confronted with the quantum Casimir experiments running in our lab.

Finally, depending on the schedule, the ultimate possibility of achieving a Casimir torque effect (by means of either quantum or acoustic chiral structures) will be addressed.

Required skills:
The PhD candidate must have a solid background in physics and maths. A large and healthy dose of curiosity will be appreciated. She/He will be supervised within the NOF team of Neel Institute by a specialist in acoustic quantum analogs (Cédric Poulain) and by researchers on the quantum Casimir effect (Olivier Arcizet and Benjamin Pigeau).

Physics, Acoustics, Quantum analogs, Interest in theoretical and experimental problems in fundamental physics

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