Universal experimental test for the role of dissipation in the Casimir force

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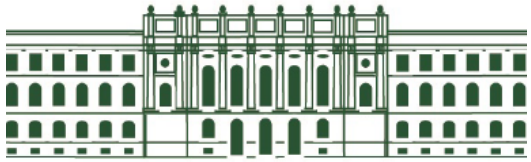


CONTENT

1. Introduction

The Casimir puzzle:

Theoretical predictions of the Lifshitz theory with taken into account relaxation properties of free charge carriers for metals (the Drude model approach) and conductivity at constant current at nonzero temperature for dielectrics are experimentally excluded.

Theoretical predictions of the Lifshitz theory with disregarded relaxation properties of free charge carriers for metals (the plasma model approach) and omitted conductivity at constant current at nonzero temperature for dielectrics are experimentally consistent.

The Drude model approach violates the Nernst heat theorem for metals with perfect crystal lattices, whereas the plasma model approach is thermodynamically consistent.

For dielectrics with taken into account and omitted dc conductivity the Nernst heat theorem is violated and satisfied, respectively.

The relative difference between theoretical predictions of the Drude and plasma model approaches for metals and for dielectrics with taken into account and omitted dc conductivity in the measurement range was up to 5%. In spite of up to an order of magnitude lower relative error in the experiments performed up to 2016, the possible role of several background effects was noted by different authors, which could potentially lead to just the opposite results.

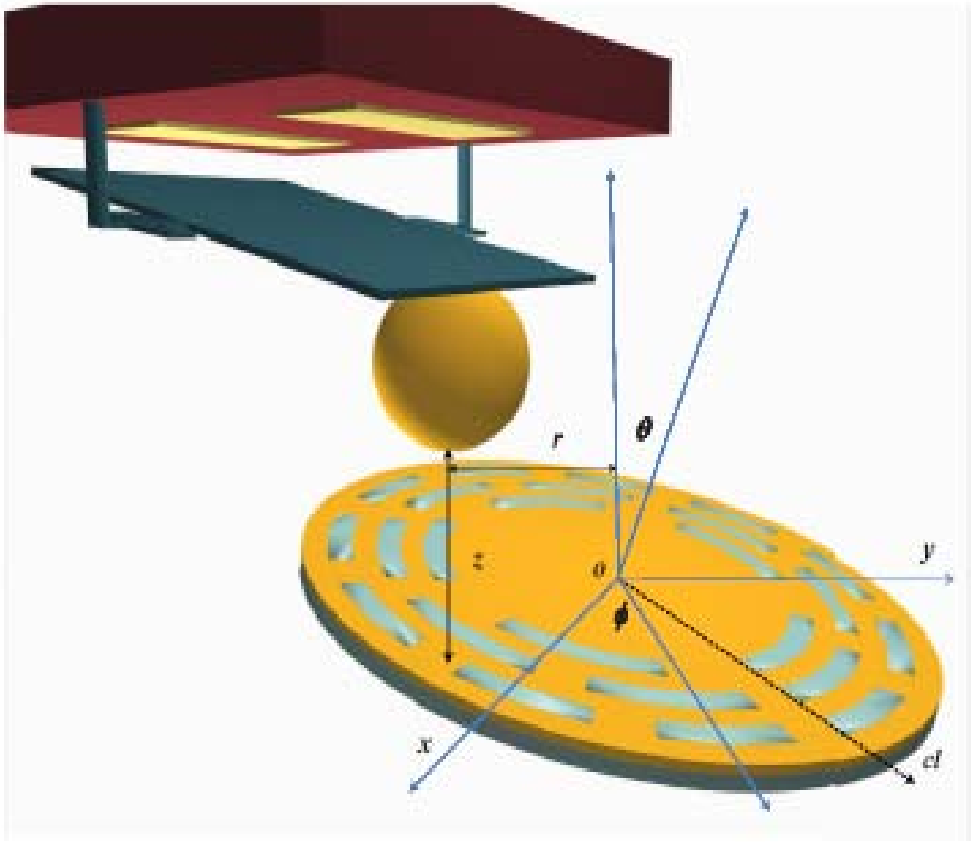
Some of the background effects are:

- The role of surface roughness.
- Corrections to the proximity force approximation.
- The contribution of nonlocal effects.
- The alternative sets of optical data.
- Additional forces due to patch potentials.

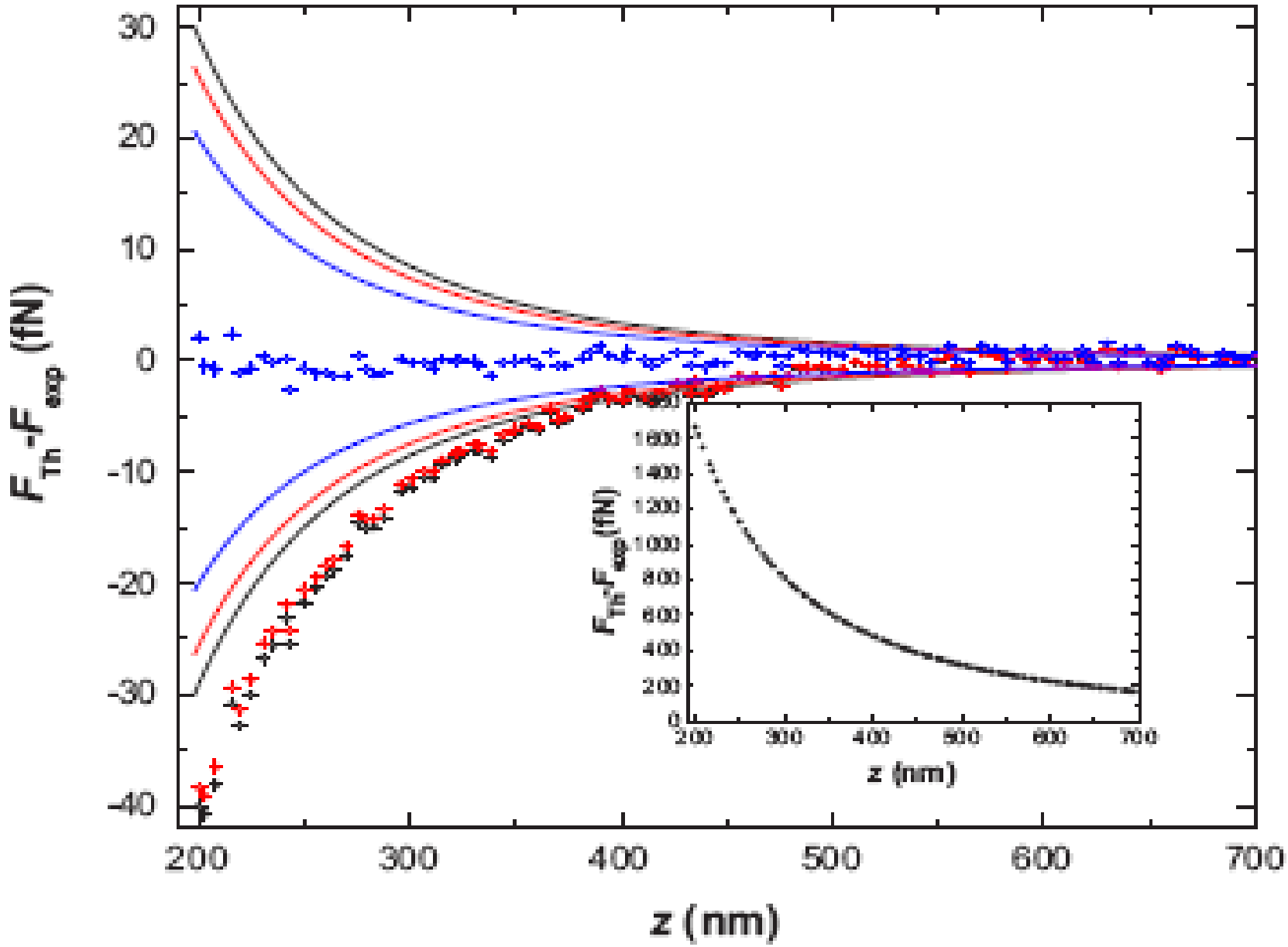
Here, we remind about the differential experiment of 2016 by Bimonte, Lopez and Decca, which made the experimental situation certain for metals in the separation region of a few hundred nanometers.

Then we present the new scheme of a universal differential experiment, which should lead to conclusive results for both metals and dielectrics in the separation region from several hundred nanometers to a few micrometers.

2. Differential force measurement conclusively excludes the Drude model approach to the Casimir force



- **The difference of the Casimir forces between a Ni-coated sphere and**
- **either a Au or a Ni strips covered by a Au overlayer was measured.**
- **Bimonte, Lopez, Decca, Phys. Rev. B v.93, 184434 (2016).**


30
20
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F_{Th}-F_{exp} (fN)
z (nm)
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1400
1200
1000
800
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200
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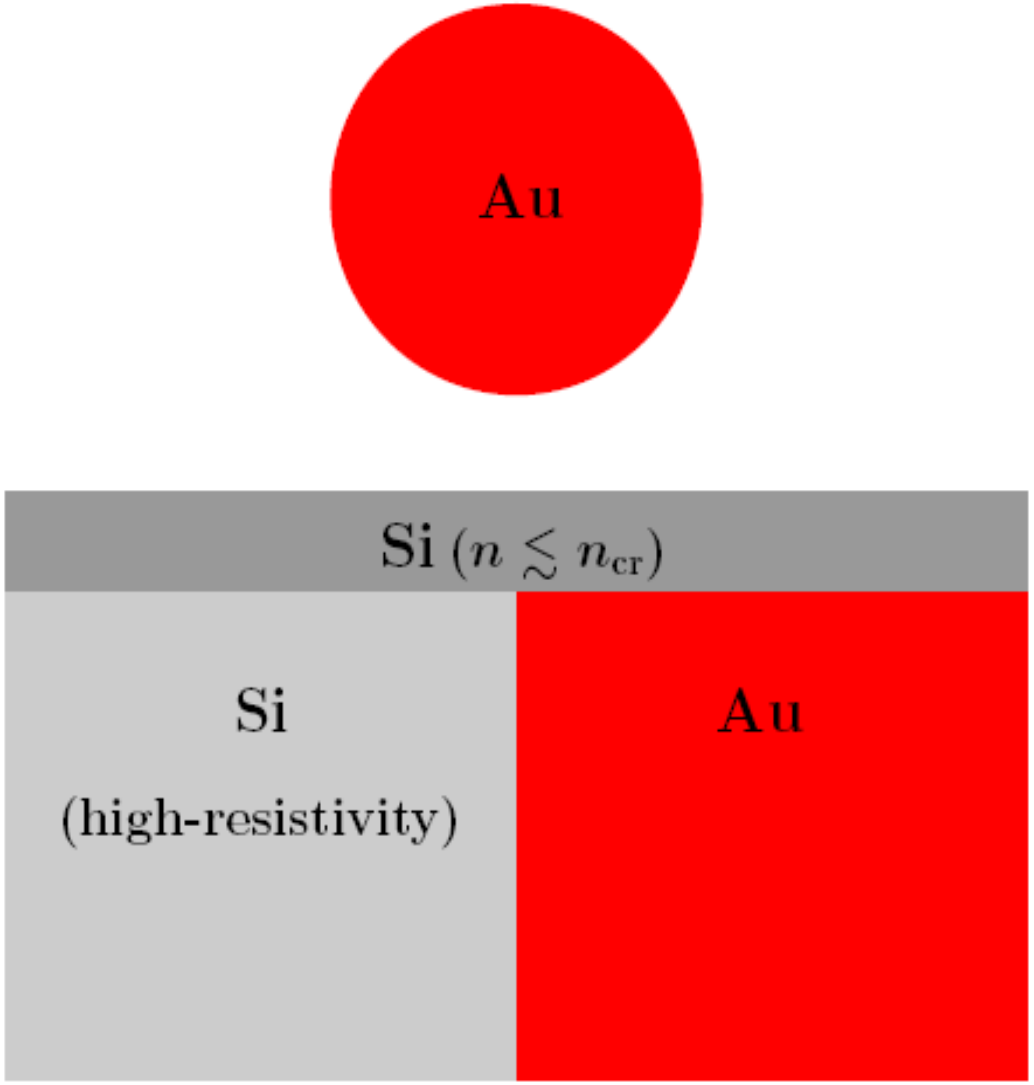
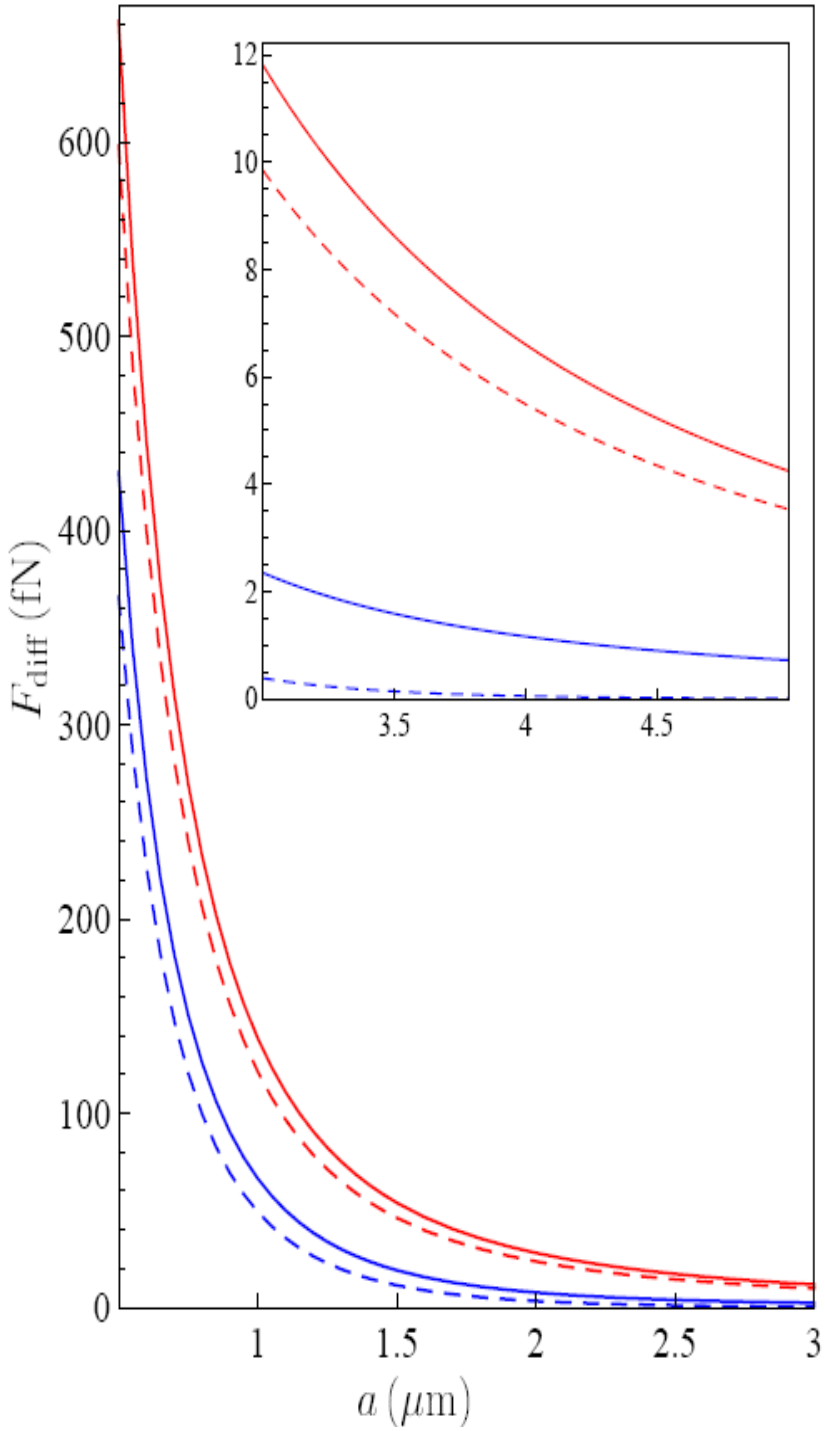
F_{Th}-F_{exp} (fN)
z (nm)

3. Proposed differential force measurement between Au sphere and structured plate with a Si overlayer



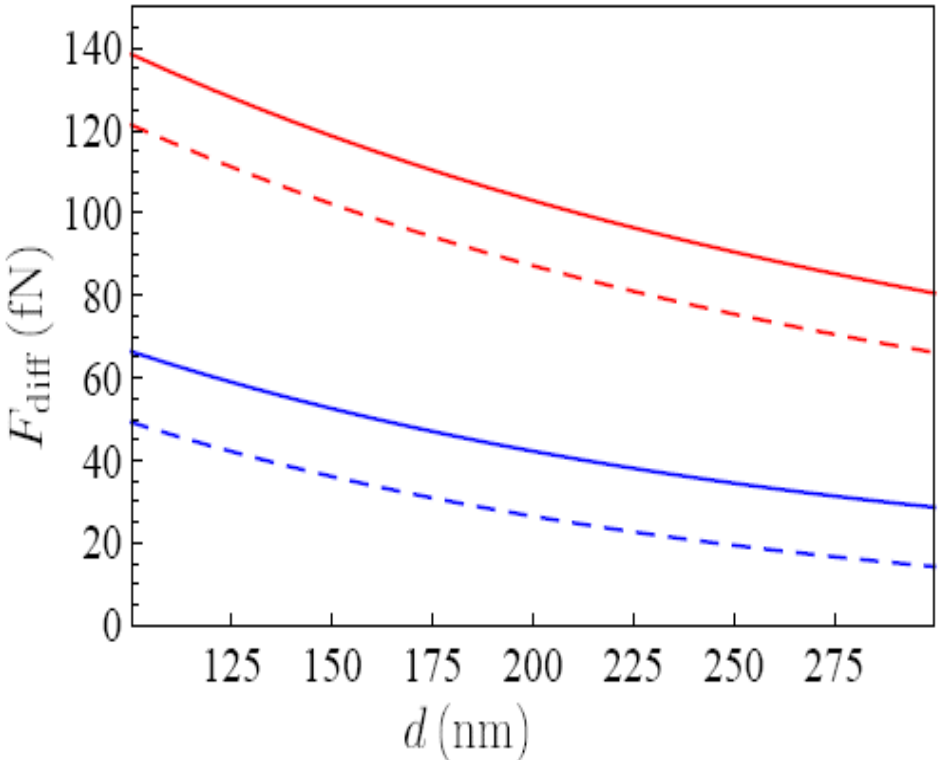
Bimonte, Klimchitskaya, Mostepanenko, Phys. Rev. A v.95, 052508 (2017)



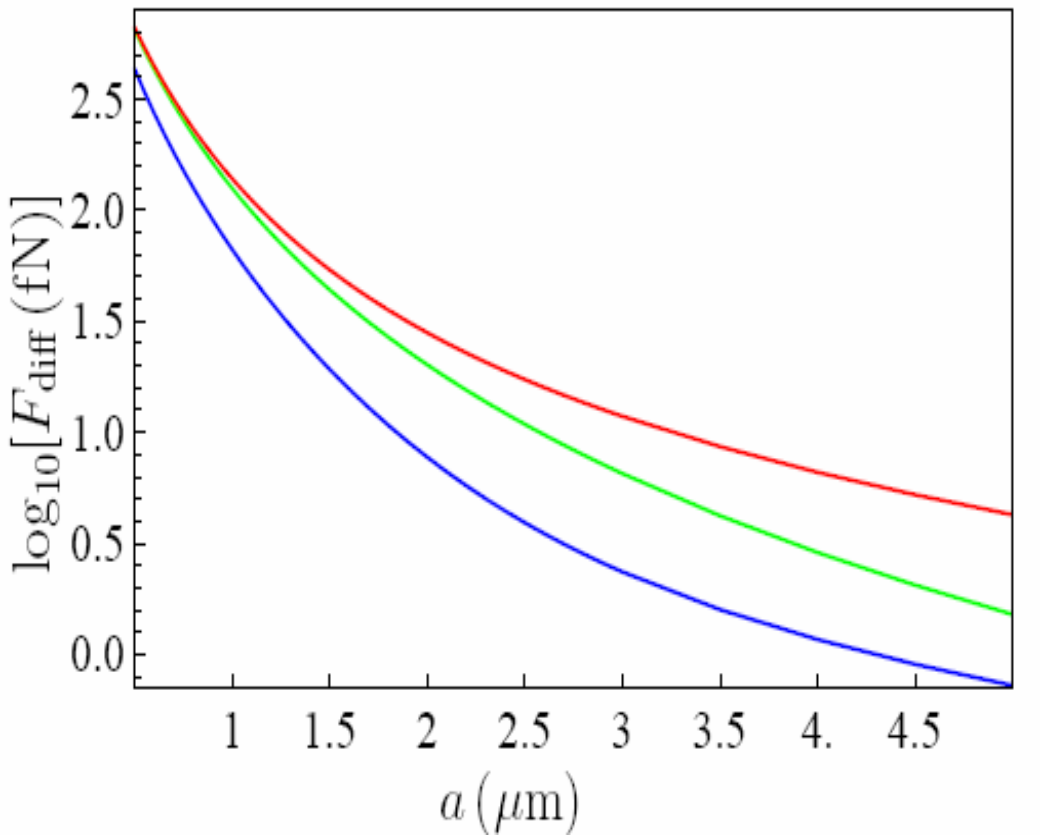
Predicted values of the differential Casimir force for the configuration with structured Au-Si plate

Differential Casimir force computed at room temperature using the plasma model for Au with disregarded and taken into account free charge carriers in dielectric materials (top pair of solid and dashed lines, respectively) and using the Drude model for Au with disregarded and included free charges in dielectrics (bottom pair of solid and dashed lines, respectively) are shown as functions of separation.
The Si overlayer is of 100nm thickness.

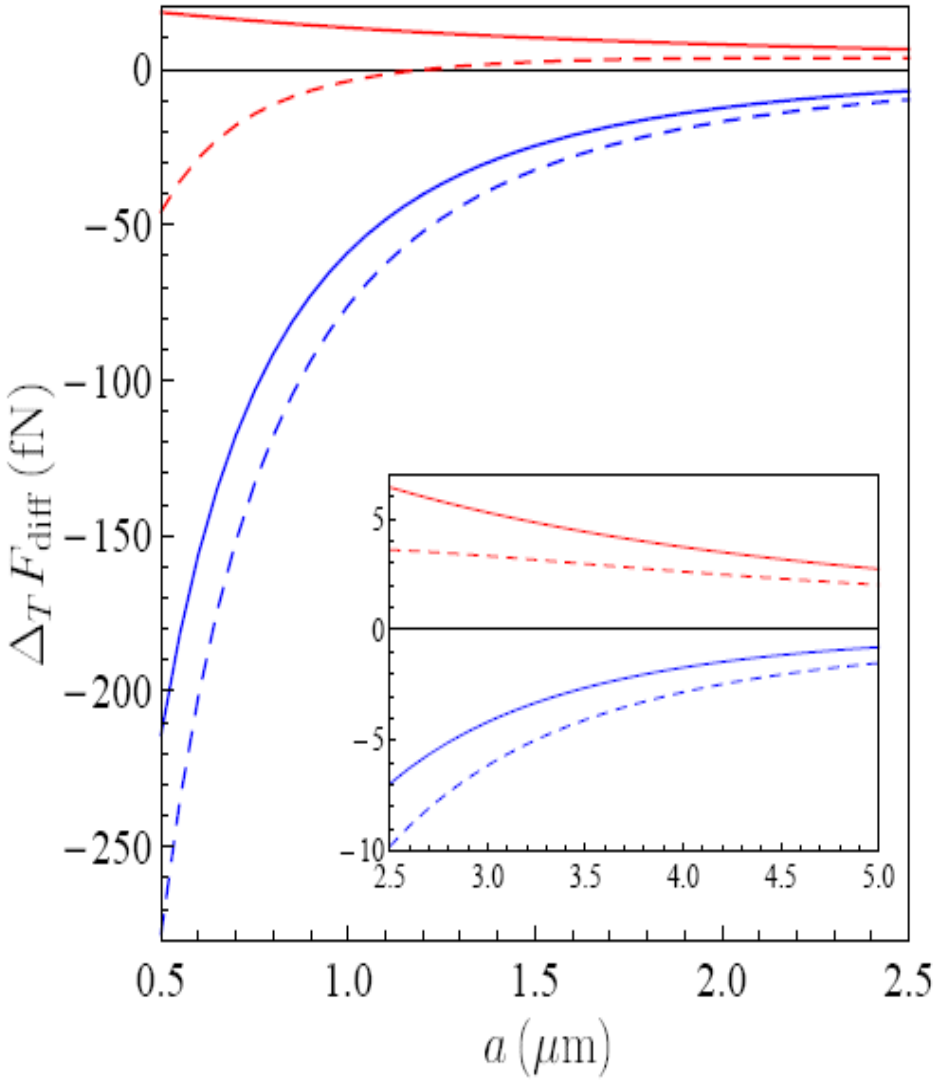
Predicted values of the differential Casimir force for the configuration with structured Au-Si plate



Differential Casimir force computed at room temperature using the plasma model for Au with disregarded and taken into account free charge carriers in dielectric materials (top pair of solid and dashed lines, respectively) and using the Drude model for Au with disregarded and included free charges in dielectrics (bottom pair of solid and dashed lines, respectively) are shown as functions of overlayer thickness at the separation of one micrometer.

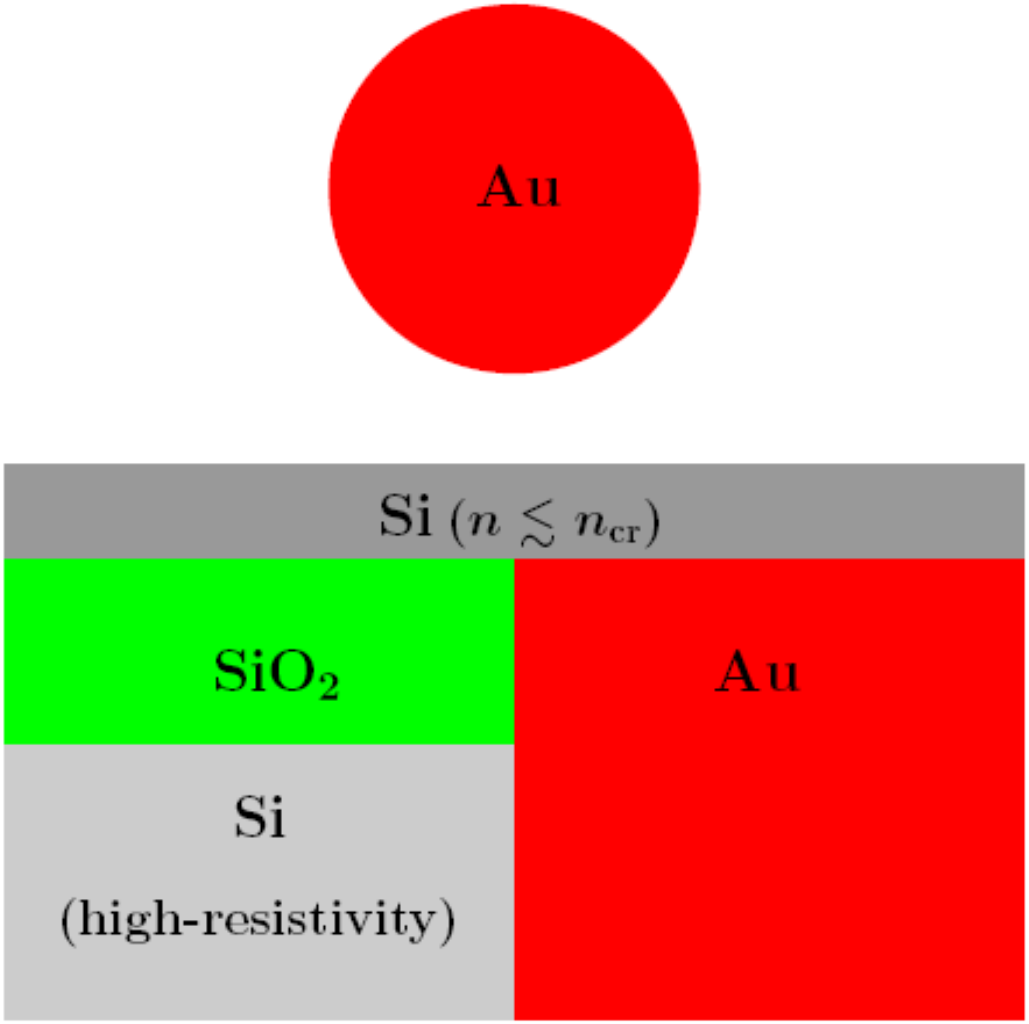


Logarithms of the differential Casimir forces computed at 300K using the plasma and Drude models for Au with disregarded free charges in dielectric Si are shown as functions of separation by the top and bottom lines, respectively. The medium line shows common computational results for the differential Casimir force at zero temperature. The Si overlayer is 100nm thick.

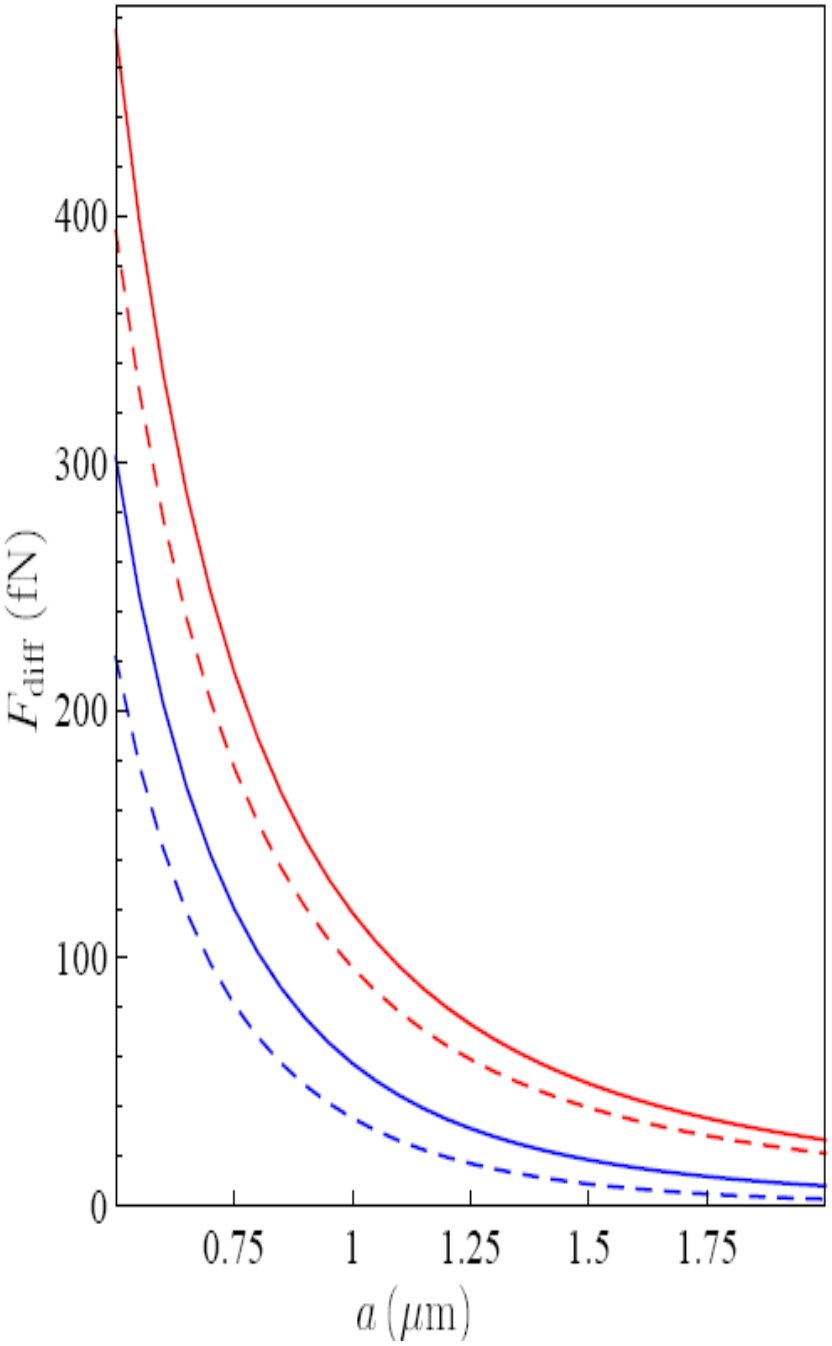


Thermal corrections to the differential Casimir force computed at room temperature using the plasma model for Au with disregarded and taken into account free charge carriers in dielectric Si (top pair of solid and dashed lines, respectively) and using the Drude model for Au with disregarded and included free charges in dielectric Si (bottom pair of solid and dashed lines, respectively) are shown as functions of separation.
The Si overlayer is 100nm thick.

4. Proposed differential force measurement between Au sphere and structured plate with additional silica layer and Si overlayer

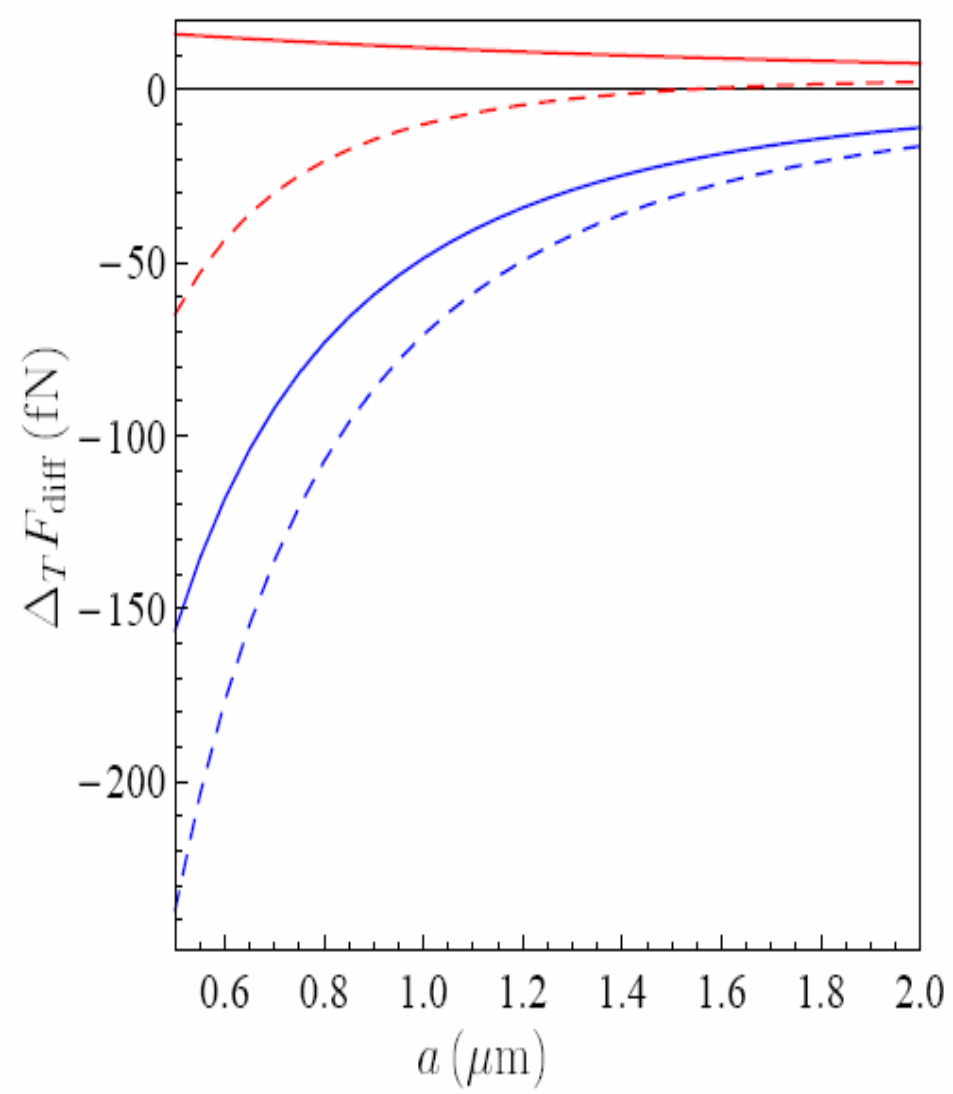


Bimonte, Klimchitskaya, Mostepanenko, Phys. Rev. A v.95, 052508 (2017)



Predicted values of the differential Casimir force for the configuration with additional silica layer

Differential Casimir force computed at room temperature using the plasma model for Au with disregarded and taken into account free charge carriers in dielectric materials (top pair of solid and dashed lines, respectively) and using the Drude model for Au with disregarded and included free charges in dielectrics (bottom pair of solid and dashed lines, respectively) are shown as functions of separation.
The Si overlayer is 200nm thick, and the silica layer is 400nm thick.



Thermal corrections to the differential Casimir force computed at room temperature for the configuration with additional silica layer using the plasma model for Au with disregarded and taken into account free charge carriers in dielectric materials (top pair of solid and dashed lines, respectively) and using the Drude model for Au with disregarded and included free charges in dielectric materials (bottom pair of solid and dashed lines, respectively) are shown as functions of separation.
The Si overlayer is 200nm thick, and the silica layer is 400nm thick.

5. Conclusions and discussion

1. For metallic test bodies at separations up to a few hundred nanometers it is demonstrated by many experiments and conclusively confirmed recently that the dissipation of free charge carriers does not influence the Casimir force.

2. This experimental fact is in direct contradiction with some commonly used concepts of quantum statistical physics and requests for their reconsideration or, at least, for narrowing down their application range.

3. For dielectric materials till the moment there were three experiments whose results are in favor of the statement that the contribution of conductivity on constant current to the Casimir force should be omitted. This conclusion was made at separations below a few hundred nanometers, and the relative difference between different theoretical predictions was below several percent.

4. We have proposed the universal differential test for the role of dissipation of free charge carriers in the Casimir force between both metallic and dielectric test bodies in one experiment using already existing experimental setup.

5. **The proposed test allows to confidently discriminate the theoretical predictions of the Drude and plasma model approaches for Au within the separation region up to 5 micrometers. In the same experiment theoretical predictions with included and omitted conductivity of Si at a constant current can be confidently discriminated in the separation region up to 3 micrometers.**

6. **After performing this test in near future, experimentallists will finish their part of the work and theorists will be obliged to explain the observed facts and their relevance to other physical phenomena involving interaction of matter with quantum fluctuations.**