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Editorial

Advances and Prospects in Casimir Physics

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Abstract: In the present introductory to the Special Issue "75 Years of the Casimir Effect: Advances and Prospects", we summarize the state of the art in this field of physics, briefly describe the topics of the contributing papers, formulate several unresolved problems, and outline possible pathways towards their resolution. Special attention is given to experiments on measuring the Casimir force, to the known problem of the dissipation of conduction electrons when one compares experiment with theory, and to the Casimir effect in novel materials and non-traditional situations. We conclude that in the future, this multidisciplinary quantum effect will continue to play a crucial role in both fundamental physics and its applications.

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1. Introduction

The Casimir effect [1] was discovered 75 years ago, and now is an appropriate time to summarize its role in different physical phenomena, the results thus far obtained, and the unsolved problems, as well as to outline possible pathways towards their resolution.

At first sight, the Casimir prediction of the attractive force acting between two parallel, uncharged ideal metal planes kept at zero temperature could be considered to have a rather modest physical significance. The reason is that this force takes noticeable values only at extremely short separations between the plates, and both the ideal metal and the zero temperature are idealizations which are literally unrealizable in physical experiments.

The importance of the Casimir discovery greatly exceeded these expectations. The Casimir force is determined by the vacuum fluctuations of the electromagnetic and other quantum fields. These fluctuations are inherent to all physical phenomena in which Casimir forces may play some role. A few years after its discovery, the Casimir effect was generalized for the case of ideal metal planes kept at non-zero temperatures [2–4] and, within the framework of the Lifshitz theory [5–7], for two thick plates made of any material. It was shown that the Casimir force is a generalization of the van der Waals force [8] for separations where relativistic effects come into play, and to any temperature. The forces in question also act between atoms, molecules, and material surfaces, and in this case they are called Casimir–Polder forces [9].

There are a great number of applications of the Casimir force caused by the zero-point and thermal fluctuations of the electromagnetic field in condensed matter physics and atomic physics. In condensed matter physics, the Casimir force acts between any closely spaced surfaces made of metallic, dielectric, and semiconductor materials (see, e.g., Refs. [10–31], reviews [32,33], and monographs [34,35]). In atomic physics, the Casimir–Polder force has been calculated in many systems [36–47]. It plays a primary role in the phenomena of quantum reflection [48–55] and Bose–Einstein condensation [56–61] (see also the monograph [62,63]).

Many measurements of the Casimir force have been performed by means of an atomic force microscope, where the sharp tip was replaced with a relatively large sphere (see Refs. [32,34,64–78]), and by means of a micromechanical torsional oscillator [32,34,79–85].

Based on these measurement results, the Casimir force was applied for the creation of various next-generation micro- and nanoelectromechanical devices [86–99]. The Casimir–Polder force has been measured in experiments on quantum reflection [49–52] and Bose–Einstein condensation [56,57,60,61].

The Casimir effect for other than electromagnetic (scalar, spinor, gluon, etc.) fields has found prospective applications in elementary particle physics, for instance, in the bag model of hadrons (see Refs. [100–106] and the monograph [107]). It has been demonstrated that the Casimir effect is also of high importance in topologically non-trivial cosmological models, where the identification conditions play the same role as the materials boundaries, changing the spectrum of the vacuum fluctuations and leading to non-zero Casimir energy density [108–113]. A similar effect was found in multi-dimensional physics, where the extra spatial dimensions are compactified at some energy scale [114–116].

All of the above permits us to conclude that the Casimir force, regarded initially as an interesting but toy and somewhat exotic example, has developed over time into a broad research area, which is often called Casimir physics.

2. The Topics Highlighted in This Special Issue

This Special Issue, entitled "75 Years of the Casimir Effect: Advances and Prospects", presents several scientific directions within the wide research area of Casimir-related phenomena. After the creation of the Lifshtz theory, which allows for the calculation of the Casimir force in plane-parallel configurations only, it was generalized for the case of arbitrary-shaped bodies [117–126] and, specifically, for the experimentally important configuration of a sphere above a plate [127–135]. In this Special Issue, this line of research is represented by Ref. [136], which is devoted to the application of the scattering approach for calculating the Casimir–Polder interaction with magnetodielectric bodies, by Ref. [137], which reviews an application of the method of derivative expansion in Casimir physics, by Ref. [138], which considers the Casimir forces with periodic structures, and by Ref. [139], calculating the Casimir–Polder force for a conducting cone.

Special attention in this Special Issue is devoted to recent progress in measuring the Casimir force. Reference [140] reviews the last experiments performed by means of an atomic force microscope. This includes measuring the normal Casimir force between the smooth surfaces of both non-magnetic and magnetic metals, normal and lateral Casimir forces between the corrugated surfaces, and the thermal Casimir force in graphene systems. The comparison of the experimental results with theory for graphene systems required the development of a novel approach to describing the response of graphene to the electromagnetic field because the previously used semi-phenomenological approaches, based on the Kubo formula, the two-dimensional Drude model, and density–density correlation functions [141–144], turned out to be insufficient. The new approach, which was found to be in agreement with the measurement data, uses the polarization tensor of graphene with non-zero values of the energy gap and the chemical potential found within the framework of thermal quantum field theory in (2 + 1) dimensions [145–148].

Two other experimental papers are devoted to the dynamical sensitivity of three-layer microelectromechanical systems exploiting the Casimir force to the optical properties of the intervening liquid layer [149] and to the planned experiment on measuring the Casimir pressure between two parallel plates spaced at micrometer separations [150]. Realization of the last experiment will allow to strengthen the constraints on the Yukawa-type corrections to the Newton law of gravitation and on the hypothetical constituents of dark matter and dark energy, such as axions, chameleons, symmetrons, and environment-dependent dilatons [151–155], which are often constrained from measuring the Casimir force [156–162]. One more experimentally oriented paper considers the possibility of compensating the electrostatic interaction between dielectric and metallic test bodies [163]. This investigation is directed towards solving the problem of surface patches, which complicates measurements of the Casimir force [164,165].

The major problem of Casimir physics, which has remained unresolved over the last 25 years, is the question of how to describe the free charge carriers correctly when calculating the Casimir force. It has been shown Refs. [32,34,72,74,75,80,81,85] that for metallic test bodies the Casimir force, calculated by means of the Lifshitz theory using the dissipative Drude model at low frequencies, is excluded by the measurement data. If the dissipationless plasma model is used in the calculations, the theoretical results agree with all precise experiments on measuring the Casimir force [32,34,72,74,75,80,81,85]. For the dielectric test bodies, theory comes into agreement with the measurement data only if the role of free charge carriers, which are present in all real dielectrics at any non-zero temperature, is omitted in the computations [32,34,65,69,70,166].

According to the results of Ref. [167] published in this Special Issue, the roots of the problem are not in accounting for or disregarding the dissipation properties of the conduction electrons in calculations of the Casimir force, but in the necessity of accounting for these properties correctly. It is shown that an account of the relaxation properties of conduction electrons at low frequencies by means of the Drude model in the region of propagating waves with any polarization and transverse magnetic evanescent waves does not lead to contradictions with the measurement data. The contradiction between the calculated and measured Casimir forces arises only when the Drude model is used to describe the response of metals to the low-frequency evanescent waves with transverse electric polarization.

It is common knowledge that the Drude model has numerous experimental confirmations in the region of propagating waves. It has also been confirmed by special experiments in the area of transverse magnetic evanescent waves [168]. As to the area of transverse electric evanescent waves, the Drude model lacks any reliable experimental confirmation. On this basis, it was concluded [167] that the experiments on measuring the Casimir force invalidate the Drude model in the area of transverse electric evanescent waves. An alternative experiment in the field of classical electrodynamics was proposed, which can independently confirm this important conclusion [169,170]. Reference [171] of this Special Issue suggests another experimental means of distinguishing between the Drude and plasma models, which is based on measuring the Lorentz force originating from thermal fluctuations.

It is interesting that for the Casimir force between two graphene sheets considered in Ref. [172] of this Special Issue, theory is in good agreement with the measurement data. The reason for this is that the electromagnetic response of graphene is described on the rigorous basis of quantum electrodynamics at non-zero temperature do not using any phenomenological approach like the Drude model. This is reached by employing the polarization tensor of graphene with any energy gap and the chemical potential found in the framework of thermal quantum field theory [145–148].

Several papers belonging to this Special Issue are devoted to the investigation of the Casimir effect in various specific configurations. Thus, in Ref. [173] the Casimir energy in (2 + 1)-dimensional field theories is considered which is interesting in connection with its application to novel two-dimensional materials, such as graphene, silicene, stanene, phosphorene, and others [174–177]. The Casimir forces in conformal field theories with defects and boundaries are discussed in Ref. [178]. The normal Casimir force for the planes with isotropic conductivity in the state of lateral motion is found in Ref. [179]. In Ref. [180], the Casimir–Lifshitz force of friction, which arises due to the relative motion of interacting bodies, and resulting heating are considered in the framework of fluctuational electrodynamics. Finally, it is explained in Ref. [181] how the Casimir force can be used to stabilize the levitation of a graphene sheet lifted by the repulsive force arising in an inhomogeneous magnetic field.

In a few papers included in this Special Issue, the Casimir effect is considered in rather non-standard situations and using some alternative approaches. For instance, in Ref. [182] the Casimir effect in axion electrodynamics is investigated where, due to the presence of an additional pseudoscalar quantity, the relationship between the vectors of the electric field, magnetic induction, electric displacement, and the magnetic field becomes more complicated than in the standard electrodynamics of continuous media. This subject is closely related to new materials called topological insulators, which are of great practical interest.

An interesting approach to the Casimir effect based on semi-classical electrodynamics is discussed in Ref. [183] in this Special Issue. This paper includes a preface discussing different concepts of intermolecular forces in the early history of physics. It is shown how the semi-classical approach results in the familiar Lifshits formula for Casimir free energy. One more study [184] is devoted to a derivation of the Casimir pressure between two Chern–Simons boundary layers deposited on dielectric substrates. For this purpose, gauge-invariant formalism was developed using the electric and magnetic Green functions. Two more papers are devoted to the dynamical Casimir effect. One of them [185] considers an analogy between the dynamical Casimir effect, black holes, and the radiation temperature of an accelerated electron. The other one [186] investigates an asymmetric force acting on a moving mirror modeled by the potential, which is equal to the difference between the delta function and its derivative in two-dimensional space–time. We also list one more paper published in this Special Issue which is devoted to the one-loop correction to the mass of an electron in a homogeneous magnetic field [187]. This issue has been considered by several authors but with somewhat differing results. Keeping in mind that the radiative corrections are similar in their physical nature to the Casimir effect, it is necessary to resolve all existing discrepancies.

As was discussed in Section 1, the Casimir effect arises not only in configurations with material boundaries but also in spaces with non-trivial topology. Because of this, it plays a significant role in gravitation and cosmology and in multi-dimensional theories of elementary particle physics. Four papers in this Special Issue represent this scientific direction in the field of Casimir physics. It is known that anti-de Sitter space–time plays a significant role in cosmology. Generally speaking, the braneworld model contains the fields propagating in the bulk or localized on the branes. The boundary conditions on the branes induce Casimir-type contributions to the expectation values of physical observables. In Ref. [188], the vacuum expectation of the surface stress–energy tensor for a scalar field is calculated in the configuration of two parallel branes orthogonal to the boundary of anti-de Sitter space–time.

Other objects of importance to cosmology are the so-called cosmic strings, i.e., the topological defects which could have been created in the early Universe during cosmological phase transitions. The Casimir interaction between two cosmic strings arising due to vacuum fluctuations of the scalar field with minimal coupling is considered in Ref. [189] in the cases both small and large separation distances, taking into account the transverse size of a string.

Finally, the Casimir effect for two parallel plates in a weak gravitational field and the wormholes determined by the Casimir energy densities of the Yang–Mills field are discussed in Ref. [190]. The same paper studies the Casimir energy density in Euclidean space–time with a non-trivial topology, equivalent to imposing the so-called helix identification conditions.

3. Future Prospects

As has been demonstrated above, the Casimir effect is a wide research area, with implications for practically all branches of modern physics. It is actively investigated both theoretically and experimentally by many research groups working in many countries. Over the last few years, a number of new breakthrough results have been obtained. Below, we outline the most crucial problems in this research area to be solved in the future.

Although for metallic test bodies at separations below several micrometers, the Casimir force was already measured with high precision, at larger separations, and for the test bodies made of semiconductor and dielectric materials, new breakthrough experimental results are expected in near future. Progress in precise force measurements can be stimulated using the traditional and novel techniques (see Refs. [140,150] published in this Special Issue) and by compensating for the spurious electric forces [163–165]. The obtained results are considered to be used for the creation of next-generation micro- and nanoelectromechanical devices driven by the Casimir force (see Ref. [149] of this Special Issue, elaborating this scientific direction).

One can expect that the problem of disagreement between experiment and theory, taking into account the dissipation of conduction electrons by means of the Drude model (this problem is often called the Casimir puzzle [32,34,75]), will be solved soon. In this Special Issue, the problem has already been narrowed down to the inapplicability of the Drude model in the region of transverse electric evanescent waves [167]. It has been shown [191–193] that if to modify the Drude model in this area phenomenologically by adding a spatially non-local contribution, the theoretical predictions come to an agreement with the measurement data. It remains to put the phenomenology on a solid fundamental basis as has already been made for the electromagnetic response of graphene [77,78,145–148].

In near future, Casimir physics is going also to find new applications in modern theoretical approaches beyond the Standard Model, e.g., in the brane models, multi-dimensional physics with compacted extra dimensions, the theory of topological defects, etc. It is to be used for obtaining stronger constraints on the Yukawa-type corrections to Newtonian gravity and the hypothetical particle constituents of dark matter and dark energy.

We hope that the papers published in this Special Issue, “75 Years of the Casimir Effect: Advances and Prospects”, will be helpful by stimulating further developments in this prospective field of physics.

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References

1. Casimir, H.B.G. On the attraction between two perfectly conducting plates. *Proc. Kon. Ned. Akad. Wetensch. B* **1948**, *51*, 793–795. Available online: https://dwc.knaw.nl/DL/publications/PU00018547.pdf (accessed on 11 August 2024).
2. Fierz, M. Zur Anziehung leitender Ebenen im Vakuum. *Helv. Phys. Acta* **1960**, *33*, 855–858. [CrossRef]
3. Mehra, J. Temperature correction to Casimir effect. *Physica* **1967**, *37*, 145–152. [CrossRef]
4. Brown, L.S.; Maclay, G.J. Vacuum stress between conducting plates—An image solution. *Phys. Rev.* **1969**, *184*, 1272–1279. [CrossRef]
5. Lifshitz, E.M. The theory of molecular attractive forces between solids. *Zh. Eksp. Teor. Fiz.* **1955**, *29*, 94–110 (In Russian); *Sov. Phys. JETP* **1956**, *2*, 73–83. Available online: http://jetp.ras.ru/cgi-bin/e/index/e/2/1/p73?a=list (accessed on 11 August 2024).
6. Dzyaloshinskii, I.E.; Lifshitz, E.M.; Pitaevskii, L.P. The general theory of van der Waals’ forces. *Usp. Fiz. Nauk* **1961**, *73*, 381–422 (In Russian); *Sov. Phys. Uspekhi* **1961**, *4*, 153–176. [CrossRef]
7. Lifshitz, E.M.; Pitaevskii, L.P. *Statistical Physics, Part 2* ; Pergamon: Oxford, UK, 1980. Available online: https://haidinh89.files.wordpress.com/2015/08/landau-l-d-lifshitz-e-m-course-of-theoretical-physics-vol-09-statistical-physics-part-2-3455.pdf (accessed on 11 August 2024).
8. Parsegian, V.A. *Van der Waals Forces: A Handbook for Biologists, Chemists, Engineers, and Physicists*; Cambridge University Press: New York, NY, USA, 2005. [CrossRef]
9. Casimir, H.B.G.; Polder, D. The influence of retardation on the London–van der Waals forces. *Phys. Rev.* **1948**, *73*, 360–372. [CrossRef]
10. Hargreaves, C.M. Corrections to retarded dispersion force between metal bodies. *Proc. Kon. Ned. Akad. Wetensch. B* **1965**, *68*, 231–236.
11. Boyer, T.H. Quantum electromagnetic zero-point energy of a conducting spherical shell and Casimir model for a charged particle. *Phys. Rev.* **1968**, *174*, 1764–1776. [CrossRef]
12. Richmond, P.; Ninham, B.W. A note on the extension of the Lifshitz theory of van der Waals forces to magnetic media. *J. Phys. C* **1971**, *4*, 1988–1993. [CrossRef]

13. Boyer, T.H. Van der Waals forces and zero-point energy for dielectric and permeable materials. *Phys. Rev. A* **1974**, *9*, 2078–2084. [CrossRef]
14. Boström, M.; Sernelius, B.E. Comment on "Calculation of the Casimir force between imperfectly conducting plates". *Phys. Rev. A* **2000**, *61*, 046101. [CrossRef]
15. Boström, M.; Sernelius, B.E. Thermal effects on the Casimir force in the 0.1–5 µm range. *Phys. Rev. Lett.* **2000**, *84*, 4757–4760. [CrossRef] [PubMed]
16. Lambrecht, A.; Reynaud, S. Casimir force between metallic mirrors. *Eur. Phys. J. D* **2000**, *8*, 309–318. [CrossRef]
17. Genet, C.; Lambrecht, A.; Maia Neto, P.; Reynaud, S. The Casimir force between rough metallic plates. *EPL (Europhys. Lett.)* **2003**, *62*, 484–490. [CrossRef]
18. Boström, M.; Sernelius, B.E. Entropy of the Casimir effect between real metal plates. *Phys. A* **2004**, *339*, 53–59. [CrossRef]
19. Torgerson, J.R.; Lamoreaux, S.K. Low-frequency character of the Casimir force between metallic films. *Phys. Rev. E* **2004**, *70*, 047102. [CrossRef] [PubMed]
20. Bimonte, G.; Calloni, E.; Esposito, G.; Milano, L.; Rosa, L. Towards measuring variations of Casimir energy by a superconducting cavity. *Phys. Rev. Lett.* **2005**, *94*, 180402. [CrossRef]
21. Bimonte, G.; Calloni, E.; Esposito, G.; Rosa, L. Variations of Casimir energy from a superconducting transition. *Nucl. Phys. B* **2005**, *726*, 441–463. [CrossRef]
22. Bimonte, G. Comment on "Low-frequency character of the Casimir force between metallic films". *Phys. Rev. E* **2006**, *73*, 048101. [CrossRef]
23. Bimonte, G. A theory of electromagnetic fluctuations for metallic surfaces and van der Waals interactions between metallic bodies. *Phys. Rev. Lett.* **2006**, *96*, 160401. [CrossRef]
24. Bimonte, G. Bohr-van Leeuwen theorem and the thermal Casimir effect for conductors. *Phys. Rev. A* **2009**, *79*, 042107. [CrossRef]
25. Levin, M.; McCauley, A.P.; Rodrigues, A.W.; Reid, M.T.H.; Johnson, S.G. Casimir repulsion between metallic objects in vacuum. *Phys. Rev. Lett.* **2010**, *105*, 090403. [CrossRef] [PubMed]
26. Bimonte, G. Making precise predictions of the Casimir force between metallic plates via a weighted Kramers-Kronig transform. *Phys. Rev. A* **2011**, *83*, 042109. [CrossRef]
27. Schwinger, J.; DeRaad, L.L.; Milton, K.A. Casimir effect in dielectrics. *Ann. Phys.* **1978**, *115*, 1–23. [CrossRef]
28. Inui, N. Temperature dependence of the Casimir force between silicon slabs. *J. Phys. Soc. Jpn.* **2003**, *72*, 2198–2202. [CrossRef]
29. Canaguier-Durand, A.; Gérardin, A.; Guérout, R.; Maia Neto, P.A.; Nesvizhevsky, V.V.; Voronin, A.Y.; Lambrecht, A.; Reynaud, S. Casimir interaction between a dielectric nanosphere and a metallic plane. *Phys. Rev. A* **2011**, *83*, 032508. [CrossRef]
30. Rosa, F.S.S.; Dalvit, D.A.R.; Milonni, P.W. Electrodynamic energy, absorption, and Casimir forces. II. Inhomogeneous dielectric media. *Phys. Rev. A* **2011**, *84*, 053813. [CrossRef]
31. Inui, N. Temperature dependence of the Casimir force between a superconductor and a magnetodielectric. *Phys. Rev. A* **2012**, *86*, 022520. [CrossRef]
32. Klimchitskaya, G.L.; Mohideen, U.; Mostepanenko, V.M. The Casimir force between real materials: Experiment and theory. *Rev. Mod. Phys.* **2009**, *81*, 1827–1885. [CrossRef]
33. Woods, L.M.; Dalvit, D.A.R.; Tkatchenko, A.; Rodriguez-Lopez, P.; Rodriguez, A.W.; Podgornik, R. Materials perspective on Casimir and van der Waals interactions. *Rev. Mod. Phys.* **2016**, *88*, 045003. [CrossRef]
34. Bordag, M.; Klimchitskaya, G.L.; Mohideen, U.; Mostepanenko, V.M. *Advances in the Casimir Effect*; Oxford University Press: Oxford, UK, 2015.:oso/9780199238743.001.0001 [CrossRef]
35. Sernelius, B.E. *Fundamentals of van der Waals and Casimir Interactions*; Springer: Cham, Switzerland, 2018. 978-3-319-99831-2 [CrossRef]
36. Zhou, F.; Spruch, L. Van-der-Waals and retardation (Casimir) interactions of an electron or an atom with multilayered walls. *Phys. Rev. A* **1995**, *52*, 297–310. [CrossRef] [PubMed]
37. Caride, A.O.; Klimchitskaya, G.L.; Mostepanenko, V.M.; Zanette, S.I. Dependences of the van der Waals atom-wall interaction on atomic and material properties. *Phys. Rev. A* **2005**, *71*, 042901. [CrossRef]
38. Babb, J.F. Long-range atom–surface interactions for cold atoms. *J. Phys. Conf. Ser.* **2005**, *19*, 1. [CrossRef]
39. Safari, H.; Welsch, D.-G.; Buhmann, S.Y.; Scheel, S. van der Waals potentials of paramagnetic atoms. *Phys. Rev. A* **2008**, *78*, 062901. [CrossRef]
40. Haakh, H.; Intravaia, F.; Henkel, C.; Spagnolo, S.; Passante, R.; Power, B.; Sols, F. Temperature dependence of the magnetic Casimir–Polder interaction. *Phys. Rev. A* **2009**, *80*, 062905. [CrossRef]
41. Ellingsen, S.; Buhmann, S.Y.; Scheel, S. Temperature-independent Casimir–Polder forces despite large thermal photon numbers. *Phys. Rev. Lett.* **2010**, *104*, 223003. [CrossRef]
42. Passante, R.; Rizzuto, L.; Spagnolo, S.; Tanaka, S.; Petrosky, T.Y. Harmonic oscillator model for the atom-surface Casimir–Polder interaction energy. *Phys. Rev. A* **2012**, *85*, 062109. [CrossRef]
43. Sun, W. Interaction forces between a spherical nanoparticle and a flat surface. *Phys. Chem. Chem. Phys.* **2014**, *16*, 5846–5854. [CrossRef]
44. Khusnutdinov, N.; Kashapov, R.; Woods, L.M. Casimir–Polder effect for a stack of conductive planes. *Phys. Rev. A* **2016**, *94*, 012513. [CrossRef]

45. Fuchs, S.; Crosse, J.A.; Buhmann, S.Y. Casimir–Polder shift and decay rate in the presence of nonreciprocal media. *Phys. Rev. A* **2017**, *95*, 023805. [CrossRef]
46. Milton, K.A.; Li, Y.; Kalauni, P.; Parashar, P.; Guérout, P.; Ingold, G.-L.; Lambrecht, A.; Reynaud, S. Negative entropies in Casimir and Casimir–Polder interactions. *Fortschr. Phys./Prog. Phys.* **2017**, *65*, 1600047. [CrossRef]
47. Fuchs, S.; Bennett, R.; Krems, R.V.; Buhmann, S.Y. Nonadditivity of optical and Casimir–Polder potentials. *Phys. Rev. Lett.* **2018**, *121*, 083603. [CrossRef] [PubMed]
48. Berkhout, J.J.; Luiten, O.J.; Setija, I.D.; Hijmans, T.W.; Mizusaki, T.; Walraven, J.T.M. Quantum reflection: Focusing of hydrogen atoms with a concave mirror. *Phys. Rev. Lett.* **1989**, *63*, 1689–1693. [CrossRef]
49. Yu, I.A.; Doyle, M.J.; Sandberg, J.C.; Cesar, C.L.; Kleppner, D.; Greytak, T.J. Evidence for universal quantum reflection of hydrogen from liquid ^{4}He. *Phys. Rev. Lett.* **1993**, *71*, 1589–1593. [CrossRef] [PubMed]
50. Shimizu, F. Specular reflection of very slow metastable neon atoms from a solid surface. *Phys. Rev. Lett.* **2001**, *86*, 987–991. [CrossRef] [PubMed]
51. Friedrich, H.; Jacoby, G.; Meister, C.J. Quantum reflection by Casimir-van der Waals potential tails. *Phys. Rev. A* **2002**, *65*, 032902. [CrossRef]
52. Druzhinina, V.; DeKieviet, M. Experimental observation of quantum reflection far from threshold. *Phys. Rev. Lett.* **2003**, *91*, 193202. [CrossRef]
53. Oberst, H.; Tashiro, Y.; Shimizu, K.; Shimizu F. Quantum reflection of He* on silicon. *Phys. Rev. A* **2005**, *71*, 052901. [CrossRef]
54. Madroñero, J.; Friedrich, H. Influence of realistic atom wall potentials in quantum reflection traps. *Phys. Rev. A* **2007**, *75*, 022902. [CrossRef]
55. Bezerra, V.B.; Klimchitskaya, G.L.; Mostepanenko, V.M.; Romero, C. Lifshitz theory of atom-wall interaction with applications to quantum reflection. *Phys. Rev. A* **2008**, *78*, 042901. [CrossRef]
56. Harber, D.M.; McGuirk, J.M.; Obrecht, J.M.; Cornell, E.A. Thermally induced losses in ultra-cold atoms magnetically trapped near room-temperature surfaces. *J. Low Temp. Phys.* **2003**, *133*, 229–238. [CrossRef]
57. Leanhardt, A.E.; Shin, Y.; Chikkatur, A.P.; Kielpinski, D.; Ketterle, W.; Pritchard, D.E. Bose–Einstein condensates near a microfabricated surface. *Phys. Rev. Lett.* **2003**, *90*, 100404. [CrossRef]
58. Antezza, M.; Pitaevskii, L.P.; Stringari, S. Effect of the Casimir–Polder force on the collective oscillations of a trapped Bose–Einstein condensate. *Phys. Rev. A* **2004**, *70*, 053619. [CrossRef]
59. Lin, Y.-J.; Teper, I. Chin, C.; Vuletić, V. Impact of the Casimir–Polder potential and Johnson noise on Bose–Einstein condensate stability near surfaces. *Phys. Rev. Lett.* **2004**, *92*, 050404. [CrossRef] [PubMed]
60. Harber, D.M.; Obrecht, J.M.; McGuirk, J.M.; Cornell, E.A. Measurement of the Casimir–Polder force through center-of-mass oscillations of a Bose–Einstein condensate. *Phys. Rev. A* **2005**, *72*, 033610. [CrossRef]
61. Obrecht, J.M.; Wild, R.J.; Antezza, M.; Pitaevskii, L.P.; Stringari, S.; Cornell, E.A. Measurement of the temperature dependence of the Casimir–Polder force. *Phys. Rev. Lett.* **2007**, *98*, 063201. [CrossRef]
62. Buhmann, S.Y. *Dispersion Forces I: Macroscopic Quantum Electrodynamics and Ground-State Casimir, Casimir–Polder and van der Waals Forces*; Springer: Berlin/Heidelberg, Germany, 2012. [CrossRef]
63. Buhmann, S.Y. *Dispersion Forces II: Many-Body Effects, Excited Atoms, Finite Temperature and Quantum Friction*; Springer: Berlin/Heidelberg, Germany, 2012. [CrossRef]
64. Mohideen, U.; Roy, A. Precision measurement of the Casimir force from 0.1 to 0.9 µm. *Phys. Rev. Lett.* **1998**, *81*, 4549–4552. [CrossRef]
65. Chen, F.; Klimchitskaya, G.L.; Mostepanenko, V.M.; Mohideen, U. Control of the Casimir force by the modification of dielectric properties with light. *Phys. Rev. B* **2007**, *76*, 035338. [CrossRef]
66. de Man, S.; Heeck, K.; Wijngaarden, R.J.; Iannuzzi D. Halving the Casimir force with Conductive Oxides. *Phys. Rev. Lett.* **2009**, *103*, 040402. [CrossRef]
67. de Man, S.; Heeck, K.; Iannuzzi D. Halving the Casimir force with conductive oxides: Experimental details. *Phys. Rev. A* **2010**, *82*, 062512. [CrossRef]
68. Torricelli, G.; van Zwol, P.J.; Shpak, O.; Binns, C.; Palasantzas, G.; Kooi, B.J.; Svetovoy, V.B.; Wuttig, M. Switching Casimir force with phase-change materials. *Phys. Rev. A* **2010**, *82*, 010101. [CrossRef]
69. Chang, C.-C.; Banishev, A.A.; Klimchitskaya, G.L.; Mostepanenko, V.M.; Mohideen, U. Reduction of the Casimir force from indium tin oxide film by UV treatment. *Phys. Rev. Lett.* **2011**, *107*, 090403. [CrossRef] [PubMed]
70. Banishev, A.A.; Chang, C.-C.; Castillo-Garza, R.; Klimchitskaya, G.L.; Mostepanenko, V.M.; Mohideen, U. Modifying the Casimir force between indium tin oxide film and Au sphere. *Phys. Rev. B* **2012**, *85*, 045436. [CrossRef]
71. Laurent, J.; Sellier, H.; Mosset, A.; Huant, S.; Chevrier, J. Casimir force measurements in Au-Au and Au-Si cavities at low temperature. *Phys. Rev. B* **2012**, *85*, 035426. [CrossRef]
72. Banishev, A.A.; Klimchitskaya, G.L.; Mostepanenko, V.M.; Mohideen, U. Demonstration of the Casimir force between ferromagnetic surfaces of a Ni-coated sphere and a Ni-coated plate. *Phys. Rev. Lett.* **2013**, *110*, 137401. [CrossRef]
73. Sedighi, M.; Svetovoy, V.B.; Palasantzas, G. Casimir force measurements from silicon carbide surfaces. *Phys. Rev. B* **2016**, *93*, 085434. [CrossRef]
74. Liu, M.; Xu, J.; Klimchitskaya, G.L.; Mostepanenko, V.M.; Mohideen, U. Examining the Casimir puzzle with an upgraded AFM-based technique and advanced surface cleaning. *Phys. Rev. B* **2019**, *100*, 081406. [CrossRef]

75. Liu, M.; Xu, J.; Klimchitskaya, G.L.; Mostepanenko, V.M.; Mohideen, U. Precision measurements of the gradient of the Casimir force between ultraclean metallic surfaces at larger separations. *Phys. Rev. A* **2019**, *100*, 052511. [CrossRef]
76. Svetovoy, V.B.; Postnikov, A.V.; Uvarov, I.V.; Stepanov, F.I.; Palasantzas, G. Measuring the dispersion forces near the van der Waals–Casimir transition. *Phys. Rev. Appl.* **2020**, *13*, 064057. [CrossRef]
77. Liu, M.; Zhang, Y.; Klimchitskaya, G.L.; Mostepanenko, V.M.; Mohideen, U. Demonstration of unusual thermal effect in the Casimir force from graphene. *Phys. Rev. Lett.* **2021**, *126*, 206802. [CrossRef] [PubMed]
78. Liu, M.; Zhang, Y.; Klimchitskaya, G.L.; Mostepanenko, V.M.; Mohideen, U. Experimental and theoretical investigation of the thermal effect in the Casimir interaction from graphene. *Phys. Rev. B* **2021**, *104*, 085436. [CrossRef]
79. Decca, R.S.; López, D.; Fischbach, E.; Krause, D.E. Measurement of the Casimir force between dissimilar metals. *Phys. Rev. Lett.* **2003**, *91*, 050402. [CrossRef]
80. Decca, R.S.; López, D.; Fischbach, E.; Klimchitskaya, G.L.; Krause, D.E.; Mostepanenko, V.M. Precise comparison of theory and new experiment for the Casimir force leads to stronger constraints on thermal quantum effects and long-range interactions. *Ann. Phys.* **2005**, *318*, 37–80. [CrossRef]
81. Decca, R.S.; López, D.; Fischbach, E.; Klimchitskaya, G.L.; Krause, D.E.; Mostepanenko, V.M. Tests of new physics from precise measurements of the Casimir pressure between two gold-coated plates. *Phys. Rev. D* **2007**, *75*, 077101. [CrossRef]
82. Decca, R.S.; López, D.; Osquiguil, E. New results for the Casimir interaction: Sample characterization and low temperature measurements. *Int. J. Mod. Phys. A* **2010**, *25*, 2223–2230. [CrossRef]
83. Bao, Y.; Guérout, R.; Lussange, J.; Lambrecht, A.; Cirelli, R.A.; Klemens, F.; Mansfield, W. M.; Pai, C.S.; Chan, H.B. Casimir force on a surface with shallow nanoscale corrugations: Geometry and finite conductivity effects. *Phys. Rev. Lett.* **2010**, *105*, 250402. [CrossRef]
84. Intravaia, F.; Koev, S.; Jung, I.W.; Talin, A.A.; Davids, P.S.; Decca, R.S.; Aksyuk, V.A.; Dalvit D.A.R.; López, D. Strong Casimir force reduction through metallic surface nanostructuring. *Nat. Commun.* **2013**, *4*, 2515. [CrossRef]
85. Bimonte, G.; López, D.; Decca, R.S. Isoelectronic determination of the thermal Casimir force. *Phys. Rev. B* **2016**, *93*, 184434. [CrossRef]
86. Buks, E.; Roukes, M.L. Stiction, adhesion, and the Casimir effect in micromechanical systems. *Phys. Rev. B* **2001**, *63*, 033402. [CrossRef]
87. Buks, E.; Roukes, M.L. Metastability and the Casimir effect in micromechanical systems. *EPL (Europhys. Lett).* **2001**, *54*, 220–226. [CrossRef]
88. Chan, H.B.; Aksyuk, V.A.; Kleiman, R.N.; Bishop, D.J.; Capasso, F. Quantum mechanical actuation of microelectromechanical system by the Casimir effect. *Science* **2001**, *291*, 1941–1944. [CrossRef] [PubMed]
89. Chan, H.B.; Aksyuk, V.A.; Kleiman, R.N.; Bishop, D.J.; Capasso, F. Nonlinear micromechanical Casimir oscillator. *Phys. Rev. Lett.* **2001**, *87*, 211801. [CrossRef]
90. Barcenas, J.; Reyes, L.; Esquivel-Sirvent, R. Scaling of micro- and nanodevices actuated by the Casimir force. *Appl. Phys. Lett.* **2005**, *87*, 263106. [CrossRef]
91. Palasantzas, G. Contact angle influence on the pull-in voltage of microswitches in the presence of capillary and quantum vacuum effects. *J. Appl. Phys.* **2007**, *101*, 053512. [CrossRef]
92. Palasantzas, G. Pull-in voltage of microswitch rough plates in the presence of electromagnetic and acoustic Casimir forces. *J. Appl. Phys.* **2007**, *101*, 063548. [CrossRef]
93. Esquivel-Sirvent, R.; Pérez-Pascual, R. Geometry and charge carrier induced stability in Casimir actuated nanodevices. *Eur. Phys. J. B* **2013**, *86*, 467. [CrossRef]
94. Broer, W.; Palasantzas, G.; Knoester, G.; Svetovoy, V.B. Significance of the Casimir force and surface roughness for actuation dynamics of MEMS. *Phys. Rev. B* **2013**, *87*, 125413. [CrossRef]
95. Sedighi, M.; Broer, W.; Palasantzas, G.; Kooi, B.J. Sensitivity of micromechanical actuation on amorphous to crystalline phase transformations under the influence of Casimir forces. *Phys. Rev. B* **2013**, *88*, 165423. [CrossRef]
96. Zou, J.; Marcet, Z.; Rodriguez, A.W.; Reid, M.T.H.; McCauley, A.P.; Kravchenko, I.I.; Lu, T.; Bao, Y.; Johnson, S.G.; Chan, H.B. Casimir forces on a silicon micromechanical chip. *Nat. Commun.* **2013**, *4*, 1845. [CrossRef]
97. Broer, W.; Waalkens, H.; Svetovoy, V.B.; Knoester, J.; Palasantzas, G. Nonlinear actuation dynamics of driven Casimir oscillators with rough surfaces. *Phys. Rev. Appl.* **2013**, *4*, 054016. [CrossRef]
98. Liu, X.-F.; Li, Y.; Jing, H. Casimir switch: Steering optical transparancy with vacuum forces. *Sci. Rep.* **2016**, *6*, 27102. [CrossRef] [PubMed]
99. Inui, N. Optical switching of a graphene mechanical switch using the Casimir effect. *J. Appl. Phys.* **2017**, *122*, 104501. [CrossRef]
100. Milton, K.A. Fermionic Casimir stress on a spherical bag. *Ann. Phys.* **1983**, *150*, 432–438. [CrossRef]
101. Baacke, J.; Igarashi, Y. Casimir energy of confined massive quarks. *Phys. Rev. D* **1983**, *27*, 460–463. [CrossRef]
102. Bordag, M.; Elizalde, E.; Kirsten, K.; Leseduarte, S. Casimir energies for massive scalar fields in a spherical geometry. *Phys. Rev. D* **1997**, *56*, 4896–4904. [CrossRef]
103. Elizalde, E.; Santos, F.C.; Tort, A.C. The Casimir energy of a massive fermionic field confined in a $(d+1)$-dimensional slab-bag. *Int. J. Mod. Phys. A* **2003**, *18*, 1761–1772. [CrossRef]
104. Cruz, M.B.; Bezerra de Mello, E.R.; Petrov A.Y. Fermionic Casimir effect in a field theory model with Lorentz symmetry violation. *Phys. Rev. D* **2019**, *99*, 085012. [CrossRef]

105. Mandlecha, Y.V.; Gavai, R.V. Lattice fermionic Casimir effect in a slab bag and universality. *Phys. Lett. B* **2022**, *835*, 137558. [CrossRef]
106. Rohim, A.; Romadani, A.; Adam, A.S. Casimir effect of Lorentz-violating charged Dirac field in background magnetic field. *Prog. Theor. Exp. Phys.* **2024**, *2024*, 033B01. [CrossRef]
107. Milton, K.A. *The Casimir Effect: Physical Manifestations of Zero-Point Energy*; World Scientific: Singapore, 2001. [CrossRef]
108. Ford, L.H. Quantum vacuum energy in a closed universe. *Phys. Rev. D* **1976**, *14*, 3304–3313. [CrossRef]
109. Dowker, J.S.; Critchley, R. Covariant Casimir calculations. *J. Phys. A Math. Gen.* **1976**, *9*, 535–540. [CrossRef]
110. Isham, C.J. Twisted quantum fields in a curved space-time. *Proc. R. Soc. Lond. A Math. Phys. Sci.* **1978**, *362*, 383–404.
111. DeWitt, B.S.; Hart, C.F.;Isham, C.J. Topology and quantum field theory. *Phys. A* **1979**, *96*, 197–211. [CrossRef]
112. Ford, L.H. Vacuum polarization in a non-simply connected spacetime. *Phys. Rev. D* **1980**, *21*, 933–948. [CrossRef]
113. Helliwell, T.M.; Konkowski, D.A. Vacuum fluctuations outside cosmic strings. *Phys. Rev. D* **1986**, *34*, 1918–1920. [CrossRef]
114. Candelas, P.; Weinberg, S. Calculation of gauge couplings and compact circumferences from self-consistent dimensional reduction. *Nucl. Phys. B* **1984**, *237*, 397–441. [CrossRef]
115. Chodos, A.; Myers, E. Gravitational contribution to the Casimir energy in Kaluza-Klein theories. *Ann. Phys.* **1984**, *156*, 412–441. [CrossRef]
116. Birmingham, D.; Kantowski, R.; Milton, K.A. Scalar and spinor Casimir energies in even-dimensional Kaluza–Klein spaces of the form $M^4 \times S^{N_1} \times S^{N_2} \times \cdots$. *Phys. Rev. D* **1988**, *38*, 1809–1822. [CrossRef]
117. Emig, T.; Jaffe, R.L.; Kardar, M.; Scardicchio, A. Casimir interaction between a plate and a cylinder. *Phys. Rev. Lett.* **2006**, *96*, 080403. [CrossRef]
118. Emig, T.; Graham, N.; Jaffe, R.L.; Kardar, M. Casimir forces between arbitrary compact objects. *Phys. Rev. Lett.* **2007**, *99*, 170403. [CrossRef] [PubMed]
119. Kenneth, O.; Klich, I. Casimir forces in a T-operator approach. *Phys. Rev. B* **2008**, *78*, 014103. [CrossRef]
120. Emig, T.; Graham, N.; Jaffe, R.L.; Kardar, M. Casimir forces between compact objects: The scalar case. *Phys. Rev. D* **2008**, *77*, 025005. [CrossRef]
121. Rahi, S.J.; Emig, T.; Graham, N.; Jaffe, R.L.; Kardar, M. Scattering theory approach to electromagnetic Casimir forces. *Phys. Rev. D* **2009**, *80*, 085021. [CrossRef]
122. Fosco, C.D.; Lombardo, F.C.; Mazzitelli, F.D. Proximity force approximation for the Casimir energy as a derivative expansion. *Phys. Rev. D* **2011**, *84*, 105031. [CrossRef]
123. Bimonte, G.; Emig, T.; Jaffe, R.L.; Kardar, M. Casimir forces beyond the proximity force approximation. *EPL (Europhys. Lett.)* **2012**, *97*, 50001. [CrossRef]
124. Bimonte, G.; Emig, T.; Kardar, M. Material dependence of Casimir force: Gradient expansion beyond proximity. *Appl. Phys. Lett.* **2012**, *100*, 074110. [CrossRef]
125. Graham, N. Electromagnetic Casimir forces in elliptic cylinder geometries. *Phys. Rev. D* **2013**, *87*, 105004. [CrossRef]
126. Spreng, B.; Hartmann, M.; Henning, V.; Maia Neto, P.A.; Ingold, G.-L. Proximity force approximation and specular reflection: Application of the WKB limit of Mie scattering to the Casimir effect. *Phys. Rev. A* **2018**, *97*, 062504. [CrossRef]
127. Bulgac, A.; Magierski, P.; Wirzba, A. Scalar Casimir effect between Dirichlet spheres or a plate and a sphere. *Phys. Rev. D* **2006**, *73*, 025007. [CrossRef]
128. Bordag, M. Casimir effect for a sphere and a cylinder in front of a plane and corrections to the proximity force theorem. *Phys. Rev. D* **2006**, *73*, 125018. [CrossRef]
129. Maia Neto, P.A.; Lambrecht, A.; Reynaud, S. Casimir energy between a plane and a sphere in electromagnetic vacuum. *Phys. Rev. A* **2008**, *78*, 012115. [CrossRef]
130. Canaguier-Durand, A.; Maia Neto, P.A.; Cavero-Pelaez, I.; Lambrecht, A.; Reynaud, S. Casimir interaction between plane and spherical metallic surfaces. *Phys. Rev. Lett.* **2009**, *102*, 230404. [CrossRef] [PubMed]
131. Bordag, M.; Pirozhenko, I. Casimir entropy for a ball in front of a plane. *Phys. Rev. D* **2010**, *82*, 125016. [CrossRef]
132. Teo, L.P. Material dependence of Casimir interaction between a sphere and a plate: First analytic correction beyond proximity force approximation. *Phys. Rev. D* **2013**, *88*, 045019. [CrossRef]
133. Bimonte, G. Going beyond PFA: A precise formula for the sphere-plate Casimir force. *EPL (Europhys. Lett.)* **2017**, *118*, 20002. [CrossRef]
134. Hartmann, M.; Ingold, G.-L.; Maia Neto, P.A. Plasma versus Drude modeling of the Casimir force: Beyond the proximity force approximation. *Phys. Rev. Lett.* **2017**, *119*, 043901. [CrossRef]
135. Hartmann, M.; Ingold, G.-L.; Maia Neto, P.A. Advancing numerics for the Casimir effect to experimentally relevant asect ratios. *Phys. Scr.* **2018**, *93*, 114003. [CrossRef]
136. Bimonte, G.; Emig, T. Surface scattering expansion of the Casimir–Polder interaction for magneto-dielectric bodies: Convergence properties for insulators, conductors, and semiconductors. *Physics* **2024**, *6*, 194–205. [CrossRef]
137. Fosco, C.D.; Lombardo, F.C.; Mazzitelli, F.D. Casimir Physics beyond the Proximity Force Approximation: The Derivative Expansion. *Physics* **2024**, *6*, 290–316. [CrossRef]
138. Castillo-López, S.G.; Esquivel-Sirvent, R.; Pirruccio, G.; Villarreal, C. Casimir forces with periodic structures: Abrikosov flux lattices. *Physics* **2024**, *6*, 394–406. [CrossRef]
139. Graham, N. Electromagnetic Casimir–Polder interaction for a conducting cone. *Physics* **2023**, *5*, 1003–1012. [CrossRef]

140. Dhital, M.; Mohideen, U. A Brief review of some recent precision Casimir force measurements. *Physics* **2024**, *6*, 891–904. [CrossRef]
141. Hult, E.; Hyldgaard, P.; Rossmeisl, J.; Lundqvist, B.I. Density-functional calculation of van der Waals forces for free-electron-like surfaces. *Phys. Rev. B* **2001**, *64*, 195414. [CrossRef]
142. Drosdoff, D.; Woods, L.M. Casimir forces and graphene sheets. *Phys. Rev. B* **2010**, *82*, 155459. [CrossRef]
143. Sernelius, B.E. Retarded interactions in graphene systems. *Phys. Rev. B* **2012**, *85*, 195427. [CrossRef]
144. Zhu, T.; Antezza, M.; Wang, J.-S. Dynamical polarizability of graphene with spatial dispersion. *Phys. Rev. B* **2021**, *103*, 125421. [CrossRef]
145. Bordag, M.; Fialkovsky, I.V.; Gitman, D.M.; Vassilevich, D.V. Casimir interaction between a perfect conductor and graphene described by the Dirac model. *Phys. Rev. B* **2009**, *80*, 245406. [CrossRef]
146. Fialkovsky, I.V.; Marachevsky, V.N.; Vassilevich, D.V. Finite-temperature Casimir effect for graphene. *Phys. Rev. B* **2011**, *84*, 035446. [CrossRef]
147. Bordag, M.; Klimchitskaya, G.L.; Mostepanenko, V.M.; Petrov, V.M. Quantum field theoretical description for the reflectivity of graphene. *Phys. Rev. D* **2015**, *91*, 045037. [CrossRef]
148. Bordag, M.; Fialkovskiy, I.; Vassilevich, D. Enhanced Casimir effect for doped graphene. *Phys. Rev. B* **2016**, *93*, 075414. [CrossRef]
149. Tajik, F.; Palasantzas, G. Dynamical sensitivity of three-layer micro electromechanical systems to the optical properties of the intervening liquid layer. *Physics* **2023**, *5*, 1081–1093. [CrossRef]
150. Haghmoradi, H.; Fischer, H.; Bertolini, A.; Galić, I.; Intravaia, F.; Pitschmann, M.; Schimpl, R.; Sedmik, R.I.P. Force metrology with plane parallel plates: Final design review and outlook. *Physics* **2024**, *6*, 690–741. [CrossRef]
151. Khoury, J.; Weltman, A. Chameleon fields: Awaiting surprises for tests of gravity in space. *Phys. Rev. Lett.* **2004**, *93*, 171104. [CrossRef] [PubMed]
152. Olive, K.A.; Pospelov, M. Environmental dependence of masses and coupling constants. *Phys. Rev. D* **2008**, *77*, 043524. [CrossRef]
153. Hinterbichler, K.; Khoury, J. Screening long-range forces through local symmetry restoration. *Phys. Rev. Lett.* **2010**, *104*, 231301. [CrossRef] [PubMed]
154. Hinterbichler, K.; Khoury, J.; Levy, A.; Matas, A. Symmetron cosmology. *Phys. Rev. D* **2011**, *84*, 103521. [CrossRef]
155. Brax, P.; Fischer, H.; Käding, C.; Pitschmann, M. The environment dependent dilaton in the laboratory and the solar system. *Eur. Phys. J. C* **2022**, *82*, 934. [CrossRef]
156. Decca, R.S.; López, D.; Chan, H.B.; Fischbach, E.; Krause, D.E.; Jamell, C.R. Constraining new forces in the Casimir regime using the isoelectronic technique. *Phys. Rev. Lett.* **2005**, *94*, 240401. [CrossRef]
157. Antoniadis, I.; Baessler, S.; Bücher, M.; Fedorov, V.V.; Hoedl, S.; Lambrecht, A.; Nesvizhevsky, V.V.; Pignol, G.; Protasov, K.V.; Reynaud, S.; et al. Short-range fundamental forces. *Comptes Rendus Phys.* **2011**, *12*, 755–778. [CrossRef]
158. Klimchitskaya, G.L.; Mostepanenko, V.M. Improved constraints on the coupling constants of axion-like particles to nucleons from recent Casimir-less experiment. *Eur. Phys. J. C* **2015**, *75*, 164. [CrossRef]
159. Chen, Y.-J.; Tham, W.K.; Krause, D.E.; López, D.; Fischbach, E.; Decca, R.S. Stronger limits on hypothetical Yukawa interactions in the 30–8000 nm range. *Phys. Rev. Lett.* **2016**, *116*, 221102. [CrossRef] [PubMed]
160. Klimchitskaya, G.L.; Mostepanenko, V.M. Constraints on axionlike particles and non-Newtonian gravity from measuring the difference of Casimir forces. *Phys. Rev. D* **2017**, *95*, 123013. [CrossRef]
161. Klimchitskaya, G.L. Recent breakthrough and outlook in constraining the non-Newtonian gravity and axion-like particles from Casimir physics. *Eur. Phys. J. C* **2017**, *77*, 315. [CrossRef]
162. Klimchitskaya, G.L.; Kuusk, P.; Mostepanenko, V.M. Constraints on non-Newtonian gravity and axionlike particles from measuring the Casimir force in nanometer separation range. *Phys. Rev. D* **2020**, *101*, 056013. [CrossRef]
163. Svetovoy, V.B. Casimir forces between a dielectric and metal: Compensation of the electrostatic interaction. *Physics* **2023**, *5*, 814–822. [CrossRef]
164. Speake, C.C.; Trenkel, C. Forces between conducting surfaces due to spatial variations of surface potential. *Phys. Rev. Lett.* **2003**, *90*, 160403. [CrossRef]
165. Behunin, R.O.; Dalvit, D.A.R.; Decca, R.S.; Genet, C.; Jung, I.W.; Lambrecht, A.; Liscio, A.; López, D.; Reynaud, S.; Schnoering, G.; et al. Kelvin probe force microscopy of metallic surfaces used in Casimir force measurements. *Phys. Rev. A* **2014**, *90*, 062115. [CrossRef]
166. Klimchitskaya, G.L.; Mostepanenko, V.M. Conductivity of dielectric and thermal atom-wall interaction. *J. Phys. A Math. Theor.* **2008**, *41*, 312002. [CrossRef]
167. Klimchitskaya, G.L.; Mostepanenko, V.M. Casimir effect invalidates the Drude model for transverse electric evanescent waves *Physics* **2023**, *5*, 952–967. [CrossRef]
168. Törmä, P.; Barnes, W.L. Strong coupling between surface plasmon polaritons and emitters: A review. *Rep. Prog. Phys.* **2015**, *78*, 013901. [CrossRef] [PubMed]
169. Klimchitskaya, G.L.; Mostepanenko, V.M.; Svetovoy, V.B. Probing the response of metals to low-frequency s-polarized evanescent fields. *EPL (Europhys. Lett.)* **2022**, *139*, 66001. [CrossRef]
170. Klimchitskaya, G.L.; Mostepanenko, V.M.; Svetovoy, V.B. *Experimentum crucis* for electromagnetic eesponse of metals to evanescent waves and the Casimir puzzle. *Universe* **2022**, *8*, 574. [CrossRef]
171. Henkel, C. Rectified Lorentz force from thermal current fluctuations. *Physics* **2024**, *6*, 568–578. [CrossRef]
172. Klimchitskaya, G.L.; Mostepanenko, V.M. The Casimir force between two graphene sheets: 2D Fresnel reflection coefficients, contributions of different polarizations, and the role of evanescent waves. *Physics* **2023**, *5*, 1013–1030. [CrossRef]

173. Asorey, M.; Iuliano, C.; Ezquerro, F. Casimir energy in (2 + 1)-dimensional field theories. *Physics* **2024**, *6*, 613–628. [CrossRef]
174. Geim, A.K.; Novoselov, K.S. The rise of graphene. *Nat. Mater.* **2007**, *6*, 183–191. [CrossRef]
175. Lalmi, B.; Oughaddou, H.; Enriquez, H.; Kara, A.; Vizzini, S.B.; Ealet, B.N.; Aufray, B. Epitaxial growth of a silicene sheet. *Appl. Phys. Lett.* **2010**, *97*, 223109. [CrossRef]
176. Garcia, J.C.; de Lima, D.B.; Assali, L.V.C.; Justo, J.F. Group IV graphene- and graphane-like nanosheets. *J. Phys. Chem. C* **2011**, *115*, 13242. [CrossRef]
177. Carvalho, A.; Wang, M.; Zhu, X.; Rodin, A.S.; Su, H.; Castro Neto, A.H. Phosphorene: From theory to applications. *Nat. Rev. Mater.* **2016**, *1*, 16061. [CrossRef]
178. Brax, P.; Fichet, S. Casimir forces in CFT with defects and boundaries. *Physics* **2024**, *6*, 544–667. [CrossRef]
179. Khusnutdinov, N.; Emelianova, N. The normal Casimir force for lateral moving planes with isotropic conductivities. *Physics* **2024**, *6*, 148–163. [CrossRef]
180. Dedkov, G.V. Casimir–Lifshitz frictional heating in a system of parallel metallic plates. *Physics* **2024**, *6*, 13–30. [CrossRef]
181. Inui, N. Stabilizing diamagnetic levitation of a graphene flake through the Casimir effect. *Physics* **2023**, *5*, 923–935. [CrossRef]
182. Brevik, I.; Pal, S.; Li, Y.; Gholamhosseinian, A.; Boström, M. Axion electrodynamics and the Casimir effect. *Physics* **2024**, *6*, 407–421. [CrossRef]
183. Boström, M.; Gholamhosseinian, A.; Pal, S.; Li Y.; Brevik, I. Semi-classical electrodynamics and the Casimir effect. *Physics* **2024**, *6*, 456–467. [CrossRef]
184. Marachevsky, V.N.; Sidelnikov, A.A. Casimir interaction of Chern–Simons layers on substrates via vacuum stress tensor. *Physics* **2024**, *6*, 496–514. [CrossRef]
185. Ievlev, I.; Good, M.R.R. Larmor temperature, Casimir dynamics, and Planck's law. *Physics* **2023**, *5*, 797–813. [CrossRef]
186. Gorban, M.J.; Julius, W.D.; Brown, P.M.; Matulevich, J.A.; Radhakrishnan, R.; Cleaver, G.B. First and second-order forces in the asymmetric dynamical Casimir effect for a single $\delta-\delta'$ mirror. *Physics* **2024**, *6*, 760–779. [CrossRef]
187. Bordag, M.; Pirozhenko, I.G. Mass and magnetic moment of the electron and the stability of QED— A critical review. *Physics* **2024**, *6*, 237–250. [CrossRef]
188. Saharian, A. Surface Casimir densities on branes orthogonal to the boundary of anti-de Sitter spacetime. *Physics* **2023**, *5*, 1145–1162. [CrossRef]
189. Grats, Y.V.; Spirin, P. Vacuum interaction of topological strings at short distances. *Physics* **2023**, *5*, 1163–1180. [CrossRef]
190. Bezerra, V.B.; Mota, H.F.S.; Lima, A.P.C.M.; Alencar, G.; Muniz, C.R. Casimir effect in finite temperature and gravitational scenarios. *Physics* **2024**, *6*, 1046–1071. [CrossRef]
191. Klimchitskaya, G.L.; Mostepanenko, V.M. An alternative response to the off-shell quantum fluctuations: A step forward in resolution of the Casimir puzzle. *Eur. Phys. J. C* **2020**, *80*, 900. [CrossRef]
192. Klimchitskaya, G.L.; Mostepanenko, V.M. Casimir effect for magnetic media: Spatially nonlocal response to the off-shell quantum fluctuations. *Phys. Rev. D* **2021**, *104*, 085001. [CrossRef]
193. Klimchitskaya, G.L.; Mostepanenko, V.M. Theory-experiment comparison for the Casimir force between metallic test bodies: A spatially nonlocal dielectric response. *Phys. Rev. A* **2022**, *105*, 012805. [CrossRef]