View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by NASA Technical Reports Server

N94-10594

QUANTUM MECHANICAL EFFECTS OF TOPOLOGICAL ORIGIN

I.H.Duru
University of Trakya
Mathematics Department
Edirne, Turkey

and

TUBITAK, Marmara Research Centre
P.O.Box 21, 41470 Gebze, Turkey[1]

Abstract

Following a brief review of the original Casimir and Aharonov-Bohm effects, some other effects of similar natures are mentioned. A Casimir interaction between AB fluxes is presented. Possible realizations of the Casimir effects for massive charged fields in solid state structures; and a new AB effect for photons are suggested.

1 Casimir and Aharonov-Bohm Effects

There are two types of quantum mechanical effects which can be attributed to the non-trivial topologies of the configuration or phase spaces.

First kinds of these effects are named after Casimir [1]. When the space is bounded the vacuum expectation value of quantized fields acquires non-zero values and becomes space dependent, which then creates a force on the boundaries. The attractive force between the parallel conductive plates is the first example of this kind [1]: the vacuum fluctuations of the electromagnetic field produces an attractive force on the unit area of the plates given by $F = -(\pi^2/240)(\hbar c/a^4)$ where a is the seperation of the plates. This force is already observed in experiments [2]. The topological nature of this effect is in the fact that the field momentum perpendicular to the plates is discretized; i.e., the effective topology is not $\mathbf{R}^3$ but $\mathbf{S}^1 \times \mathbf{R}^2$.

The second kind of effects are known as the Aharonov-Bohm (AB) effects, which involve the electron field: when a confined flux is placed in the space, the electrons moving in te outside region pick up a phase which is observable in the interferance experiments [3]. In this effect the topology of the plane perpendicular to the flux line is multiply connected.

These exist some other examples which are similar to the above mentioned effects:

Several calculations have been made for Casimir effects involving boundaries of different shapes [2]. Examples with moving boundaries are also studied which are used to obtain squezzed states of light [4].

[1]Mailing address.

Some of the physical effects which have been proposed to be similar to the AB effect are the followings:

Introducing an impenetrable charged line in place of the magnetic flux and replacing the electrons with neutral magnetic dipoles one obtains a system equivalent to the AB effect [5].

AB experiments involving the correlated charged particles are also proposed. Ideas involving electron-positron pairs extended to obtain AB effect for the effective photon field [6].

2 An Interaction Connecting Two Effects

Consider two parallel, tightly wound solenoids, confining fluxes Φ_1 and Φ_2 in them, which are seperated by the distance a. The vacuum expectation value of the energy for the massive, charged field in the region outside the flux lines have a finite "interaction" term depending on $\Phi_1\Phi_2$ and on a. For a scalar charged field the interaction energy in the slice of space with unit thickness having its normal parallel to the fluxes is

$$E_{\Phi_1\Phi_2} = -\frac{\hbar c}{2\pi^2}\frac{\Lambda_1^2\Lambda_2^2}{a^2}, \; \Lambda \equiv \frac{e\Phi}{2\pi}. \tag{1}$$

Note that the mass of the field does not contribute to the interaction term which only appears in the self energy terms involving Φ_1^2 and Φ_2^2 seperately. The energy (1) leads to an attractive force on the unit length of the flux lines given by

$$F_{\Phi_1\Phi_2} = -\frac{\partial}{\partial a}E_{\Phi_1\Phi_2} = \frac{\hbar c}{\pi^2}\frac{\Lambda_1^2\Lambda_2^2}{a^3}. \tag{2}$$

The above force is derived for a hypotetical scalar, charged field. For charged fields with spin, for each spin degree of freedom we expect to thave a force equivalent to (2). For example for the electron field the force should be multiplied by two.

If the fluxes are quantized, for integer fluxes, fields with integer charges, that is $e^\pm$, $\mu^\pm$, $\tau^\pm$ particles contribute to the Casimir interaction. On the other hand the quark fields can contribute only to the interaction of the fluxes quantized to the one or two-thirds of integers. In conclusion we can say that the Casimir force between the quantized AB fluxes may count the number of families [7].

3 Comments on Possible New Realizations

The recent developments in solid state physics enables one to create two-dimensional and one-dimensional structures (=quantum dots) in which we can trap charged particles. These structures my raise the hope of observing new Casimir effects involving massive fields.

Finally we like to suggest an experimental set up which may realize an AB geometry for the photon field: In the double slit experiment, if we place an infinitely long, thin, neutral and perfectly conductive wire perpendicular to the incoming light beam, we expect to observe an AB type effect for the photon field. This, unlike the one suggested in Ref.[6], would be a purely neutral AB effect.

References

[1] H.B.G. Casimir, Proc.K.Ned.Akad.Wet,**51**, 793(1948); Physica **19**, 846(1956).

[2] See the references in V.M.Mostepanenko and N.N.Trunov, Sov.Phys.Usp. **31**, 965 (1988).

[3] Y.Aharonov and D.Bohm, Phys.Rev. 115,485(1959); and W.Ehrenberg and R.E.Sidney, Proc.Phys.Soc. **62B**, 8(1949).

[4] V.V.Dodonov, A.B.Klimov and V.I.Man'ko, Phys.Lett. **A142**, 511(1989).

[5] Y.Aharonov and A.Casher, Phys.Rev.Lett. **53**, 319(1989).

[6] M.P.Silverman, Phys.Lett. **A156**, 131(1991).

[7] I.H.Duru, to be published in Foundations of Physics, special issue honoring A.O.Barut (1992).