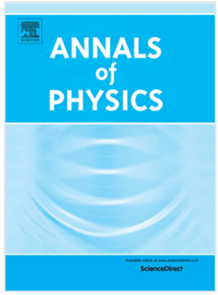
Accepted Manuscript



Spontaneous decay of a two-level system close to a perfectly reflecting sphere

R.P.A. Lima, F.N. Lima, M.L. Lyra

PII: S0003-4916(17)30033-7
DOI: http://dx.doi.org/10.1016/j.aop.2017.01.017
Reference: YAPHY 67315

To appear in: *Annals of Physics*

Received date: 17 November 2016
Accepted date: 20 January 2017

Spontaneous decay of a two-level system close to a perfectly reflecting sphere

R.P.A. Lima[a], F.N. Lima[b], M.L. Lyra[a]

[a] *GFTC and GISC, Instituto de Física, Universidade Federal de Alagoas, 57072-970, Maceió-AL, Brazil*
[b] *Instituto Federal do Piauí, 64770-000, São Raimundo Nonato-PI, Brazil*

Abstract

Within a first-order time-dependent perturbation approach, we compute the spontaneous decay rate of a two-level system placed in the vicinity of a perfectly reflecting spherical surface. We consider a model system on which the emitter is represented by a two-level monopole coupled to a Hermitian massless scalar field. Using the method of images, we determine the appropriate Green's function evaluated in the world line of the atom. The change in the spontaneous decay rate results from the interaction of the atom with its image. We provide a detailed analysis of the dependence of the decay rate on the sphere's radius, the atom's location, and the emitted radiation frequency. Both exterior and interior problems are discussed.

Keywords: Spontaneous decay, radiation-matter interaction, reflecting sphere, perturbation theory, method of images

1. Introduction

Tuning the rate of spontaneous emission of radiation by excited single atoms, molecules and quantum dots has been considered as a fundamental step towards the development of a new class of quantum optical devices. These include nanospectrometers and nanolasers, as well as electroluminescent and photonic band-gap structures[1, 2, 3, 4, 5].

Since the seminal work of Purcell[6], it has been known that the environment has a profound influence on the decay rate of excited systems. In particular, when the excited system is close to interfaces, the imposed boundary conditions modify the density of possible electromagnetic modes. As result, the decay rate changes due to the system's coupling with the modified vacuum quantum fluctuations.

Over the last decades, several works have explored the possibility of enhancement or suppression of the decay rate of emitters placed near conducting walls, wedges, spheres and cylinders, or trapped in microcavities such as parallel walls, spheres and ellipsoids[7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32]. In particular, when a two-level system is trapped between parallel walls, the spontaneous decay process can be substantially suppressed when the distance between the walls is much smaller than the wavelength of the emitted radiation. On the other hand, the decay rate can be strongly enhanced due to the emergence of resonant modes. Recently, the spontaneous decay rate of quantum entangled atoms near interfaces has been a subject of increasing interest due to the possibility of generating and controlling quantum entangled radiation fields[33, 34, 35, 36].

In the present work, we study the spontaneous decay rate of a two-level system close to a sphere with a perfectly reflecting surface, within a first-order time-dependent perturbation approach. Experiments performed with spherical SiO_2 colloids with two different diameters doped with Erbium at different concentrations showed a large difference in the spontaneous emission rate for both colloid sizes[18]. However, two factors that influence on the spontaneous decay process are usually superposed: the modification of the field quantum fluctuations and polarization effects[20, 26, 28]. In order to focus on the specific contribution of the modified field fluctuations, we will consider a simple model on which the atom is represented by a two-level monopole coupled to a massless scalar field. Although not including polarization features, such model captures the essential ingredients needed to understand the influence of the field's mode changes induced by the presence of bounding surfaces on the atom's spontaneous emission. This approach has been successfully used in the literature to describe the process of photodetection[37, 38, 39, 40], the influence of parallel mirrors and strings on the radiation process[15, 41] and, more recently, on the entanglement generation by accelerated atoms[34, 42, 43, 44, 45, 46].

This work is organized as follows. In the next section, we will present the main lines related to the first-order perturbation theory for the spontaneous decay rate of an excited monopole coupled to a scalar massless field. We also compute the decay rate for the case on which the two-level system is placed in the vicinity of a sphere with

Email addresses: rodrigo@fis.ufal.br (R.P.A. Lima), nogueira@ifpi.edu.br (F.N. Lima), marcelo@fis.ufal.br (M.L. Lyra)