J. At. Mol. Sci.
doi: 10.4208/jams.030112.032212a

Vol. **4** , No. 1 , pp. 18-29
February 2013

Muon's anomalous magnetic moment effects on laser assisted Coulomb scattering process

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Received 1 March 2012; Accepted (in revised version) 22 March 2012
Published Online 8 December 2012

Abstract. Laser assisted Coulomb scattering by relativistic electron and heavy electron (muon) is studied by using Salamin waves [3] in the Weak Field Approximation (WFA). Both electron and muon are described by the Dirac equation, with the anomalous magnetic moment effects fully included. The generalization of this paper to heavy electron (muon) gives interesting insights as to how the mass affects the magnitude of the differential cross sections. No significant difference in the muon's DCS with and without AMM effects was detected.

PACS: 34.80.Dp, 12.20.Ds

Key words: laser assisted, QED calculation

1 Introduction

The muon anomalous magnetic moment is one of the most precisely measured quantities in particle physics. Recent high precision measurements at Brookhaven reveal a discrepancy by 3.2 standard deviations from the electroweak Standard Model which could be a hint for an unknown contribution from physics beyond the Standard Model. A muon looks like a copy of an electron, which at first sight is just much heavier $m_\mu/m_e \sim$ 206.7682838. However, unlike the electron, it is unstable and its lifetime is actually rather short. The first measurement of $(g_\mu - 2)/2$ was performed at Columbia in 1960 [4] with a result $a_\mu = 0.00122$ at a precision of about 5%. Soon later in 1961, at the CERN cyclotron

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(1958-1962), the first precision determination became available [5]. Surprisingly, nothing special was observed within the 0.4% level of accuracy of the experiment. It was the first real evidence that the muon was just a heavy electron. In particular, this meant that the muon is point-like and no extra short distance effects could be seen. This latter point of course is a matter of accuracy and the challenge to go further was evident.

The $E821$ experiment at Brookhaven National Laboratory (BNL) [7] studied the precession of muon and anti-muon in a constant external magnetic field as they circulated in a confining storage ring. The $E821$ experiment reported the following average value (from the July 2007 review by Particle Data Group)

$$a_\mu = \frac{g-2}{2} = 0.00116592080$$

Our aim in this paper is to shed some light on a difficult and recently addressed description of laser-assisted processes that incorporate the muon's anomaly. The process under study is the laser-assisted coulomb scattering collision of a Dirac-Volkov muon. We focus on the relativistic muonic dressing with the addition of the muon's anomaly. Some results are rather surprising, bearing in mind the small value of a_μ. In Sec. 2, we present the formalism as well as the coefficients that intervene in the expression of the DCS. In Sec. 3, we discuss the results we have obtained. Throughout this work, we use atomic units $\hbar = m_e = e$ and work with the metric tensor $g^{\mu\nu} = g_{\mu\nu} = diag(1,-1,-1,-1)$. In many equations of this paper, the Feynman 'slash notation' is used. For any $4-$vector A, $\not{A} = A^\mu \gamma_\mu = A^0\gamma_0 - \mathbf{A}.\gamma$ where the matrices γ are the well known Dirac matrices.

2 Theory

The second-order Dirac equation for a muon in the presence of an external electromagnetic field is given by

$$\left[\left(p - \frac{1}{c}A\right)^2 - m_\mu^2 c^2 - \frac{i}{2c} F_{\mu\nu}\sigma^{\mu\nu}\right]\psi(x) = 0 \tag{1}$$

where m_μ represents the mass of the muon, $\sigma^{\mu\nu} = \frac{1}{2}[\gamma^\mu, \gamma^\nu]$, γ^μ are the Dirac matrices and $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$ is the electromagnetic field tensor. A^μ is the four-vector potential. The plane wave solution of the second-order equation is known as the Volkov state [2]

$$\psi(x) = \left(1 + \frac{\not{k}\not{A}}{2c(kp)}\right)\frac{u(p,s)}{\sqrt{2VQ_0}}\exp\left[-i(qx) - i\int_0^{kx}\frac{(Ap)}{c(kp)}d\phi\right] \tag{2}$$

The second-order Dirac equation for a muon with anomalous magnetic moment (AMM) effects in the presence of an external electromagnetic field is given by

$$\left[\left(p - \frac{1}{c}A\right)^2 - m_\mu^2 c^2 - \frac{i}{2c} F_{\mu\nu}\sigma^{\mu\nu} + i a_\mu \left(\not{p} - \frac{\not{A}}{c} + m_\mu c\right) F_{\mu\nu}\sigma^{\mu\nu}\right]\psi(x) = 0 \tag{3}$$