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Effects of an additional dimension in the Young experiment

Allan Kardec Barros

Universidade Federal do Maranhao, Brazil

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ABSTRACT

The results of the Young experiment can be analyzed either by classical or Quantum Physics. The later one though leads to a more complete interpretation, based on two different patterns that appear when one works either with single or double slits. Here we show that the two patterns can be derived from a single principle, in the context of General Relativity, if one assumes an additional spatial dimension to the four known today. The found equations yield the same results as those in Quantum Mechanics.

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1. Introduction

The wave–particle duality defies intuition, as it appeared in many studies [1–4]. Let us take the classical Young double-slit experiment. It basically consists of making a light source to focus on a thin plate with two parallel slits, with a screen behind them (as in Fig. 1). It is well known that the experiment works in the following fashion: (1) If only one slit is open (or, one shut), after a large number of particles have reached the screen, one should find a non-periodic pattern. This is regarded as "particle behavior" [1,2]. If the two slits are open, one finds a periodic pattern. This case is regarded as "wave behavior". Even if we send one photon at a time, the phenomenon repeats. Still, one is forced to wait until a large number has been sent, to characterize the well-known periodicity, as shown in Tonomura experiment [3].

The theoretical prediction of the pattern appearing at the screen is historically well described and precise, either using classical or Quantum Physics. In fact, in the case of one slit, the pattern can be described by the Fraunhofer diffraction equation. While in the two slits case, one can use a squared cosine function modulated by a sinc function. It is interesting though that the pattern at the screen is

E-mail address: allan@elo.com.br.

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formed by small dots, which thus explains the particle aspect. It is even more intriguing the results of a study where it was observed the averaged trajectories of single photons [5], suggesting a particle trajectory.

It is also important to notice the large growth of interest on extra dimensions recently. A number of issues appeared suggesting the increase of the number of dimensions, which yielded the appearance of String theory, M-theory [6,7] and many other related theories, generally called Kaluza–Klein theories. An interesting review was carried out by Maartens and Koyama [8]. However, one of the important points of those theories remains critical, which is the lack of real world evidences to ground them, a problem faced here. Moreover, there are different works in the literature regarding the physical interpretation of the 5th dimension. Indeed, it is not always length-like, at it could be also mass [9] with various consequences, with one which is particularly important for this work is that studied by Wesson [9], which describes waves in vacuum.

The fact is that, although an old one, the Young experiment is still used today to demonstrate the claim of duality. This would work in a complementary way: either we would find a particle or a wave behavior not both at the same time. Indeed, a sharp transition would split the two behaviors. In order to explain those phenomena using a single principle, we propose to increase the number of dimensions basically in the same way of that of Kaluza and Klein [10,11]. In this regard, Kaluza first suggested an additional dimension to include the electromagnetic forces [10,11]. Then, answering to the question of why the fifth dimension was not observed, Klein proposed that this dimension would have a circular topology with its radius proportional to the Planck length [10,11]. To our knowledge, the large majority of the consequent theories are grounded on the later assumption. In this work, we drop that. The additional dimension should also have a circular topology, but with a radius proportional to the particle wavelength, or, to be more appropriate, we take De Broglie's relation and use the term "wavelength". Here we follow the strategy in the literature of connecting the 5th dimension to properties of the particle, for example, to mass [11]. With this, the trajectories of particles in the 3D space are rotated by an angle proportional to the shifts in the circular dimension. The two behaviors can then be predicted simply by estimating the trajectories of individual particles.

2. Methods

Let us define a five dimensional coordinate vector, x, and the corresponding spacetime metric tensor,

$$g_{AB} = \begin{pmatrix} g_{\alpha\beta} + \kappa^2 \phi A_\alpha A_\beta & \kappa\phi A_\alpha \\ \kappa\phi A_\beta & \phi \end{pmatrix} \tag{1}$$

where $g_{\alpha\beta}$ is the fourth dimensional metric tensor, A_α is the electromagnetic potential, κ is a scaling parameter and ϕ is a negative scalar field. We used Greek letters to characterize the four dimensional spacetime. The four-dimensional metric signature is taken to be $(-+++)$, and we work in units such that $c = 1$. We assume therefore that the fifth coordinate has a circular topology (S^1), and is periodic in y, where the radius changes according to the relation $\lambda = h/p$, where p is the linear momentum of the particle and h is the Planck constant. Thus, the fields, $f(y)$, become periodic and they can be rewritten in Fourier terms as follows,

$$f^A(y) = \sum_{i=-\infty}^{\infty} \hat{f}^A(i) e^{(ji\pi y/\lambda)}, \tag{2}$$

where $\hat{f}^A(i)$ are Fourier coefficients.

When there are no external masses or charges, $g_{\alpha\beta} = \eta_{\alpha\beta}$ and $A_\alpha = 0$, where $\eta_{\alpha\beta}$ is the Minkowski metric. Remembering that $\eta_{\alpha\beta}$ is part of a Lorentz group, i.e., $\eta_{\alpha\beta} = \Psi(y)^\rho_\alpha \Psi(y)^\sigma_\beta \hat{\eta}_{\rho\sigma}$, the theorem below shows that $\Psi(y)^\rho_\alpha$ should be a rotation matrix.

Theorem. *When one of the coordinates, e.g., y, has a circular topology, and the metric is that of Minkowski, $\eta_{\alpha\beta}$, then there is a rotation matrix $\Psi(y)^{\alpha'}_\delta$, which obeys $\eta_{\alpha\beta} = \Psi(y)^\rho_\alpha \Psi(y)^\sigma_\beta \hat{\eta}_{\rho\sigma}$, and whose elements are periodic.*

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