Intensity-intensity correlations as a probe of interferences under conditions of noninterference in the intensity

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The different behavior of first-order interferences and second-order correlations are investigated for the case of two coherently excited atoms. For intensity measurements this problem is in many respects equivalent to Young’s double-slit experiment and was investigated in an experiment by Eichmann et al. [Phys. Rev. Lett. 70, 2359 (1993)] and later analyzed in detail by Itano et al. [Phys. Rev. A 57, 4176 (1998)]. Our results show that in cases where the intensity interferences disappear the intensity-intensity correlations can display an interference pattern with a visibility of up to 100%. The contrast depends on the polarization selected for the detection and is independent of the strength of the driving field. The nonclassical nature of the calculated intensity-intensity correlations is also discussed.

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I. INTRODUCTION

Young’s double-slit experiment along with its modern variants has been central to our understanding of many important aspects of quantum mechanics [1,2]. In this experiment the interferences arise because the photon can reach the screen either by passing through one or the other slit and it is the inability to distinguish between the two paths that produces the interference fringes. If, however, one could devise a method so as to detect the path the photon took then the interference would be wiped out [3–10]. Young’s double-slit experiment and other experiments have also been performed with matter waves [11–13] where one has clearly understood the disappearance or the fuzziness in the interference pattern if one tries to identify the atomic path, e.g., by detecting the scattered light or probing the internal levels of the diffracted particles [14–18]. There are also proposals involving cavi- ties to efface the interference by getting Welcherweg information and to recover the interference by using quantum eraser [5]. A recent experiment by Bertet et al. [17] follows a scheme very close to the one proposed by Scully and Drühl [4]. All these experiments provide us with a clear understanding of the close relationship between complementarity, Welcherweg information, and the presence or absence of an interference pattern.

Recently, Eichmann et al. carried out a very interesting experiment where the two slits were replaced by two microscopical objects, namely, two Hg + ions well localized in a linear Paul trap [19] (see also Refs. [20–24]). The two ions were driven coherently by a linear polarized laser field close to the 6s 2S 1/2 – 6p 2P 1/2 transition in 198Hg +. To measure the intensity profile of the scattered fluorescence light in the far field they used a polarization selective detection. In this case well defined interference fringes were reported for π-polarized scattered radiation whereas no interference was found for σ-polarized emitted light. A detailed theoretical analysis of these findings was given by Itano et al. [20]. The results are again interpreted in terms of Welcherweg information: for π-polarized detection the final states of the two ions are the same after scattering of a photon, whereas for σ-polarized detection they are different and thus one does not (does) have which-path information [20].

In this paper we examine the question whether it is possible to see interference fringes even for σ-polarized emitted light if one changed the setup and decided to measure other physical quantities. We know from previous work [25] that the radiation emitted by a coherently driven system can have highly nonclassical characteristics. Therefore, in order to understand all the features of the scattered radiation it becomes almost mandatory to study higher-order correlations, in particular intensity-intensity correlations of the field emitted by the two atom system [26–28]. In what follows we thus turn our attention to the intensity-intensity second-order correlation function. We demonstrate that for two four-level atoms quantum interferences in the second-order correlations of the emitted fluorescence light can be observed for the case of joint detection with two detectors (see Fig. 1). We derive the remarkable result that the depth of modulation in such coincidences can be 100% for both σ- and π-polarized fluorescence light, independent of the strength of the driving field. This is in strong contrast to the visibility of the interference pattern of the far-field intensity profile that can be observed only in case of π-polarized emitted radiation and strongly

FIG. 1. Two-atom system considered: a plane wave with wave vector $k \vec{n}_1$ is impinging on two atoms fixed at positions $\vec{R}_A$ and $\vec{R}_B$. The light scattered by the two atoms is registered in the far field by two detectors positioned at $\vec{r}_1$ and $\vec{r}_2$. 

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