Loss of wave-packet coherence in atomic collisions

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Synopsis We present a Quantum Mechanical analog of the well-known van-Cittert-Zernike theorem of Optics, and employ it to describe how the outcome of a scattering process might be distorted by the degree of coherence of the projectiles' beam. In particular, we apply this model to describe the results of recent ion-atom and ion-molecule collision experiments.

When sunlight reaches the Earth, it exhibits spatial coherent over a length of tens of μm [1]. The explanation of this remarkable effect, where the light emitted from an incoherent source becomes approximately coherent at large distances, relies on a theorem [2] demonstrated eighty years ago by van Cittert and Zernike [3, 4].

Based on a direct analogy between electromagnetic and de Broglie waves, this theorem from Optics has been applied to the study of coherent properties of particle beams [5]. In particular, it has been recently considered [6] as a possible explanation for some new experimental results in the area of atomic collisions [7].

It has been usually assumed that under very general and common conditions, the outcome of a scattering experiment is independent of the properties of the projectiles' beam [8]. However, recent experimental evidence regarding ionization and electron capture processes by ion impact (see, e.g. [7, 9]) points to a breakdown of these conditions and a dependence of the collision outcome on the incident beam's coherence properties.

While the strategy of borrowing results from classical optics and applying them to the study of particle's coherence might be sound for qualitative analysis, it should be validated by a Quantum Mechanical approach for quantitative applications. For instance, an atom optics version of the van Cittert-Zernike theorem was proposed by Taylor [10] in terms of a second-quantization model. More recently, Inpens and Guéry-Odelin [11] employed a classical phase-space approach based on the Truncated Wigner equation.

In this communication we present a derivation of van Cittert-Zernike theorem for an incoherent mixture of identical particles in terms of its density operator. We evaluate its time evolution by solving the Liouville - von Neumann equation. Actually, we demonstrate that a "coherence length" can be defined, such that in the Fraunhofer limit the standard expression of van Cittert - Zernike theorem is recovered [12].

Finally we employ this model to describe how the "degree of coherence" of the projectiles' beam might affect a scattering process. In particular, we explore its applicability to recent ion-atom and ion-molecule collision experiments [7, 9, 13, 14, 15, 16, 17, 18] .

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