Diffraction of massive particles from nanolattices: origin of the particle-wave duality

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Modern experiments have clearly demonstrated that single massive particles (heavy rare gas atoms [1,2] and He clusters [3], fullerenes and their derivatives of high molecular mass [4-12], meso-tetraphenylporphyrin [6], phthalocyanine and its derivatives [5,7,13]), when scattered from nanolattices, form diffraction patterns in quite the same way as particles of smaller mass and photons. The diffraction pattern can be understood as resulting from matter wave interfering with itself and is readily obtained as a solution of Schrödinger's equation. The formation of the interference pattern on the detection screen occurs, however, as a result of many repeated experiments. In each experiment a single particle is detected at a well defined local site on the screen. This transition from wave to particle behaviour is commonly claimed to be a "collapse" of the wave function, which itself is believed not to be understood by solving Schrödinger's equation or within any kind of well defined dynamics.

We develop a quantum field theory which accounts for the coupling of a high dimensional continuum of environmental states to the incident particle in a very localized and very weak fashion [14]. For the model presented Schrödinger's equation can be solved practically exactly and the result does demonstrate that the incoming matter wave extinguishes, except at a single interaction center on the detection screen. The physics behind the theory is discussed in detail. The transion from wave to particle behaviour, the so called "collapse", occurs in our theory as a sticking process of the particle from the vacuum to the surface of the detection screen. This situation is verified in the experiment by Arndt et al. using massive molecules of phthalocyanine and a heavier derivative [13]. In our theory this wave-particle transition is connected to the different dimensionalities of the phase space for particle motion and the environmental dynamics. The fact that the particle is detected at apparently statistically determined points on the screen is traced back to the weakness of the interaction with the environment which allows coupling on the energy shell alone. The interaction with the environment is less pronounced than the variation of the energies of the interaction centers on the detection screen. In order to suggest possible experimental tests of our theory, the wave-particle transition is studied as a function of the screen surface and the boson structure defining the environment.

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