The "Stern-Gerlach-Experiment" revisited

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The Stern-Gerlach-Experiment SGE performed in 1922 is the seminal benchmark experiment of quantum physics providing evidence for several fundamental properties of quantum systems (1-5). Based on the knowledge of today we try to illustrate in this paper the different benchmark results of the SGE for the development of modern quantum physics and chemistry. Its results contradicted in 1922 the expectations of classical physics. Only when Heisenberg and Schrödinger (6) in 1925/6 presented their new quantum dynamical theories the SGE findings could be explained. The SGE provided the first direct experimental evidence for angular momentum quantization in the quantum world and for the existence of directional quantization DQ of all angular momenta in the process of measurement. Furthermore it measured for the first time a ground state property of an atom, it produced for the first time a fully "spin-polarized" atomic beam, and it discovered almost also the electron spin. The SGE was the first fully successful Molecular Beam experiment where by measuring in vacuum the kinematics of particles could be determined with high momentum-resolution (corresponds to an energy resolution of about 1 μeV). This technique provided a new kind of kinematic microscope which allows to reveal inner atomic or nuclear properties.

Historic facts of the original SGE are described together with the early attempts of Einstein, Ehrenfest, Heisenberg, etc. to understand the physical processes creating DQ in the SGE. Heisenbergs and Einsteins "Gedanken Experimente" (7) of an improved multi-stage SGE are presented. The first realization of these "Gedanken Experimente" by Stern, Phipps, Frisch and Segrè is described (8). The experimental set-up proposed by Einstein can be considered as a "pre-Rabi" apparatus with time-varying fields. Also recent theoretical work by Wennerström et al. and Devereux is mentioned in which the DQ process and possible interference effects of the two different spin states are investigated. Wennerström et al. consider the full dynamics of a single atom passing through the SG magnet with a stochastic coupling of the atomic magnetic moment to the spins of the atoms in the magnet. Devereux theoretically investigates the passage of the atoms through the magnet and shows that the two separated spin states cannot interfere since their trajectories are experimentally distinguishable. In full agreement with the results of new quantum theory DQ appears as a general and universal feature of quantum measurements. One experimental example for such DQ in scattering processes is shown. Last but not least the early history of the "almost" discovery of the electron spin in the SGE is revisited.

In Stern's apparatus the atoms were prepared as a fully controlled dynamical state (momentum). By measuring the momentum perfect control of DQ along the atom trajectory inside the magnetic field region was obtained. After entering the inhomogeneous B field region between the poles of the magnet each atom is accelerated by the magnetic force $\delta B/\delta z \bullet \mu$ in z direction due to its magnetic moment μ. At the point of exiting the magnetic field region each atom has a well-defined transverse momentum $\Delta p_z \sim \delta B/\delta z \bullet \mu \bullet t_F$ (t_F is the transit time of the atom inside the magnetic field). Measuring this transverse momentum, which was found to have two discrete values, allowed Stern and Gerlach to determine the value of the quantized magnetic moment. It is to be noticed that the SGE provides a momentum measurement but not a measurement of position. Each atom follows shortly after entering the magnetic field a perfectly steady, classical trajectory in the SG device. Since the de Broglie wave length λ is < 0.02 Angström, diffraction at the slits is completely negligible.

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