In continuation of previous work explicitly demonstrating the basic quantum-mechanical principles of the static and the time-dependent superposition of spinors, a new double-resonance interferometer experiment is described, where a spin-flip process associated with an exchange of energy quanta happens in both a perfect-crystal neutron interferometer. It is shown that under the given circumstances of neutron self-interference coherence is preserved in spite of the energy transfer to every neutron, which must be understood in terms of the underlying quantum-mechanical phenomena. Partly the interpretation of quantum mechanics on a macroscopic time scale has been observed by introducing an exceedingly small energy difference of $8.6 \times 10^{-17} \text{eV}$ between the two interfering beams. According to the statistical accuracy of the data thereby an energy sensitivity of $2.7 \times 10^{-19} \text{eV} \cdot \text{h}^{-1}$ has been achieved.

I. INTRODUCTION

During the last decade neutron interferometry has offered a conceptually new access to a variety of fields in physics research. So, it has proven to be an almost ideal tool to test fundamental principles of quantum mechanics with massive particles on a macroscopic space-time scale. Such experiments have stimulated renewed epidemiological discussions about the foundations of quantum mechanics.

Now in a series of experiments the interaction of the neutron wave function with nuclear, magnetic, and gravitational potentials has been investigated. Most-Michel-like interferometers out of perfect silicon crystals were used which essentially consist of three plane-parallel plates. Dynamical diffraction within the first crystal plate splits the incident neutron beam coherently into two widely separated partial beams. By means of the middle plate these two beams are then superposed at the third crystal plate which acts as an analyzer of the resulting interference pattern. In this paper a new experiment is described in which in particular refers to the magnetic interaction and continues earlier activities in this field ranging from the explicit experimental verification of the 4$f^5$ symmetry of spinor wave functions to the demonstration of the quantum-mechanical principles of both stationary and time-dependent superposition of fermion spin-states on a macroscopically observable level. In these earlier spin-superposition experiments the two separated coherent beams propagating within the interferometer are prepared to be in mutually orthogonal spin eigenstates, i.e., with equal to zero in the stationary case this orthogonality is broken by inserting a second spin-flip device into one of the two interfering sub-beams [Fig. 1(a)], which causes Larmor rotation along a well-defined distance by sudden nonadiabatic spatial change of the magnetic field direction and hence leads to an arbitrarily adjustable final spin state. Since no explicitly time-dependent interaction is involved, the total energy of each neutron is conserved during the flip process and therefore a stationary interference pattern results. Polarization analysis behind the interferometer reveals the fact that the emerging beams are in a spin state which is orthogonal to those of their interfering constituents.

II. EXPERIMENTAL

If, on the other hand, the static spin-turn device is replaced by a radio-frequency (rf) spin-flip coil [Fig. 1(b)] the spin-reversal process is associated with a change of the total energy of the neutrons according to mission or absorption of photons. This energy transfer has been directly measured in a separate experiment by means of a high-resolution neutron backscattering spectrometer. The interference experiment the change of energy of one of the sub-beams causes a time dependence of the interference pattern as a result the magnetic detection method therefore has to be applied. However, in such an experiment the energy transfer does not represent a measuring process since this would imply a violation of the momentum-position uncertainty relation of the neutron. In this context Vinet and co-workers proposed an experiment with two separate resonance coils inverting the spin state of each sub-beam within the interferometer [Fig. 2]. They claim that because of the indivisibility of each exchanged photon the energy transfer has to be associated with the particle properties of the neutron only, if any at all, is inside the interferometer. The succeeding one is usually still confined within the uranium nucleus of the reactor fuel.

III. EXPERIMENTAL

The experiments were performed at the interferometer instrument S18 at the high-flux reactor of the Institute Laue-Langevin in Grenoble. An arrangement similar to that of the preceding experiments on spinor superposition was used. However, the original symmetric triple-crystal interferometer was replaced by a new skew-symmetrically cut interferometer as shown in Fig. 2. ...

IV. RESULTS

[...]

V. CONCLUDING REMARKS

All results we have obtained so far are in complete agreement with the formalism of quantum mechanics. Our experiments transfer quantum-mechanical phenomena to a macroscopically observable level either in space or in time. By observing the interference pattern one can, in particular, determine its energy with an accuracy $\Delta E \propto 10^{-17} \text{ eV}$. The energy resolution is determined as $2 \times 10^{-19} \text{ eV}$. The observed beat effect is caused by the interference of beams with a wavelength of $6 \times 10^{-17} \text{m}$ and the energy resolution is determined as $2 \times 10^{-19} \text{ eV}$.

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