Detection of the He-McKellar-Wilkens phase shift by atom interferometry

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Abstract

The Aharonov-Bohm effect [?], predicted in 1959, is the first example of a family of topological phase effects [?] which contains also the Aharonov-Casher effect and the He-McKellar-Wilkens (HMW) effect [?], introduced independently by X.-G. He and B.H.J. McKellar and by M. Wilkens for the motion of a constant electric dipole moment interacting with a magnetic field. The case of a polarizable neutral particle considered by H. Wei et al., is closer to an experiment. All these topological phases are independent of the particle velocity.

Following H. Wei et al., the HMW phase shift which appears when an atom propagates in crossed electric field $\mathbf{E}$ and magnetic field $\mathbf{B}$ is given by $\Delta\phi_{HMW} = 4\pi\varepsilon_0 \int \alpha \mathbf{v}\cdot(\mathbf{B}\times\mathbf{E})\, dt/\hbar$. To detect this effect, we must be able to cancel the considerably larger polarizability phase shift equal to $\Delta\phi_{pol} = 2\pi\varepsilon_0 \int \alpha \mathbf{E}^2 dt/\hbar$.

We have built an experiment using our Mach-Zehnder atom interferometer [?] based on a thermal lithium atomic beam and laser diffraction in the Bragg regime which provides high quality signals and a high phase sensitivity ca. 10 mrad/$\sqrt{\text{Hz}}$. The atom propagation is perturbed by a double capacitor with a septum located in between the interferometer arms. The capacitor is placed just before the second laser standing wave, where the arm separation is largest and it creates opposite electric fields $E_m \approx \pm 5\times 10^5$ V/m on the two interferometer arms while a coil create an homogeneous magnetic field $B_m \approx \pm 0.02$ Tesla. The electric field is horizontal while the magnetic field is vertical. The capacitor is as symmetric as possible and we apply slightly different voltages to compensate for the residual asymmetry of the polarisability shift.

The HMW effect should appear as a phase shift which is not the sum of phase shift due to the electric field and of the one due to the magnetic field alone. With our parameters, we expect a phase-shift $\Delta\phi_{HMW} \approx \pm 15$ milliradians. We have already collected a large data set which proves the existence of this phase-shift and we work to improve the accuracy of its measurement, limited by phase drifts. We will soon verify that the HMW phase-shift is independent of the atom velocity.

In conclusion, we have made the first detection of the He-McKellar-Wilkens topological phase shift. This effect is particularly interesting as it modifies the propagation in a non-reciprocal way i.e. the phase sign would be opposite for atoms propagating backwards.

Keywords: He-McKellar-Wilkens phase-shift, atom interferometer, high phase sensitivity

References

[1] Y. Aharonov and A. Bohm, Phys. Rev. **115**, 485 (1959).

[2] J.P. Dowling, C.P. Williams and J.D. Franson, Phys. Rev. Lett. **83**, 2486 (1999).

[3] X.-G. He and B.H.J. McKellar, Phys. Rev. A **47**, 3424 (1993); M. Wilkens, Phys. Rev. Lett. **72**, 5 (1994) ; H. Wei, R. Han and X. Wei, Phys. Rev. Lett. **75**, 2071 (1995).

[4] A. Miffre, M. Jacquey, M. Büchner, G. Trénec and J. Vigué, Eur. Phys. J. D **33**, 99 (2005)