Multiple-Beam Atom Interferometry using Intense Pulses of Light

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During the past decade a vast variety of interferometers for atoms has been realised and, in general, the interference signal obtained is based on the observation of two path interferences. However, it is worth noting that in light optics it is standard practice to increase the number of interfering paths in order to increase the resolution of an interferometer. This increased resolution results from the fact that one obtains a sinusoidal interference signal in 2-beam interferometry whereas, in multiple-beam interferometry, a sharply peaked Airy function-like pattern is observed (e.g. the Fabry-Perot interferometer). An additional advantage of multiple-beam interferometry arises when one changes the accumulated phase by varying, for example, the time delay between laser pulses applied at the different interaction regions. Rather than a loss of signal, as in 2-beam interferometry, one can observe a collapse and subsequent revival of the interference fringes once the accumulated quadratic phase between all adjacent interferometer paths reaches a multiple of 2π. Thus, a higher sensitivity is achievable due to the longer interaction times permissible. Such effects have been previously observed by our group using a thermal beam of Caesium atoms, which were optically pumped into a spatially separated, multi-level, dark state. Up to five interfering beams were obtained, the total number being limited by the number of Zeeman sublevels in the dark state [1], [2], [3].

As a continuation of our work on multiple-beam atom interferometry we are currently realising an interferometer that will have a far greater number of interfering paths in addition to longer interaction times, thus yielding a corresponding increase in the phase-sensitivity of the interferometer. ^{85}Rb atoms are magneto-optically trapped in the $6S_{1/2}$ $F = 3$ ground state and are then launched vertically upwards using a standard atomic fountain configuration in which the frequencies of the upwards (resp. downwards) moving molasses beams are blue-shifted (resp. red-shifted) by $\sim 0.5MHz$ with respect to the trapping beams. The atoms can be launched a maximum distance of $5cm$ depending on the frequency shift selected. An optical pumping beam pumps the atoms into the $F = 3, m_F = 0$ ground state sublevel in order to avoid any effects caused by the presence of stray magnetic fields.

Once the atoms are prepared a standing-wave, light pulse of specific polarisation illuminates atoms in the first interaction region. The pulse is aligned along the direction of propagation of the atoms and is chosen such that it is resonant with an open atomic transition and the pulse-length is shorter than the natural lifetime of the transition in question. A novel source of phase-coherent laser pulses is being used for the generation of the intense pulses of $200W$ and $15ns$ duration. [4]. For this purpose, light from a Ti:Saph laser is stored and enhanced in a high-finesse resonator. By applying short, radio-frequency pulses to an intracavity acoustooptical modulator the entire optical energy within the cavity can be extracted. By multiple absorptions and stimulated emissions of photons, coherent beams with different momenta (in units of $2\hbar k$), but the same internal state, are generated. Thus, the number of beam components in the ground state that contribute to the interference signal is no longer limited by the internal atomic structure, but rather by the available laser power and this, in turn, can be very large. Those components that remain in the excited state decay spontaneously.

A multiple-beam interferometer can be realised by using a sequence of three such standing-wave pulses. The interference signal is observed by scanning the delay of the third pulse and measuring the fraction of the atomic wave-packet left in the ground state via the fluorescence scattered onto a photo-multiplier tube . In order to ensure that only those atoms in the $m_F = 0$ ground state sublevel are detected, a microwave pulse tuned to the $F = 3, m_F = 0 \rightarrow F = 2, m_F = 0$ transition is applied. A blow-away optical pulse is then applied from the $F = 3 \rightarrow F' = 4$ levels. A second microwave pulse transfers the atoms back from $F = 2, m_F = 0 \rightarrow F = 3, m_F = 0$ and these are then detected.

Some important aims of this work include precise measurements of the photon recoil energy of rubidium and of physical values associated with gravitation.

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