Acceleration of ultracold atoms : measurement of h/M_A

S. Guellati[2], C. Winisdoerffer[1], C. Schwob[1], B. Grémaud[1], F. Nez[1], L. Julien[1] and F. Biraben[1]

[1] *Laboratoire Kastler Brossel, Ecole Normale Supérieure et Université Pierre et Marie Curie*
4 place Jussieu, 75252 Paris cedex 05, France
Tel 33-1-44277248, Fax 33-1-44273845
[2] *Institut National de Métrologie-Bureau National de Métrologie*
292 rue Saint Martin, 75141 Paris cedex 03, France

We present here the development for a new experiment with ultracold atoms. The purpose is to measure the atomic recoil frequency shift of photons absorbed or emitted by an atom. From the measurement, one can deduce the ratio $\frac{h}{M_A}$ between the Planck constant and the mass of the atom.

An aim of our experiment is to measure the fine structure constant α. The value of α can be extracted from different measurements in large field area (see [1] for a review of these measurements). The relative uncertainties of these measurements are in the order of 10^{-8}, but with a total dispersion of about 3×10^{-7}. So it is interesting to use another method to determine α with an uncertainty of 10^{-8}. The relationship between α and the $\frac{h}{M_X}$ ratio is :

$$\alpha^2 = \frac{2R_\infty}{c} \times \frac{A_r(X)}{A_r(e)} \times \frac{h}{M_X} \tag{1}$$

where R_∞ is the Rydberg constant, $A_r(X)$ is the relative atomic mass of the atom X with mass M_X and $A_r(e)$ the relative atomic mass of the electron. The relative atomic mass $A_r(X)$ is the ratio of the mass of the atom X and the atomic mass constant [1]. This method can be used for neutron or neutral atoms. The measurement of h/M_{Cs} using atom interferometry is in realization in S. Chu's group [2]. We have proposed another method using cold atoms to measure h/M_{atom} [3].

With magnetic trapping and laser cooling methods, the atomic velocity can be reduced to few times recoil velocity (v_r) or even less than recoil velocity. If the width of the atomic velocity distribution is narrower than v_r, the recoil transferred to the atom when absorbing a photon can be directly measured. The absorption of a photon leads to an increase of $\frac{h\nu}{c}$ (the photon momentum). But, as the spontaneous emission takes place in a random direction, the total momentum transferred to the atom is not well defined. A way to solve this problem is to submit the atom to Raman transitions between the two hyperfine structure levels of the ground state in the case of an alkaline atom. We choose the geometrical situation where the atom interacts with two counterpropagating beams detuned far from atomic resonance. The atom carries out a transition between the two states via absorption from one wave and stimulated emission into the other one. The transferred momentum, equal to $\frac{h(\nu_1+\nu_2)}{c}$ (where ν_1 is the first beam frequency and ν_2 the second beam frequency), is perfectly well defined. The Raman transition is velocity selective and, as the natural width of the involved levels is almost equal to zero (hyperfine sublevels of the ground state), it is possible to select a velocity class as narrow as we

want. Then this velocity class is accelerated with a succession of Raman transitions so that the atom acquires a large number of times the quantity $\frac{h(\nu_1+\nu_2)}{c}$ in the atom frame (here the Raman transitions involve only one hyperfine structure level, they change the atomic momentum and its kinetic energy, but not the internal atomic state). To realize the Raman transitions, the frequency ν_1 is fixed while ν_2 varies linearly with time.
The atom is submitted to gravity. To avoid influence of gravity on the atomic momentum in the laser beams direction, the Raman beams should be horizontal. In this configuration, the number of Raman transitions is limited by the gravity and the optical power of laser beams to some few tens [4]. To have a long interaction time, a solution is to adopt a geometry with vertical beams. In this case, the atomic momentum varies both because of gravity and Raman transitions. This leads to a much more complicated atomic motion except if the force due to Raman transitions exactly compensates the gravity. This condition is verified when the atom is placed in a vertical standing wave. The atom is initially motionless. It starts to fall because of gravity. As it acquires the momentum $-\frac{h\nu}{c}$, it may carry out a Λ transition by absorbing a photon from the up-propagating wave and emitting a stimulated photon in the down-propagating wave. Its momentum is then equal to $+\frac{h\nu}{c}$. So, because of the gravity, the atomic momentum varies between $-\frac{h\nu}{c}$ and $+\frac{h\nu}{c}$. The time required for this oscillation is equal to $\frac{2h\nu}{cM_Ag}$ (g notes the local acceleration of gravity). This process can be repeated as long as the atom stays in laser beams, the limitation is given by their transverse motion. This periodic atomic motion is known as Bloch oscillations in the solid-state approach.
Our experiment deals with the realization of Bloch oscillations of ultracold atoms in a vertical standing wave. We have chosen atomic rubidium for two reasons. As it has two stable isotopic forms, the experiment can be carried out with two "different masses" easily. It can be subrecoil cooled in 3D by Bose Einstein condensate method leading to a small atomic transverse motion with respect to Raman beams direction. The experimental steps are the following ones:
- cooling of atomic rubidium in a magneto optical trap and an optical molasse.
- selection of an initial velocity with a velocity selective Raman transition between two hyperfine structure sublevels (we should define the initial time and consider the falling velocity classes).
- turning on the standing wave: the atom makes about 1000 Raman transitions.
- measurement of the final atomic velocity with a velocity selective Raman transition.
With these measurements, it is possible to deduce the Bloch oscillations period $\frac{2h\nu}{cM_Ag}$ and the $\frac{h}{M_A}$ ratio. With reasonable parameters, it should be possible to obtain a relative uncertainty of a few 10^{-8} on this ratio. We will present the development of this experiment.

[1] P. Mohr, B. Taylor, *Rev. Mod. Phys.* **72** (2000).
[2] B. Young, M. Kasevich and S. Chu, *Atom Interferometry* (Academic Press, New York, 1997).
[3] C. Schwob, L. Masson, B. Grémaud, S. Guellati, F. Nez, L. Julien and F. Biraben, *Proccedings of COLLOQ 6*, Bordeaux, France (septembre 1999).
[4] E. Peik, M. Ben Dahan, I. Bouchoule, Y. Castin, C. Salomon, *Phys. Rev. A* **55** 2989 (1997).