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Detection of optical resonances by observation of fluorescence light emitted from a fast atomic beam when optical pumping occurs (*)

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Résumé. — La sensibilité de la méthode de détection des résonances optiques par observation de la fluorescence émise par un jet rapide en excitation laser collinéaire est bien souvent limitée par le pompage optique. Nous proposons ici de tirer parti de ce pompage optique pour observer les résonances optiques en les détectant à l'aide d'un second faisceau laser presque collinéaire.

Abstract. — The sensitivity of the method of detection of optical resonances by observation of the fluorescence light emitted from a fast beam excited by a laser in collinear geometry is often limited by the optical pumping. In our method, we propose to take advantage of the optical pumping process to detect optical resonances by using a second laser beam in almost collinear geometry which acts as a detector of optical pumping.

Two methods have been used to measure, by optical spectroscopy, the hyperfine structures and the isotopic shifts of isotopes produced as ion beam by a mass separator on line with an accelerator. In the first one the ions from the mass separator are stopped and reevaporated as neutral atoms in order to form an atomic beam [1, 2] or a vapour [3]. It has been successfully applied to alkalis and mercury atoms. The sensitivity of this method is much lower when it is transposed to other elements. In the second one [4, 5, 6], recently carried out, one uses directly the output ion beam of the mass separator, or an on line ion beam neutralized by charge transfer collision inside an alkali vapour cell [6]. With collinear geometry for laser excitation the interaction time is long enough to allow the use of low laser intensity. Furthermore due to the velocity bunching phenomenon occurring in accelerated beams the ultimate resolution given by the natural linewidth can be approached. With this method all atoms initially produced are used for the measurement whereas in the preceding ones [1, 2], the formation of an atomic beam out of a vapour imposed a collimation which reduces the number of atoms available for the measurement by a factor 10^6.

When one detects the fluorescence light emitted by the excited atoms the sensitivity of the method is limited by geometric factors depending on the detection scheme used, by the quantum efficiency of the photomultiplier, etc... Nevertheless the sensitivity is still very high provided there is no optical pumping process.

Indeed in this case the number of fluorescence photons emitted from the atomic beam excited by a collinear excitation is independent of the laser power. This number depends only on the number of atoms in the beam and on the branching ratio which characterizes the pumping. The more the laser power increases, the more the fluorescence photons, in constant number, are emitted from a limited zone, where the interaction between light and atoms begins. In the case of collinear excitation of an atomic beam obtained by neutralization of the ion beam, this zone is unfortunately inside the charge exchange cell where, for practical reasons, one cannot detect the fluorescence light. Under these conditions the fluorescence light is detected further downstream and one has to optimize the laser power to obtain a maximum of fluorescence light in the detection zone.

For a length Δx of the detection zone, located at a distance x₀ (x = 0 corresponds to the beginning of light-atom interaction), it is readily calculated that there is an optimal laser power allowing a maximum of fluorescence light, at least as soon as x₀ is larger than the distance travelled by the atoms during

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a lifetime of the excited states \(^1\). Furthermore this maximum of fluorescence light, which is at best of the order of a few photons per atom, increases as \(\Delta x / x_0\). It is therefore interesting to increase \(\Delta x\) to approach \(x_0\); but this is achieved only at the expense of an increase of stray light and of technical difficulties of collecting the fluorescence light. The distance \(x_0\) cannot be reduced due to the presence of the charge exchange cell.

When one is forced to use a geometry where \(\Delta x / x_0 \ll 1\) the number of fluorescence photons collected is much smaller than the number of fluorescence photons emitted along the length of the atomic beam. In this case, to retain the sensitivity of the method, it is preferable to try to detect this optical pumping instead of enduring its disadvantages. Because of the high velocity of the atoms it is not possible to use the magnetic deflection method as in \([1]\); we therefore propose to detect the optical pumping induced by the laser beam A by a second laser B in almost collinear geometry (Fig. 1). In this case the laser intensity is more effectively used than in the case of perpendicular excitation because the interaction time is longer and the absorption lines are only slightly widened by Doppler effect.

Let us suppose that the initial level is decomposed only into two sublevels equally populated \((i, j)\), connected to the same excited level \((e)\). In the absence of laser A, in a first step one tunes the frequency of laser B to either one of the resonant frequencies \(i \rightarrow e\) or \(j \rightarrow e\), by detecting at low resolution the fluorescence light; then one keeps this frequency locked, for example on the transition \(i \rightarrow e\). And in the final step, the analysis at high resolution, one scans the frequency of the collinear laser A.

When the variable frequency of the collinear laser A is tuned to the same transition, along the beam the atoms are transferred to the sublevel \(j\) before reaching the observation zone and the intensity of the fluorescence light detected at \(I\) decreases. On the contrary when the frequency of the laser A is tuned to the transition \(j \rightarrow e\), the atoms are gradually transferred to the sublevel \(i\) and the intensity of the fluorescence light detected increases. One observes then negative and positive resonances over a background as in method [1]. One can also consider the detection of fluorescence light on a zero background. In this case the laser light B is sent back on the atomic beam under the same incident angle and one detects the fluorescence light at \(II\). In the absence of laser A, the fluorescence light detected at \(II\) is much weaker, or at limit zero, because all the atoms are pumped out of the sublevel \(i\) at \(I\). When the frequency of the laser A is tuned to the transition \(j \rightarrow e\), between \(I\) and \(II\), the atoms are transferred back by optical pumping to the sublevel \(i\) and the fluorescence signal appears on a zero background.

The intermediate zone between \(I\) and \(II\) can also be used to induce magnetic resonance transitions as in \([7]\) or simply for the determination of nuclear spin provided a suitable choice of polarization is used as in \([1]\).

In the proposed scheme the laser A can be of low intensity but with extended scanning range which is necessary in the measurement of isotopic shift for example. This is actually achieved. The laser B, can be a broad band laser, but its intensity should be of the order the intensity needed to saturate the transition, in the limited interaction zone (about 3 cm), i.e. during an interaction time which is only of a few lifetimes.

References

\[\text{\cite{2} H\textsc{uber}, G., T\textsc{ouchard}, F., B\textsc{üttgenbach}, S., T\textsc{hibault}, C., K\textsc{lapisch}, R., L\textsc{ijberman}, S., P\textsc{inard}, J., D\textsc{uong}, H. T., J\textsc{uncar}, P., V\textsc{ialle}, J.-L., J\textsc{acquiont}, P. \textsc{et P\textsc{esnelle}, A., Phys. Rev. Lett.} 41 (1978) 459-462.}\]
\[\text{\cite{3} E\textsc{kström}, C., L\textsc{indgren}, I., I\text{ngeman}, S., O\text{lsmats}, M. \textsc{et Wannberg}, G., \textit{Phys. Lett.} 60B (1976) 146-148.}\]