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ATOMS IN CROSSED ELECTRIC AND MAGNETIC FIELDS

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Résumé - Nous avons enregistré le spectre d'excitation de l'atome de sodium placé dans deux champs perpendiculaires, électrique et magnétique. La comparaison des états proches de \( n = 11 \) et des estimations théoriques des positions de raies est bonne. La comparaison est moins bonne en ce qui concerne l'amplitude des raies. La divergence entre les résultats experimentaux et la théorie simple de l'approximation de Coulomb peut être attribuée à l'influence non négligeable de l'état 12p voisin. Ces résultats signifient que, pour la première fois, le "m-mixing" des états liés a été mis en évidence. L'effet dominant du "m-mixing" a été de rendre possible l'accès à un nombre accru d'états de Rydberg par voie optique. Ces états sont en effet inaccessibles en présence du seul champ électrique, ou magnétique, à cause des lois de sélection sur \( m \).

Abstract - The excitation spectrum of atomic sodium in crossed electric and magnetic fields has been recorded. Data for states near \( n = 11 \) are found to be in good agreement with theoretical estimates of line positions. The agreement with estimates of line strengths, however, is only fair. The lack of complete agreement between simple hydrogenic theory and experiment can be traced to a breakdown of the assumption that the influence of the nearby 12p state is negligibly small. The significance of this experiment is that, for the first time, clear evidence of m-mixing between bound states has been obtained. The dominant effect of the m-mixing has been to make accessible optically many Rydberg states. These states in the presence of electric or magnetic fields alone would not have been accessible because of selection rules on \( m \).

Atoms in crossed electric and magnetic fields are of particular interest because of a recent suggestion by Rau that the potential energy surface for a Rydberg electron exhibits a double well structure. The double well arises from the Coulomb, Stark and diamagnetic terms of the Hamiltonian. In essence, the combination of fields provide a region, removed from the nucleus, in which the electron can be localized. This localization of the Rydberg electron by electric and magnetic fields, is analogous to the trapping of charged particles by the well-known configuration of fields employed by the Penning ion trap.

The experiment described here is a first attempt to explore the level structure of atoms in crossed fields. For the fields and energy range chosen only the Coulomb, Stark and paramagnetic terms of the Hamiltonian are significant. We do not expect to observe effects due to the double well here. The experiment is carried out using a thermal sodium atomic beam. Crossed fields are provided by a 4.5 kG permanent magnet and a parallel plate capacitor. Two pulsed dye lasers are used to excite Rydberg states stepwise via the 3\(^2\)F\(_{3/2}\)/2 intermediate level. The experimental geometry is indicated in Fig. 1. The laser polarization axis is parallel to the electric axis. Excited atoms are detected by resonance fluorescence to lower levels.

The experimental excitation spectrum is shown in Fig. 2. Also shown is the result of calculations of line positions and strengths. Agreement of line positions is good, while agreement of line strengths is only fair. Observe that the worst comparison of line strengths is at the high energy side of the spectrum nearest the 12p level. We believe that this is due to the fact that the 12p state is not
included in our calculation. The calculation, which involves diagonalizing the energy matrix, uses a truncated basis of the 117 degenerate sublevels of the \( n = 11 \) manifold in sodium. (The \( 11s \) (\( m = 0 \)) and \( 11p \) (\( m = 1, 0, -1 \)) levels, which have non-trivial quantum defects, are not included in the diagonalization.) The quantum defect of the \( 11d \) state is taken to be zero. The effects of spin-orbit coupling are ignored. Shifts due to electron spin are added to the calculation after the diagonalization of the spin-free problem.

By tracing the origin of several of the prominent peaks in the data below it is evident that high \( m \) states are present. Unfortunately, there is still a high level of \( m \) degeneracy here so that while evidence of states having \( m \geq 3 \) is obtained, individual high \( m \) states are not resolved. One further experiment suggested by this work is a study of the case where the electric and magnetic field are at a 45° angle with respect to one another. Here, all 234 (117 x 2) levels of the \( n = 11 \) manifold are expected both to be accessible and individually resolvable. Later experiments will consider also effects of electron trapping.

References


FIG. 1 Experimental geometry (top view).

FIG. 2 Excitation spectrum of \( n = 11 \) sublevels. The \( 12s \) and \( 12p \) levels are off-scale. Below are theoretical predictions of line positions and strengths.