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Experimental setup for investigations of two-colour multiphoton ionization of alkali atoms

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An experimental setup for investigations of two-colour multiphoton ionization in alkali atoms is described. It consists of two tunable dye lasers pumped by the Nd:YAG nanosecond laser, source of atomic beam and ion detection system. The setup has been tested on two-colour three-photon ionization of potassium near the $4S_{1/2} \rightarrow 4P_{3/2} \rightarrow 5D_{3/2,5/2}$ resonance.

1. Introduction

Optical double resonance provides a simple technique for studying intense field effects on atomic transitions. Laser induced ionization is of considerable interest from the standpoint of both understanding the mechanism involved and practical applications, *i.e.*, the separation of isotopes, or the detection of trace amounts of impurities. As is well known, an atomic transition undergoes Stark splitting under the influence of a resonant or near-resonant intense field. The efficiency of ionization strongly depends on the detuning of each of the exciting beams of the resonance and therefore the information about the Stark shift can be obtained. Experimental conditions for such an experiment are determined by the splitting effect which depends on both detuning and the field intensity. Doppler broadening can be eliminated if the ionization is realized in the atomic beam. An atomic beam source should generate a beam of pure atoms free of impurities and dimers. Usually, excitation is realized by tunable lasers which emit narrow lines. One of the laser beams should be strong enough to modify the levels. The tuning step order is required to be comparable to the bandwidth of the laser. For the experimental determination of the photo-ionization efficiency it is necessary to control the density of the atoms and to measure and control energy, wavelength and the width of the exciting radiation.

In this paper, we describe the experimental setup for the two-colour multiphoton ionization of alkali atoms. The presented system is very flexible and enables investigation of different transitions in alkali atoms. It was tested by measuring the ionization of potassium.

2. Exciting source

Two tunable dye lasers were used as an exciting source. Both were pumped by the second harmonic of Nd:YAG pulse laser operating at the repetition rate of 15 Hz.

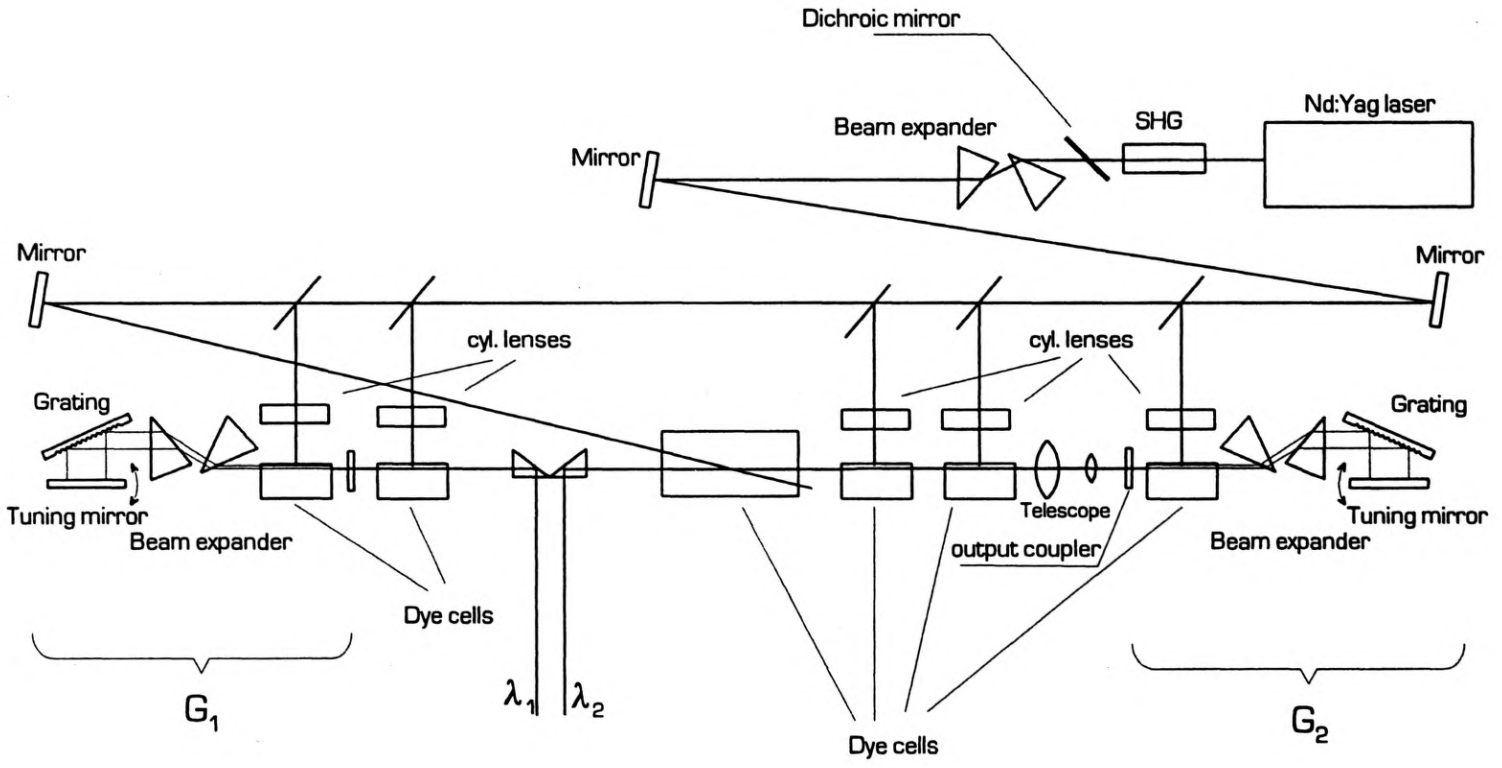

Fig. 1. Schematic outline of the excitation source

The fundamental beam of 100 mJ energy in 5 ns pulses was frequency doubled by a temperature controlled KDDP crystal. It allowed us to obtain an energetically stable pulse of the 533 nm wavelength. A biprism system [1] was applied to expand the second harmonic beam in the horizontal plane up to approximately 2 cm, so that the excitation of all transversely pumped dye cells was homogeneous. Dye laser generators were arranged in the way described by RACZ *et al.* [2]. A two-prism beam expander combined with a grazing-incidence (of high incidence angle) grating beam expander was used to achieve a narrow band operation. The resonator was closed by a totally reflecting mirror which was also used for tuning (see Fig. 1). The configuration described above has the advantage of ensuring simultaneously a narrow band and a high precision of tuning. The grating used in the experiment was a ruled reflection grating, 1300 lines/mm, made by Carl Zeiss Jena. The spectral width of the laser line was 0.6 cm^{-1} at the wave number of 17240 cm^{-1} (wavelength of 580 nm) and was completely determined by resonator configuration. The rotation of the tuning mirror was controlled by a step motor driven by a Step Motor Driver-571 CAMAC (Polon, Warsaw). The accuracy of the tuning was 1.0×10^{-2} nm and 1.2×10^{-2} nm per one motor step at the red and yellow range, respectively.

P2CDOMAT and IPC 140M dyes, synthesized by Soroka (Szczecin University), were used to obtain the wavelength tuning ranges from 550 to 645 nm and from 720 to 780 nm, respectively. The properties of the dyes have been described by KOTOWSKI *et al.* [3]. The laser beam from generator G2 (operating in the yellow range) was collimated by a two-lens telescope and was next amplified in three steps. At the first two steps the amplification was realized in two transversely pumped cells and at the third one in a cell pumped longitudinally. Laser G1 operated in the red and one transversely pumped cell was used as an amplifier in this laser. Both exciting beams were aligned and put together into the vacuum chamber, where they were focused at the atomic beam. The atomic beam was perpendicular to the direction of the light. Such a configuration eliminates the Doppler broadening of the spectral line.

3. Atomic beam source and ion detection system

The source of the atomic beam and the ion detection system were mounted in the stainless steel vacuum vessel. A high vacuum, free of impurities, was ensured by the use of an ion-sorption pump. The operation pressure was of 6×10^{-5} Pa, which means that free mean path of the atoms was about 30 times the length of the vacuum vessel. So one can neglect the collisions of the potassium atoms with the rest gases in the vacuum.

A two-stage oven with a multicollimator effusion nozzle was applied to produce an alkali atoms beam. This construction, described in detail by STRYŁA [4], allowed us to achieve the density of the atoms of about 2×10^{12} atoms/cm^2 in the exciting spot. At the same time the concentration of the dimers was reduced by two orders of magnitude in comparison to that which was attained when a one-stage oven working in similar conditions was used. Atoms in the beam flew vertically upwards, perpendicular to the exciting beam.

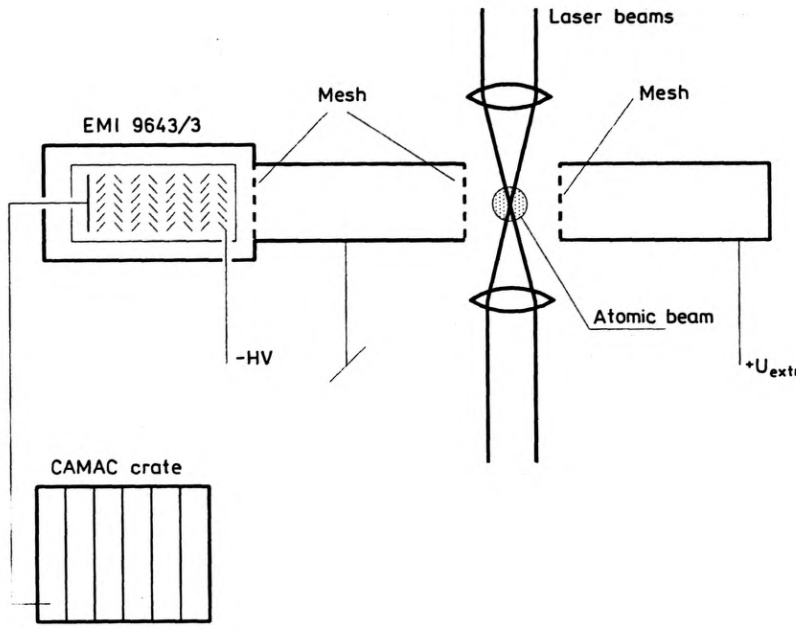

Fig. 2. Ion detection unit

The ions and electrons were extracted from the exciting spot by an electrostatic field perpendicular to the laser and the atomic beams alike. The homogeneous field was obtained using two hollow electrodes that were placed on both sides of the laser beam focus (see Fig. 2). The cylinders were closed in fronts by a fine steel wire mesh with 3600 holes/cm^2 characterized by 75% transmission. The anode at positive potential U_{extr} caught electrons. Ions produced at the focus were accelerated by the electrostatic field towards a cathode of zero potential. The ions that passed the mesh came into the field free area working as a Time of Flight Spectrometer. The free flight distance was big enough to separate the signal of the single K^+ ions from the signals of K_2^+ dimers and other noises. The two-step oven used in the experiment produced such a small amount of dimers that the signals of K_2^+ were not observed. The field-free area was closed on the other side by the steel mesh, the same as the one at the input. This mesh was also on zero potential and it worked as an electric shield which separated the spectrometer from the high negative potential of the first dynode of the electron multiplier EMI9643/3. Ions leaving the spectrometer were accelerated behind the second mesh towards the multiplier. This acceleration was necessary to achieve high efficiency detection, according to the working parameters recommended by the producer of the multiplier (Thorn-Emi Electron Multipliers data sheet). Figure 3 shows the amplitude of the signal versus the extracting potential for different potentials at the multiplier (so for different accelerating potentials). An extracting potential of 300 V and an accelerating potential of 2.3 kV are the best working conditions of the multiplier.

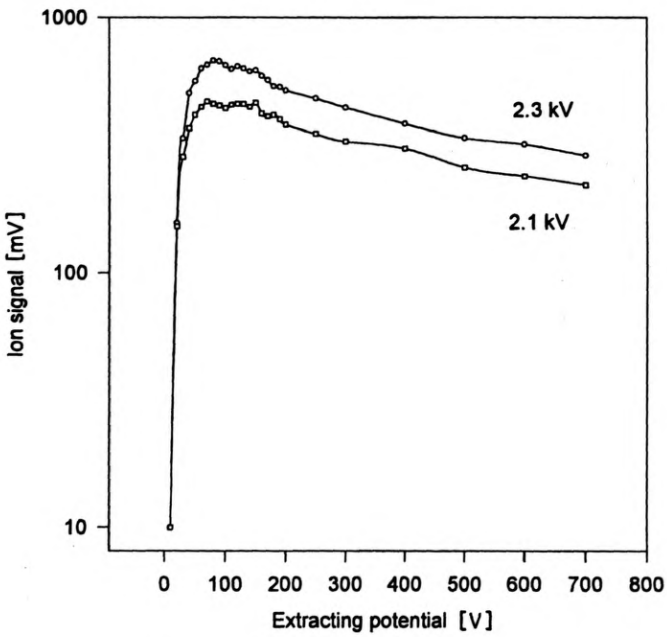

Fig. 3. Ion yield versus extracting potential

The signal from the multiplier was amplified by an active filter amplifier CAMAC, type 1101 (Polon, Warsaw). The amplification gain could vary to match the amplifier output signal to the range of the input signals of an A/D converter, type 712, which was used at the next step. If averaging of the signal was necessary for collecting data, the Amplitude Spectrum Buffer type BSWP 200A was used. The whole CAMAC system was controlled through a personal computer using the ADC2 program written in Pascal. The program allowed us to tune dye lasers by driving step motors and perform data accumulation.

4. Experimental results

The system thus constructed was tested on a three-photon ionization of atomic potassium. Atoms were excited from $4S_{1/2}$ level to $5D_{5/2}$ level using two laser beams being in resonance with the $4S_{1/2}-4P_{3/2}$ and with the $4P_{3/2}-5D_{3/2,5/2}$ transitions for the first and the second laser beam, respectively (see Fig. 4). The spectral widths for the spontaneous transitions from $4P_{3/2}$ and 5D levels were 2×10^{-4} cm^{-1} and 10^{-5} cm^{-1}, respectively, and therefore the shapes of the resonance lines were completely determined by the laser beam widths and by the modification of the levels by the exciting beams. A laser pulse of the energy of 4 μJ had the wave number of 13043 cm^{-1} and caused the first transition. The second pulse of the energy of 250 μJ had the wave number of 17143 cm^{-1} and it excited

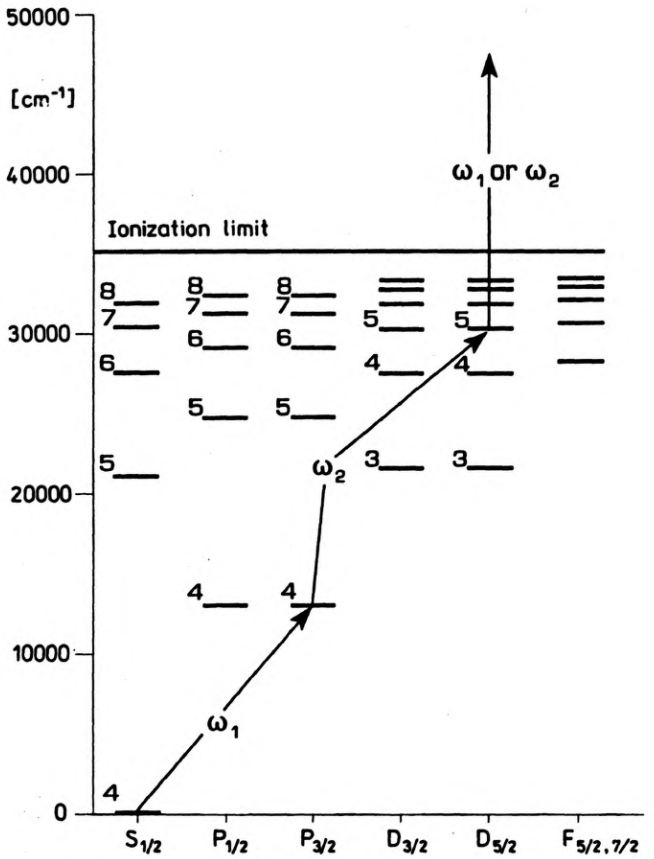

Fig. 4. Diagram of the energy levels of potassium with transitions involved

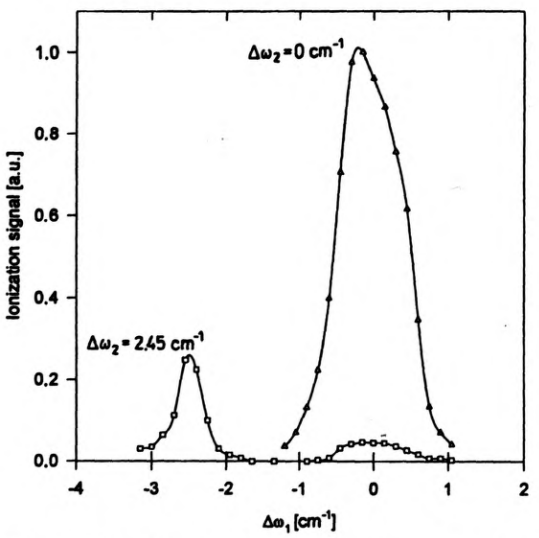

Fig. 5. Dispersion characteristics of the ion yield for different detunings of the strong laser ($\Delta\omega_2$)

atoms from the middle to the upper level. Ionization occurs from $5D_{5/2}$, being caused by any of the incident photons. Ionization from excited levels is known to be photon energy dependent [5], so the probabilities of the excited atom being ionized due to the photons of frequencies of ω_1 and ω_2 are different. However, in our experiment the intensities of the beams are substantially different, so one can state that the ionization occurs mainly with the photon of frequency ω_2 as the third in the cascade. Ionization efficiency was investigated as a function of the detuning of each of the laser beams of the resonance. For the fixed frequency of the second laser the first one was tuned to obtain a resonance curve (see Fig. 5). The frequency of the second laser was changed in several steps from resonance and for each of these frequencies the ionization was probed by the first laser. Two of the curves obtained are presented in Fig. 5. The first curve was obtained when the second laser was in resonance. The second curve shows the ion yield as a function of the probe laser detuning frequency when the frequency of the second laser was 2.45 cm^{-1} of the resonance.

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