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# PERTURBATION OF ATOMIC LEVELS NEAR TO THE IONIZATION THRESHOLD IN HIGH INTENSITY LASER FIELD

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ABSTRACT

The general multiphoton probability versus light intensity dependence of the triplet metastable He atoms was measured in case of four-photon resonances very near to the ionization threshold / about 600 $cm^{-1}$ /. Big value of the Stark shift was observed.

РЕЗЮМЕ

Общая зависимостъ пятифотонной ионизации атома гелия, находящегося в триплетном метастабильном состоянии, измерялась в случае четырёхфотонного резонанса с состоянием $13^3S$, расположенном очень близко к границе ионизации /~600 $см^{-I}$/. Наблюдалась большая величина Штарковского сдвига этого состояния в световом поле.

KIVONAT

Hélium metastabil állapotából induló ötfotonos ionizáció általános intenzitásfüggését mértük közbenső négyfotonos rezonancia esetén. A rezonancianivó / $13^3S$ / igen kis energiatávolságra van az ionizációs határtól. A rezonancianivó Stark-eltolódására nagy érték adódik.

The multiphoton ionization probability of atoms is in lowest-order approximation proportional to the square of the absolute value of the electric dipole / P / transition matrix element of order $k_o$

$$W \sim \left| \sum_{\ell,\ldots,n} \frac{\langle f|P|\ell\rangle\langle \ell|P|m\rangle\ldots\langle n|P|i\rangle}{\left[E_\ell - E_o - (k_o-1)\hbar\omega + i\gamma_\ell\right]\ldots\left[E_n - E_o - \hbar\omega + i\gamma_n\right]} \right|^2 \qquad /1/$$

$E_r$, $E_o$ are energies of the r excited respectively that of the ground state: $\gamma_r$ is the level width where $r=1,m,\ldots n$. Consequently the multiphoton ionization probability is proportional to the power $k_o$ of the light intensity /I/ :

$$W \sim \alpha I^{k_o} \qquad /2/$$

$$k_o = \left\langle \frac{IP}{\hbar\omega} + 1 \right\rangle \qquad /3/$$

where $k_o$ is the number of quanta of energy $\hbar\omega$ absorbed during the ionization process of atoms having an ionization potential IP; $\alpha$ , the cross-section of the ionization is in $k_o$ order approximation constant:

$$\alpha \sim \left| \sum_{\ell,\ldots,n} \frac{\langle f|r|\ell\rangle\langle \ell|r|m\rangle\ldots\langle n|r|i\rangle}{\left[E_\ell - E_o - (k_o-1)\hbar\omega + i\gamma_\ell\right]\ldots\left[E_n - E_o - \hbar\omega + i\gamma_n\right]} \right|^2 \qquad /4/$$

In the case of $k < k_o$ photon resonance that is, when the energy of k quanta coincides with, or is near to, the energy of the r-th atomic states the field-free detuning

$$\Delta\nu_{ro} = E_r - E_o - k\hbar\omega \qquad /5/$$

is near to zero and the $k_o$ order approximation is not suitable for description of the dependence on the light intensity. Moreover, it becomes necessary to take into account the dependence of the energy / $E_r$ / and the width / $\gamma_r$ / of the resonance state / r / on the light intensity as an approximation of higher order :

$$E_r = E_{ro} + \Delta E_r(I) \qquad /6/$$

$$\gamma_r = \gamma_{ro} + \Delta\gamma_r(I) \qquad /7/$$

where $E_{ro}$ is the field-free energy of the resonance state / r / and $\Delta E_r/I/$ is an additional energy correction term depending on the light intensity. Similarly $\gamma_{ro}$ is the field-free level width and $\Delta\gamma_r/I/$ is generally the ionization broadening of the level /r/.

Consequently in resonance the ionization probability becomes a complicated function of the light intensity, and this function contains informations about the shifting and broadening of the atomic levels. By measuring dependence of the multiphoton ionization probability on the light intensity in the case of k-photon resonance, therefore, it should be possible to determine the shift and broadening of the k-photon resonance level in the light field. Clearly this approach is a new alternative to the older method of measuring onephoton absorption for the determination of the Stark shift and broadening in the light field.

In a simple case, when only one level /1/ is in resonance and the additional energy correction term depends linearly on the light intensity

$$\Delta E_1(I) = c_1 I \qquad /8/$$

/$c_1$ is the Stark constant of the level/ while the ionization broadening is smaller than the levelwidth, the dependence of the logarithm of the ionization probability on the light intensity and field-free detuning of the level can be given by a relatively simple expression :

$$\log W\left(I,\Delta\nu_1\right) = k_o \log I - \log\left\{\left(\Delta\nu_1+c_1 I\right)^2+\gamma_1^2\right\} \qquad /9/$$

The dependence of the ionization probability on the light intensity according to expression / 9 / is plotted for the numerical values of $c_1$ $\gamma_1$ indicated in the Fig. 1.

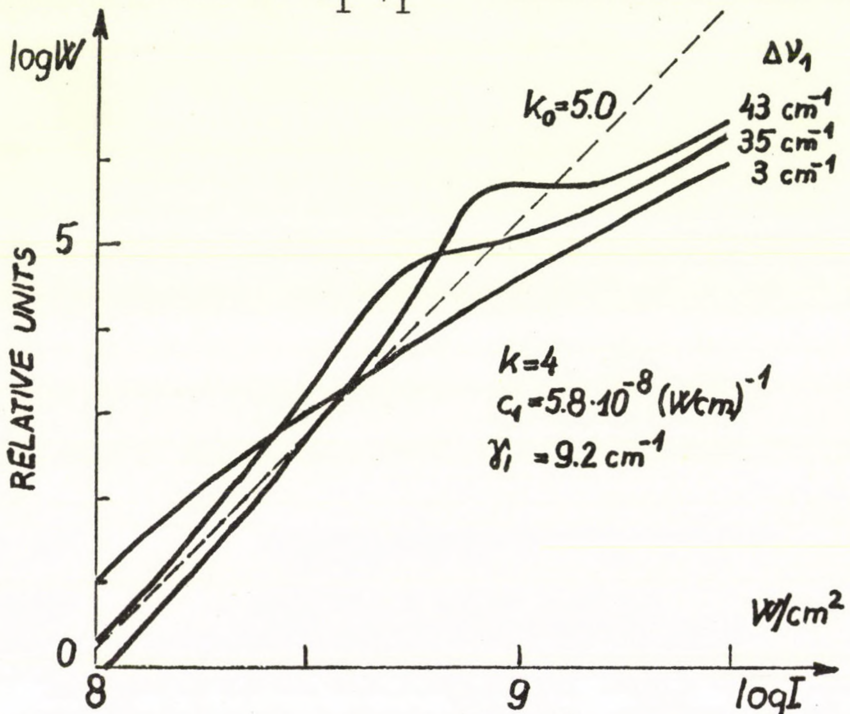


Fig. 1
The ionization probability dependence on the light intensity according to the expression /9/. The parameter is the field-free detuning.

It should be noted that the probability displays local maximum at large detuning of - for instance - the laser frequency. The probability normally depends on the detuning of the laser frequency at low light intensity / before the cross points of the curves / ; in other words, the smaller the detuning the larger the probability. But at high intensities this dependence is the reverse.

The experimental realization of this simple case is the five-photon ionization of the triplet metastable helium atom by the $Nd^{3+}$ glass laser radiation with frequency tuning. The energetic scheme of atom and the energies of the ionizing quanta are plotted in the Fig. 2.

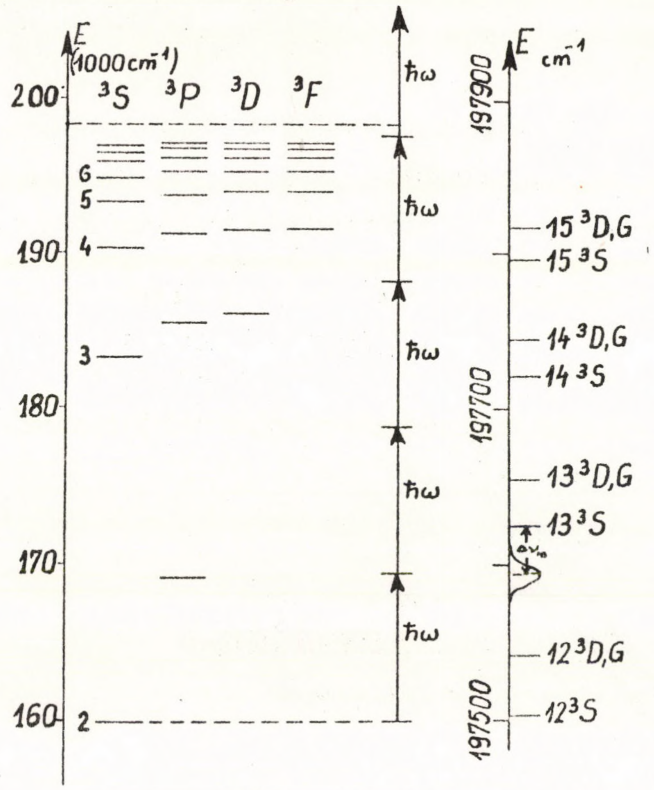


Fig. 2.
The energetic scheme of the triplet system of the He atom and the energies of the light quanta in the ionizing process.

The field-free detuning of the $13^3S$ state wich is in four--photon resonance can be changed by the laser frequency tuning. The position of the energy of the fourth quantum relative to the $13^3S$ state is also plotted in this figure in enlarged scale. The energy distance of this state from the ionization threshold is about 600 $cm^{-1}$ and it is very much smaller than the energy of the laser quanta / 9430 $cm^{-1}$ /. Therefore the one-photon ionization rate is small, and consequently the level broadening is negligible.

The experimental set-up can be seen in the Fig. 3. The laser was Q-switched by a rotating prism and its frequency was tuned by rotating a Fabry-Perot interferometer - with 50 $\mu$ distance between the plates - within the resonator of the laser itself. After frequency doubling by KDP the frepuency of the

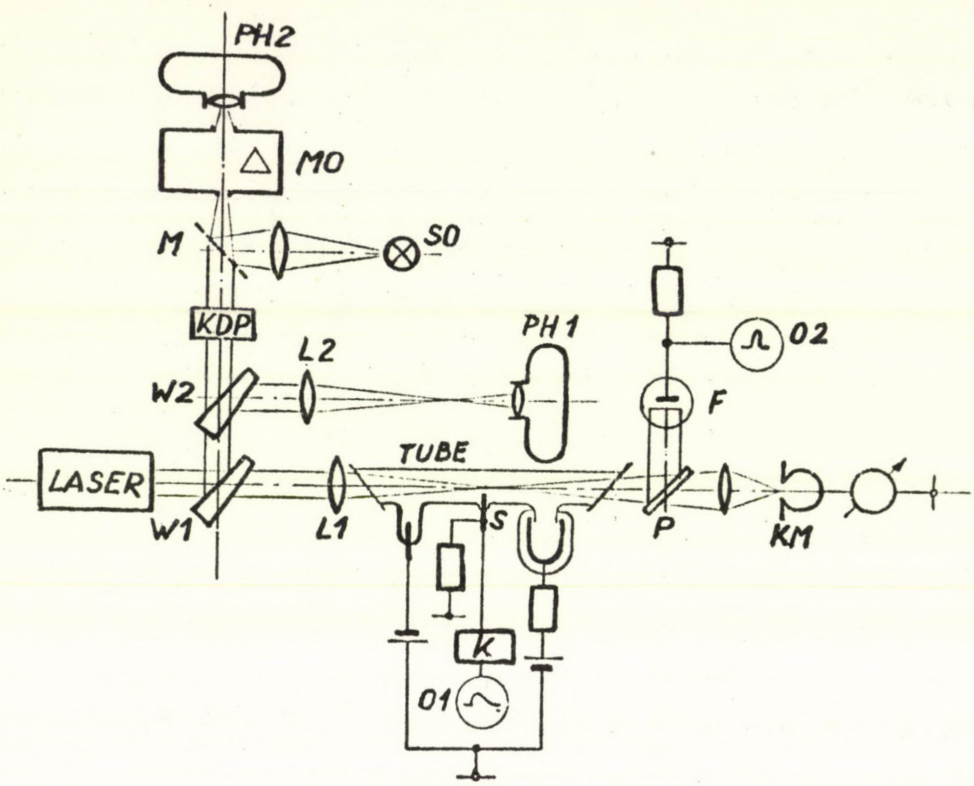


Fig. 3
The experimental set-up.

radiation was measured by spectrograph / MO / photographing the laser line together with the 5350 Å line of a Tallium light source / SO / with the camera / PH2 /. / $W_1$, $W_2$ are glass wedges /. The spatial distribution of the laser radiation in the focal point of the lense /$L_1$/ was measured by photographing the spatial distribution with the camera /PH1/ in the focal point of a second lense / $L_2$ / similar to the first. The time distribution and energy of the laser was measured by fast photodiode / F / with a high-speed oscillograph and by calorimeter / KM /, respectively. The peak light intensity can be calculated using the measured spatial distribution, time distribution and energy of laser pulse.

The radiation was focused by the lense / $L_1$ / into the middle of a glass tube /of about 11 mm diam. / containing a low-current / I=3mA / gas discharge and hence the metastable atoms. The ions were detected with a Langmuire probe placed 1 mm from the axis of the tube. The laser pulse creates excess ions and electrons in the focal volume, near to, or immediatelly before the probe, of the 400 mm focal length focusing lense. The excess ions and electrons drift as pulses of charge under the influence of the field of the gas discharge and simultaneously diffusion takes place towards tho wall i.e. in the direction of the probe. Ions reaching the probe cause an increase of the density of the ions in the double - layer of the probe, hence there is a rise in the current and a voltage pulse appears on the load resistor. The amplitude / V / of the pulse depends on the maximal value of the ion density created by the laser radiation that is, on the maximal value of the probability of the ionization, and consequently on the peak light intensity. In the experiment the dependence of the amplitude of the Langmuire probe pulses on the energy of the laser pulse was measured by placing liquid light attenuator before the lens $/L_1/$.

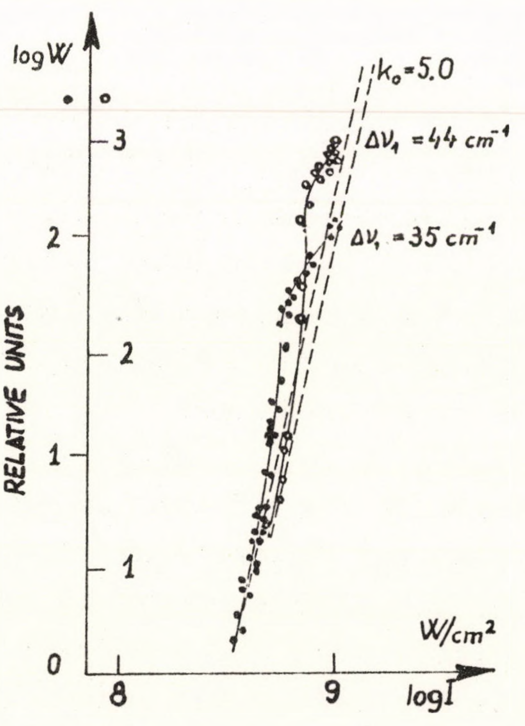


Fig. 4

The experimentally measured dependence of the ionization probability at different field-free detuning.

Fig. 4. shows two of the curves measured at different field-free detunings, the values of wich are noted in the figure. These curves clearly resemble to the theoretical curves plotted in Fig. 1. It is apparent that the $13^3S$ state is shifted into resonance down from the ionization threshold, because the higher the fild-free detuning the larger is the light intensity required to tune the level into resonance.

Summarising the result: It was possible to determine the Stark constant of the $13^3S$ state of the He atom by measuring the dependence of the five-photon ionization probability from the triplet metastable state. The observed value of the Stark shift was comparatively large, because the field of the laser radiation tuned the state having field-free detuning of 35 $cm^{-1}$ into resonance at $6 \cdot 10^8$ $Wcm^{-2}$ light intensity.

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