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LASER SPECTROSCOPY OF THE RYDBERG STATES OF THE INDIUM ATOM

Annotation

An experimental study of the main series of Rydberg np $^2P_{1/2,3/2}$ - states of the indium atom was carried out by the method of selective stepwise photoionization of atoms by laser radiation. According to photoionization spectra, quantum defects and fine structures of states are determined. Their dependence on the principal quantum number up to n = 53 has been studied. In the experiment, the inter-blit splitting of the spectrum np $^2P_{1/2,3/2}$ - states of the indium atom is al-lowed. It is shown that the dependence is well described by the ratio $\Delta E=5900/n^3$ cm^{-1} and is consistent with the hydrogen-like behavior of the atom.

Key words: highly excited state, Rydberg states, Rydberg electron, photoionization, photoions, spectrometer, gated integrator, quantum defects, fine structure.

ЛАЗЕРНАЯ СПЕКТРОСКОПИЯ СОСТОЯНИЙ РИДБЕРГА АТОМА ИНДИЯ

Аннотация

В экспериментальном исследовании основных серий состояний ридберг np $^2P_{1/2,3/2}$ атома индия методом селективной последовательной фотоионизации атомов лазерным излучением были получены спектры фотоионизации, определены квантовые дефекты и тонкие структуры состояний. Изучена их зависимость от главного квантового числа до n=53. В эксперименте была обнаружена межзонная расщепленность спектра состояний np $^2P_{1/2,3/2}$ атома индия. Показано, что эта зависимость хорошо описывается соотношением $\Delta E=5900/n^3$ см$^{-1}$ и соответствует поведению атома, подобному водородному.

Ключевые слова: высоко возбужденное состояние, состояния Ридберга, электрон Ридберга, фотоионизация, фотоионы, спектрометр, запираемый интегратор, квантовые дефекты, тонкая структура.

INDIUM ATOMINING RYDBERG HOLATLARINING LASER SPECTROSCOPIYASI

Annotatsiya

Indiy atomining np $^2P_{1/2,3/2}$ - holatlarning asosiy seriyalarining tajribaviy o'rganilishi lazer nurlari yordamida atomlarni tanlab, bosqichma-bosqich fotoionlash usuli bilan amalga oshirildi. Fotoionlash spektrlariga asoslanib, kvant defektlari va holatlarning nozik tuzilmalari aniqlandi. Ularning n (asosiy kvant soni) ga bog‘liqligi n=53 gacha bo‘lgan qiymatlari uchun o‘rganildi. Tajribada indiy atomining np $^2P_{1/2,3/2}$ holatlarining spektridagi diapazonlararo bo‘linishi imkoniyatiga ega bo‘ldi. Ko‘rsatilishicha, bu bog‘liqlik $\Delta E=5900/n^3$ sm^{-1} nisbati bilan yaxshi ta’riflanadi va atomning vodorodga o‘xshash xossalariga mos keladi.

Kalit so‘zlar: yuqori energiyali holat, Ridberg holatlari, Ridberg elektroni, fotoionlash, fotoionlar, spektrometr, qoplangan integrator, kvant defektlari, nozik struktura.

Introduction. Spectroscopy of highly excited states of atoms is an important area of atomic spec-troscopy. These include states with energies close to the atomic ionization threshold, known as Rydberg states. Such states can be effectively described in the single-particle approximation, in which one of the electrons, the so-called Rydberg electron, has a high energy and moves in the potential field of the atomic core. The core field is dominated by the monopole Coulomb potential, while the contribution of higher multipole components is relatively small. For this reason, the state of the Rydberg electron is close to hydro-gen-like, the difference from which is characterized by a correction to the principal quantum number of the Rydberg electron, called a quantum defect. Thus, it is the analysis of quantum defects in Rydber states that makes it possible to obtain information about the properties of the atomic core [1-3].

Results. If you look at the energy level and the general serial patterns of the elements of the main subgroup III (Al , Ga , In and Tl) of the periodic table, they are close to each other. Since everything refers to an element with one external p-electron. When the valence electron of these atoms is excited, one-electron spectra appear, which are characterized by the presence of doublet spectral lines [4-8]. The essential difference of these spectra from the spectra of alkaline or alkaline earth elements is that the main term is the term np $^2P_0$ rather than ns $^1S_0$. From the term np $^2P_0$ the sharp and diffuse series begin, i.e. np $^2P_0$ - ns ^2S and np $^2P_0$ - nd ^2D . It is these series that are observed in the absorption spectrum of atoms. The first members of the series represent resonant doublets. The value of the doublet splitting of the main term $^2P_0$ increases rapidly from Al to Tl . For Tl the value of the doublet splitting ($^2P_{1/2}$ - $^2P_{3/2}$) of the term is about 1 eV. The doublet splitting of the term ^2D ($^2D_{5/2}$-$^2D_{3/2}$) also increases from Al to Tl , but its absolute value is much smaller.

The second difference from the spectra of alkali or alkaline earth elements is that, along with the system of doublet terms resulting from the excitation of the p- electron, there are possible terms, quartet and doublet, arising from the excitation of one of the s-electrons. This term is the deepest excited term, the remaining terms of the nsn 2p configuration lie much higher, in most cases above the first ionization boundary ns $^{2'}S_0$.

As is known from theory, the energy states of an atom for different values of the quantum numbers n , l , and j are calculated using the Rydberg-Ritz formula [9-12].

$$E_{n,l,j} = -\frac{R_{In}}{(n^*)^2} = -\frac{R_{In}}{(n-\delta_{n,l,j})^2}. \quad (1)$$

where cm^{-1} [13]. The transition frequencies were calculated using the speed of light c=299792458 m/s. Quantum defects were found using the iterative formula::

$$\delta_{n,l,j} = z_{j,l} + \frac{\alpha_{l,j}}{(n^*)^2} + \frac{\beta_{l,j}}{(n^*)^4} + \frac{\gamma_{l,j}}{(n^*)^6} + \ldots \quad (2)$$

To calculate the quantum defect of levels c, it suffices to keep only the first two terms in the iterative formula (2). The least squares method was used to calculate the coefficients and for the P -terms of the indium atom.[14-15]

To calculate the fine splitting, we used a formula in the form of a polynomial containing odd powers of the ratio 1/n, starting from n^{-3} .

$$\Delta E_{nl} = \frac{1}{n^3}\left(A_l + \frac{B_l}{n^2} + \frac{C_l}{n^4} + \ldots\right). \quad (3)$$

Where A, B and C are constant values depending on the orbital quantum number. It is selected for each atom individually and, in our case, for the indium atom it was Å=5900.

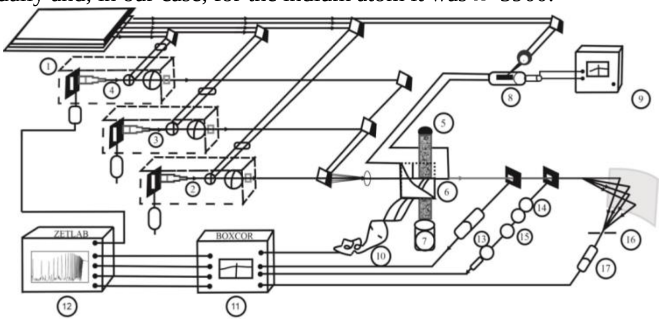

Figure 1. Scheme of the experimental setup.. 1 nitrogen laser; 2,3,4 - dye lasers; 5-atom beam; 6-electrodes; 7-atomizer; 8-discharger; 9-power supply; 10-VEU-1; 11-pulse signal averaging BOXCOR integrator; 12-multichannel recorder ZETLAB; 13-optics LSP galvanic lamp, 14-Fabry-Perot interferometer; 15-PM, 16-monochromator. 17-photodiode;.

The dye lasers were pumped by a pulsed nitrogen laser with a transverse discharge . Laser beams cross an atomic beam in vacuum between two electrodes, to which, after laser excitation and I, an electric field is applied from a pulsed voltage generator (PVG). The GVP was powered from a high-voltage direct voltage source. A gas-filled spark gap, which was triggered by nitrogen laser radiation, was used as a switch. Such a scheme makes it possible to form a single rectangular electric field pulse on a matched load . The ions that appeared as a result of the autoionization of Rydberg atoms by a pulsed electric field acquire momentum in the electric field in the direction of the field strength vector. The value of the velocity corresponding to this momentum is two orders of magnitude greater than the velocity of an atom in the beam ; therefore, the motion of the ion occurs in the direction perpendicular to the direction of motion of the atomic beam. Having reached the electrode with zero potential, the ions are drawn out through the slot in this electrode by the electric field of the cathode of the secondary electron multiplier (SEM). The ion signal from the wind turbine is fed to the pulse signal averager BOXCOR integrator and multichannel recorder ZETLAB.

The gated pulse integrator developed by us makes it possible to carry out continuous recording of the average values of the amplitude of the photoion signal pulses with the help of a recorder .

Of the dye laser radiation wavelength and tuning to the excited period were per-formed using a monochromator and a hollow cathode lamp. Simultaneously with the spectrum of the ion signal, the reference spectrum from the Fabry-Perot etalon was rec-orded. The scanning of the recorder is carried out synchronously with the rotation of the grating of the dye laser used in the last stage of excitation. The energy values of the Rydberg or autoionization states were measured by comparing the photoion spectra with the reference spectrum.

In a three-stage atomic excitation scheme, high-power radiation is required to satu-rate the selected transitions. In this case, a simple nitrogen pump laser was replaced by a two-volume nitrogen laser. In this case, the total generation energy doubled; was 20 mJ. Strictly identically manufactured laser chambers and electrical taps ensured the syn-chronous operation of two generating chambers within no worse than 1–2 ns. Studies of this laser have shown that it makes it possible to obtain two-frequency generation by filling two active volumes with different and working gases.

In general, the highly sensitive selective laser photoionization spectrometer devel-oped in this work has the following characteristics: the tuning range is 390–700 nm; emission line width - 0.01 cm^2 ; resolution -10^{12} ; selectivity at three stages at fines - 10^{15} ; sensitivity - one atom.

Experimental results and their discussion

The main series of Rydberg states of indium atoms are studied in the experiment. Quantum defects, fine structures and their dependences on the principal quantum number were determined from photoionization spectra . Highly excited Rydberg np $^2P_{1/2,3/2}$ - states of the indium atom are populated from the ground 5p $^2P_{1/2}$ or from the metastable 5p $^2P_{3/2}$ state through the intermediate 6s $^2S_{1/2}$ level according to the following scheme:

$$5s5p^2P_{1/2,3/2} \xrightarrow{\lambda_1} 6s6p^2S_{1/2} \xrightarrow{\lambda_2} np^2P_{1/2,3/2} + эn + In^+ + e^- \quad (4)$$

The main term is a doublet term $^2P_{1/2,3/2}$, and the $^2P_{1/2}$ level is located below the $^2P_{3/2}$ level. The splitting value is ~2212.56 cm^{-1}. To excite an atom, a stronger quantum transition is chosen, i.e. 5p $^2P_{1/2}$ 6s $^2S_{1/2}$, which is excited by the first stage laser with a wavelength λ_1=410.2 nm. The wavelength of the second laser was tuned in the range λ_2 = 448÷460 nm, which makes it possible to excite Rydberg states with n=17÷70. Based on the results of the experiment, averaged over three measurements, the values of the energy of quantum transitions, quantum defects of Rydberg states were determined (Fig. 2.)

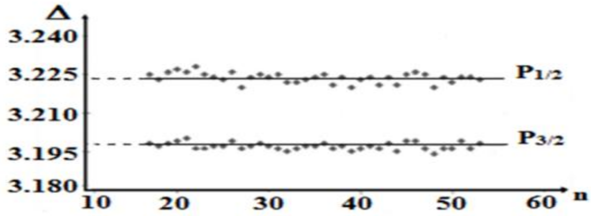

Figure 2. Dependence of the quantum defect $^2P_{1/2,3/2}$ of the state of the indium atom on the principal quantum number.

Doublet splittings of the spectrum of the P-state of the indium atom up to n =53 are allowed in the experiment . As a result of processing the spectra, the interlett splitting of the fine structure for the Rydberg states was measured and its dependence on the principal quantum number was studied. This dependence is well described by the ratio $\Delta E=5900/n^3$ cm^{-1} and is consistent with the hydrogen-like behavior of the atom. This dependence is shown in Fig.3.

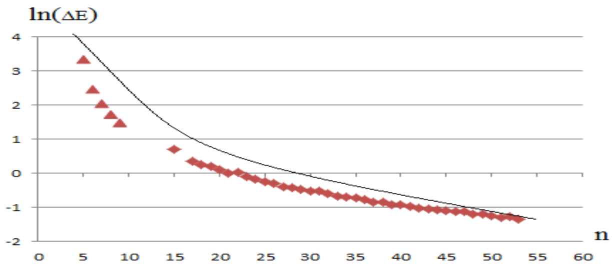

Figure 3. Dependence of the fine splitting value (ΔE) on the principal quantum number (n) for the $^2P_{1/2.3/2}$, state of the indium atom .

Conclusion. Doublet splittings of the spectrum of the P -state of the indium atom up to n=53 are allowed in the experiment . The results obtained can be used to solve some technological problems associated with the excitation of atomic levels by laser radiation. The results obtained can be used to solve some technological problems associated with the excitation of atomic levels by laser radiation

REFERENCES

1. Letokhov, V.S. Laser photoionization spectroscopy, The science. Mascow, 1987.
2. Letokhov V.S., V.I.Mishin, A.A.Puretsky. Selective photoionization of atoms by laser radiation.- Sb. St. Plasma chemistry. M. Atomizdat. 1977. No.4. pp.3-60.
3. Sobelman, I.I. Introduction to the theory of atomic spectra. The science, M, 1977.
4. Tursunov A.T., Eshkobilov N.B. - Av. certificate No.1092387 "Method of measuring the spatial distribution of atomic concentrations" with priority from 17.01.83
5. Muchnik M.L., Orlov Yu.V., Parshin G.D., Chernyak E.Ya., Letokhov V.S., Mishin V.I. - Kv. electronics. 1983. vol.10. pp.2331-2335.
6. Tursunov, A.T.; Akilov, R.; Kornienko, V.V.; Khasanov T.; Eshkobilov, N.B.; J.P.S. 1986, v.14, v.6, p.1029.
7. A.K.Kasimov, A.T.Tursunov, N.B.Eshkobilov. - /RIS-96/ USA., Renkelvani, p.141
8. Eshkabilov,N.B.; Xaydarov,Sh.R.; Kurbaniyazov, A.C. Lazer photoionization spectroscopy of Rydberg and autoionization states of rare-earth atoms. Scientific Journal of Samarkand University. Vol.2020.3 pp.137-145.
9. Eshkobilov,N.B.; Khaydarov ,Sh.R.; Technology for obtaining pure materials at the atomic-molecular level using laser radiation. Modern science and research. p.173-176 https //doi.org.10.5281/zenodo.7337055.
10. Eshkabilov N.B.; Kurbaniyazov, S.S.; Khaidarov, Sh.R. News of higher educational institutions. 2021 V.64 No.10. doi :10.17223/00213411/64/10/79

11. Eshkabilov N. B., A. S. Kurbaniyazov A. S., and Sh. R. Haidarov. - Russian Physics Journal. Pleiades Publishing, New York, 2022. -Vol. 64, - No 10, - pp. 1872-1879
12. Zainabidinov S.Z. et al. - Physics and technology of semiconductors. 2016, vol. 50, issue 1. pp. 60-66.
13. Gusev A.I. - Nanomaterials, nanostructures, nanotechnology. – M. Fizmatizdat, 2007, p.416.
14. Radzig A.A., Smirnov B.M. Parameters of atoms and atomic ions. Handbook. M., 1986. from 16-26.
15. Eshkobilov N.B. Collection of statistics. “Spectroscopy of condensed matter". 1991. pp.57-60.