Observation of Dipole Transitions in Highly Excited Rydberg States of the Gallium Atom

Napas Beknazarovich Eshkabilov
Samarkand state university, professor

Shuxrat Rustamovich Khaydarov
Samarkand state university, base doctoral

Ergashev Feruzbek Normomin ogli
Samarkand state university, master

A B S T R A C T

The effect of a constant electric field on dipole transitions in Rydberg gallium atoms is studied. In the photoionization spectrum, we simultaneously detected and identified expanded (with n=17 27) and forbidden quantum transitions (with n=16 27); (with n=15 26) and, (with n=17 27) the manifestation of which is associated with the lifting of the ban on. An analysis of the photoion spectra shows that the lifting of the prohibition begins as if in turn, i.e. first when, and then and etc. depending on the increase in the electric field strength.

A R T I C L E I N F O

Article history:
Received 19 October 2021
Received in revised form
18 November 2021
Accepted 28 December 2021

Keywords: electric field, gallium, photoion, photoionization spectrum, Stark effect, highly excited.

Hosting by Innovatus Publishing Co. All rights reserved. © 2021

Introduction

Investigations of new methods of obtaining Rydberg atoms in laboratory conditions aroused interest in studying the processes of interaction of atoms with electric and magnetic fields. Research in this direction is in many respects completely new, since the nature of the interactions of strongly excited atoms differs significantly from ordinary ones. Laboratory fields, negligible compared to atomic fields for weakly excited states, acting on an electron located far from the nucleus in a highly excited atom. Therefore, for Rydberg states, external fields can play a predominant role. This leads to a new class of atomic phenomena that judge new possibilities and pose new challenges in atomic theory.

In this work, we present theoretical and experimental results of the action of pulsed and constant electric fields on Rydberg atoms of gallium and indium.

Theoretical consideration of the process

The electric field rearranges the electronic spectrum in such a way that some of the levels of the discrete spectrum of the atom near the ionization boundary fall into the continuum, while the remaining levels become autoionization and the probability of their autoionization decay rapidly increases with the principal quantum number.

Ionization of highly excited atoms by a constant electric field

It was noted in that atoms in high-lying Rydberg states are characterized by a strong Stark effect, which quickly passes from quadratic to linear in a relatively weak electric field. The strong Stark effect is characterized by a significant shift of the levels and their splitting into several components, as well as violation of the selection rules associated with a change in the parity of the state.

This section presents the results of experiments on studying the shifts of Rydberg levels and the appearance of forbidden lines in the spectrum of a gallium atom in a constant electric field, as well as

their identification. The experiment was carried out on a laser photoionization spectrometer.

In [1], when using a highly excited state of a gallium atom, several resonances were found; the arrangement did not correspond to the excitation of Rydberg $np^2P_{1/2,3/2}$ -states of an unperturbed gallium atom. As we know, highly excited states split in an electric field and energy levels shift [2]. This effect is due to the strong Stark effect for Rydberg states [3]. In the spectrum of the ion signal, the splitting and shift of energy levels can be hardly noticeable, but quantum transitions associated with the removal of the prohibition on changing the orbital angular momentum by more than unity are clearly observed. This is apparently due to the smallness of the shift and splitting of the levels in comparison with the spectral linewidth of the laser radiation at an electric field strength of <50 V / cm.

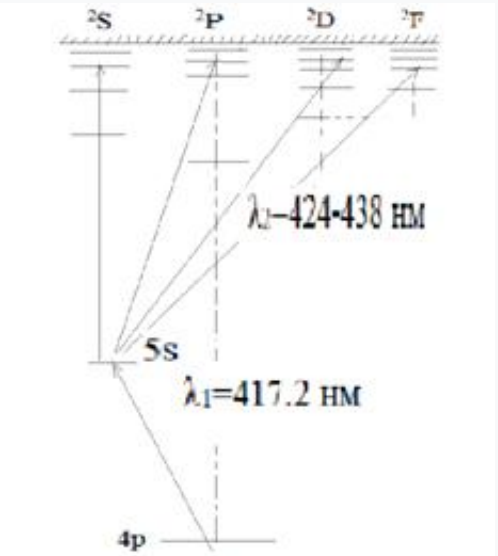


Fig. 1 Diagrams of the equations of the gallium atom and possible dipole transitions

Lines are observed in the spectra, which are associated with the lifting of the prohibition on changing the orbital angular momentum by more than unity. In such cases, transitions from a state with a low orbital angular momentum to a state with any orbital angular momentum possible for a given state become possible. As a result, the number of possible lines in the absorption spectrum of an atom increases significantly.[4] Possible transitions are shown in Fig. one 1

From the photoionization spectra, the highly excited states of the gallium atom with n = 17 -27 were detected and identified during the transition; with n = 15- 26 during the transition and with n = 17- 27 during the transition, the manifestation of which is associated with the lifting of the prohibition on.

To study the effect of a constant electric field on individual dipole transitions of Rydberg atoms, the wavelength of the second-stage lasers was smoothly tuned in the vicinity of the transition, and the photoion spectrum was recorded at different values of the electric field strength. This spectrum is shown in Fig. 2 at electric field strengths 1 - U = 0 V / cm; 2- U = 50 V / cm; 3- U = 100 V / cm; 4- U = 500 V / cm; 5- U = 5000 V / cm.

As can be seen from the spectra,at low values of the electric field strength, only transitions with. With an increase in the field, transitions from, etc.are allowed. Therefore, with an increase in the electric field strength, new resonances were observed, the appearance of which is associated with the lifting of the prohibition on changing the orbital angular momentum by more than unity. The line with the maximum amplitude appears during the transition to the 20p state. The rest of the lines are associated with transitions to states D and F. Analysis of the photoion spectra shows that the lifting of the prohibition begins as if in turn, i.e. first, when, and then, etc. depending on the increase in the electric field strength. The 20p level lies below the ionization limit by 350cm-1. The photoionic signal is the sum of two signals: a nonresonant photoionic signal arising through the channel

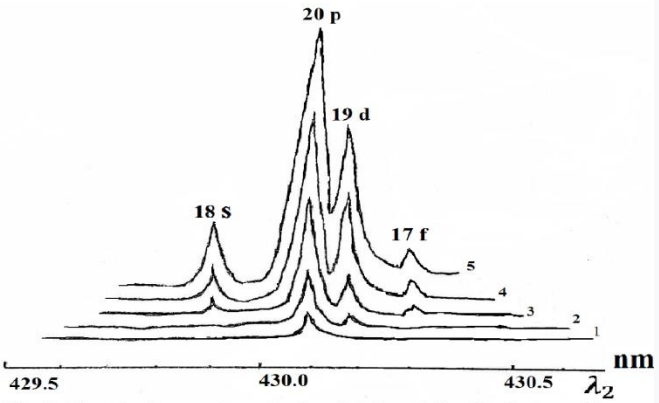


Fig. 2 Photoionic spectrum in the vicinity of the dipole transition at different values of the electric field strength. 1- 0 w / cm, 2-50 w / cm, 3- 100 w / cm, 4- 500 w / cm, 5- 5000 w / cm

$$4P_{1/2} \xrightarrow{417{,}2\ \text{нм}} 5s^2S_{1/2} \xrightarrow{417.2\ \text{нм}} \text{континуум}$$

and a resonant signal emerging through the channel.

$$4P_{1/2} \xrightarrow{417{,}2\ \text{нм}} 5s^2S_{1/2} \xrightarrow{430.1\ \text{нм}} 20p^2P_{1/2,3/2} \xrightarrow{e.f} \text{континуум}$$

Let us note some advantages and disadvantages of using the Stark effect in spectroscopy.

Ionization of highly excited atoms by a pulsed electric field

The study of the processes of excitation and ionization of Rydberg atoms allows us to assess the possibilities of selectively creating highly excited atoms in specified states, as well as the possibility of their use in various scientific and practical studies. For example, it is very promising to use a highly excited atom for the process of laser isotope separation, obtaining ultrapure substances, determining ultra-small amounts of substances, etc. One of the main drawbacks of this method when used in practical problems is the relatively low cross section for photoionization of atoms. Therefore, the search for ways to increase the cross section for the photoionization of atoms by laser radiation is still an urgent problem in experimental physics. When high-lying levels of an atom of a state with different n are split, the levels overlap, which makes it difficult to determine the quantum number of the excited state, but despite these drawbacks, the use of the Stark effect for highly excited atoms opens up new possibilities for their excitation and ionization. A significant linear shift of levels in a constant electric field provides a unique opportunity to control the energy structure of high-lying states and, consequently, the optical properties of an atom over a wide range.

It becomes possible to adjust the absorption spectrum of atoms at the last stage of excitation to the radiation frequency of lasers with a fixed generation frequency. The Stark effect for a state with large n and the removal of the prohibition on any changes in the orbital angular momentum of electrons can be used for other purposes as well.

Conclusions

1. Based on the solution of the Schrödinger equation, a theoretical estimate of the electric field strength ($E_{pore,} E_{cr}$) is given, at which the state with the principal quantum number *n* falls into the continuum. The probability of autoionization decay in an electric field is calculated for highly excited states of atoms.
2. In a pulsed electric field greater than the critical value ($E > E_{cr}$), the probability of autoionization decay is equal to unity. In this case, the value of the effective cross section of the entire ionization process is determined by the value of the cross section for the excitation of high-lying states, which is two or three orders of magnitude greater than the direct ionization into the continuum.

Literature:

1. Турсунов А.Т., Эшкобилов Н.Б., Корниенко В.В. Наблюдение эффекта Штарка при исследовании выысоколежащих состояний атома галлия. Ж.П.С. 1984. Т. 41. С. 653
2. Собельман И.И. Введение в теорию атомных спектров. М. Наука. 1977.
3. Апатин В.М., Летохов В.С., Мишин В.И. Квантовая электроника, 1978, Т. 5. С.632-640.
4. N.B. Eshkobilov, Sh.R. Khaidarov, Sh.Sh. Primkulov. Investigations of the ionization of Rydberg atoms in a pulsed electric field. Actual scientific research in the modern world. Issue 4 (72). Pereyaslav. 2021 Wed. 258-262