CONFERENCES AND SYMPOSIA

Atoms in a superatomic field of laser radiation (International Conference in Big Sky, Montana 22–25 June 1991)

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The use of today's powerful lasers as sources of electromagnetic radiation has led to a reexamination of a number of fundamental assertions about the interaction of light with matter on the atomic level. An example of this is the phenomenon of nonlinear ionization of atoms in a strong electromagnetic field. When one considers nonlinear ionization (multi-photon or tunneling ionization, etc.) the concept of the "red boundary of the photoeffect" loses its meaning. This boundary separates the frequency range of intense light absorption from the region of matter transparency. Absorption occurs at any frequency ω of radiation, not only at $\omega > E_i/\hbar$, as Einstein's law for the photoeffect states. Here E_i is the binding energy of the atom and $\hbar$ is Planck's constant.

Recently it has become necessary to reexamine a number of other fundamental assertions of the physics of the interaction of an atom with electromagnetic radiation. One such assertion is that, in a field with a strength greater than the atomic field strength (that is, in a so-called superatomic field), the atom ceases to exist as a bound system for an atomic time. Another such assertion is that the dynamic Stark shift of a highly excited atomic level in a field of electromagnetic radiation is a small quantity compared to the distance to the neighboring levels, and even more so, compared to the binding energy of this level.

Now, theory has convincingly proven that at a sufficiently high frequency of radiation the atom may have a lifetime which substantially exceeds the atomic time τ_a at a field strength which exceeds the atomic field strength F_a. The high-frequency Stark shift of a highly excited level may exceed its unperturbed binding energy, leading to a simultaneous increase in the energies of all sufficiently high atomic levels together with the continuum limit.

A new dimensionless parameter has also arisen which is equal to the ratio of the amplitude of vibrations of electrons in the field of an electromagnetic wave to the size of its orbit in the ground state of the atom. The value of this parameter for the most part defines the metastable character of the ground state of the atom in a superatomic field. When this parameter is large, the binding energy of the metastable atom is greatly reduced. However, the imaginary part of this energy, which is equal to the probability of the decay of the atom per unit time, also decreases. Thus, one can speak of this type of distorted atom as a metastable formation when the real part of the binding energy remains much larger than its imaginary part. Whether this is so depends on the selected object of investigation and the characteristics of electromagnetic radiation.

Progress in laser technology has led to a situation where researchers can obtain a field of laser radiation with a strength which exceeds the atomic field strength indicated above (we note that for other atoms, the atomic field strength is somewhat less than for a hydrogen atom, with the exception of atoms of noble gases, where the atomic field strength is somewhat higher than the above value). This explains the current worldwide interest in the problem of the interaction of an atom with a superatomic field. The sharp increase in the number of scientific publications on this subject began in the late 80s and the number of publications has increased with each passing year.

An international conference on the problems of the interaction of an atom with a superatomic field of laser radiation was held in Big Sky, Montana on 22–25 June 1991. It was organized by the prominent American physicists J. Eberly, R. Freeman, and C. Kulander. About one hundred specialists gathered from more than a dozen countries. Twenty-five invited talks were given and conference participants acquainted themselves with 32 reports in the poster section.

Before we characterize the problems discussed at the conference, let us first turn to the term "atomic field." There is no unambiguous definition of this term. Here are some rather well grounded and varied definitions of the atomic field:

1) The strength of an atomic field is a quantity composed of known constants using dimensional arguments:

$$F_a = m_e^2 e^5 \hbar^{-4}; \tag{1}$$

here m_e and e are the mass and charge of the electron, respectively, $\hbar$ is Planck's constant. Numerically, according to Eq. (1) we have $F_a = 5\cdot 10^9$ V/cm, which corresponds to the strength of the electric field at the orbit of an electron in the ground state of a hydrogen atom.

2) In an atomic field the electron is stripped from the atom and becomes free for one revolution (the so-called Kepler period) around the nucleus (or atomic core). In the case of a highly excited state this atomic field will be substantially lower than the one defined according to Eq. (1).

3) In an oscillating atomic field, ionization occurs in one period of field change; numerically this definition coincides with Eq. (1) for the ground state of a hydrogen atom at a photon energy of the order of one Rydberg.

4) An atomic field is a field in which the maximum effective potential barrier, which arises as the result of addition of atomic potential and the potential of the external

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electromagnetic field, decreases to the level of the binding energy of the electron in the atom; under these conditions the electron, from the point of view of classical physics, becomes free. For the ground state of the hydrogen atom and a low radiation frequency, the field strength for this definition is a factor of 16 lower than in Eq. (1).

5) In an atomic field the broadening of levels due to photoionization is a quantity of the order of the distance to neighboring levels, so the discrete structure of levels disappears and the spectrum has the character of a quasicontinuum. This definition is used for the highly excited states of atoms.

For the ground states of atoms and for radiation frequencies which are not too high, these definitions yield atomic field strength values which do not differ greatly. Thus, the reader should not be perplexed when various publications use different definitions of the atomic field.

The term "superatomic field" denotes a field whose strength is greater than the atomic field strength.

Today's laser technology makes it possible to obtain a radiation field strength which exceeds atomic field strength at various frequencies, from the near infrared (CO_2 laser $\hbar\omega \approx 0.1$ eV) to the near ultraviolet (excimer lasers $\hbar\omega \approx 4$–6 eV). The intensities of focused radiation obtained at present in a number of laboratories have reached $I \sim 10^{18}$ W/cm^2 (which corresponds to the strength of the electric field $F_a \sim 3 \cdot 10^{10}$ V/cm). It is expected that the maximum radiation intensity will soon increase by one to two orders of magnitude. One can also expect substantial advances in the high frequency region. The report of one of the conference organizers, R. Freeman, was devoted to a discussion of the possibility of obtaining highly intense coherent radiation at ultrahigh frequencies with a photon energy of 10 eV and higher. Various ways of solving this problem were discussed, including the generation of extremely high harmonics of near ultraviolet and visible laser radiation, the use of the undulator radiation of electron beams, and mirrors to focus the x-rays of laser plasma. There are possibilities of obtaining intensities greater than 10^{13} W/cm^2 for radiation at ultrahigh frequencies.

By comparing the characteristics of laser radiation with the atomic field strength mentioned above, it is clear that experimentalists can obtain superatomic fields, and it is possible to observe and study the results of the interaction of these fields with atoms.

At first glance it might appear that there exist no objects to be studied under these conditions. According to the definitions of the atomic field given above, it would seem that in a superatomic field the atom ceases to exist as a bound system in an atomic time (for the ground states of atoms this is $\tau_a \sim 10^{-16}$ s), and is transformed into a nucleus (ion) and a free electron. A specific example is the generally known dependence of the probability of the photoionization of an atom on the strength F of the external electromagnetic field, which, according to Fermi's golden rule, has the form

$$w \sim |V|^2 \rho \sim F^2;$$

here V is the matrix element of the bound-free transition, ρ is the density of final states. It is clear that as the strength of the external field F increases, the probability of ionization increases. It is easy to estimate that at $F \sim F_a$ the probability $w \sim 1/\tau_a$, where τ_a is the atomic lifetime mentioned above.

However, simple qualitative considerations are also known which lead to the opposite conclusion. From the point of view of quantum theory, ionization of the atom is the result of the absorption of a photon by a bound electron. It is well known that a free electron cannot absorb a photon, because it is impossible to satisfy the laws of conservation of energy and momentum simultaneously. A third body is needed for real photon absorption. The role of this third body is played by a nucleus or atomic core to which the electron is bound by Coulomb forces. However, the bond of the electron with the nucleus plays a diminishing role because of the increase in the strength of the external field, and at $F \gg F_a$ the electron can be considered virtually free with all the resultant consequences following. The picture of atomic ionization is as follows: the probability of ionization increases as the strength of the external field F increases in the region where $F < F_a$, and the probability of ionization decreases as the external field increases in the region where $F > F_a$. The maximum probability corresponds to an atomic field strength $F \approx F_a$.

This qualitative picture has long been known, and not only to specialists. With the appearance of lasers, theoreticians were attracted to it, and recently, with progress in obtaining superhigh radiation intensities, experimentalists have also been drawn to it.

The first theoretical publication in which it was shown that the probability of ionization decreases as the strength of the radiation field increases where $F > F_a$ was Ref. 1. It used Keldysh's approximation,[2] which one uses to calculate the transition between the initial unperturbed state of an atom and the final state in the form of a free electron in the field of an electromagnetic wave. As in other cases, the results are applicable only to a system bound by a short-range potential. The interaction of an atom with an electromagnetic field is described using a "velocity" gauge[3]

$$V(r, t) = \mathbf{p}\mathbf{A}(t)/c + \mathbf{A}^2(t)/2c^2;$$

here $A(t)$ is the vector potential of the electromagnetic field, $\mathbf{p}$ is the momentum of the electron. Further, one uses an atomic system of units in which $m_e = e = \hbar = 1$. As a result, the following expression is obtained for the probability of ionization w per unit time

$$w \sim (F_a/F)\ln(F_a/F). \tag{2}$$

It is clear from this expression that this probability decreases as the field increases at $F > F_a$. Qualitatively similar results are obtained in a number of other publications (see, for example, Ref. 4).

Thus, there were predictions of the stabilization effect of a quantum system with a short-range potential with regard to the ionization process for a field strength greater than the atomic field strength.

Publications in the last several years have shown that the stabilization effect should occur for atoms as well, that is, systems with long-range potential. The main results were obtained in three different areas of research: numerical quantum mechanical calculations of ionization from the ground state of a hydrogen atom, in analytical calculations of ionization from Rydberg atomic states, and in numerical calculations in the framework of classical mechanics.

Let us first turn to numerical quantum mechanical calculations, that is, to numerical calculations based on the solution of a time-dependent Schrödinger equation.

Most of the progress achieved recently has been associated with the use of the so-called Kramers coordinates and the Kramers–Henneberger transform (the term "the Kramers–Henneberger method" is generally and frequently used).

The Kramers system of coordinates[6] is a noninertial system of coordinates in which all coordinates are shifted relative to the coordinates of the laboratory system by the time-dependent quantity $a \cos \omega t$. Here ω is the frequency of the external electromagnetic field, and $a = F/\omega^2$ is the amplitude of the vibrations of an electron in this field.

The Kramers-Henneberger method[6] consists of the sue of the Kramers system of coordinates in which the probability distribution of finding the electron is in the first approximation (for a sufficiently large frequency ω) time-independent. The usual time-dependent Schrödinger equation

$$i d\Psi/dt = [-(1/2)\Delta + U(r) + V(\mathbf{r}, t)]\Psi(\mathbf{r}, t), \tag{3}$$

in which $U(r)$ is the potential of interaction of an electron with an atomic core, $V(\mathbf{r},t)$ is the potential of interaction of an electron with the electromagnetic field, and $\Psi(\mathbf{r},t)$ is a wave function, transforms into the equation

$$i d\Psi'/dt = [-(1/2)\Delta + U(\mathbf{r}')]\Psi'(\mathbf{r}, t), \tag{4}$$

where

$$\mathbf{r}' = r - \mathbf{a} \cos \omega t;$$

here Ψ' is the wave function of the system in the Kramers system of coordinates; it is linked with Ψ by a simple gauge transformation.

For a high external field strength, in the first approximation one can restrict oneself to the average value of the potential energy $\langle U(\mathbf{r}')\rangle$ over a period of the field, which is an important simplification. From the point of view of the Floquet theorem[7] this type of approximation means taking into only the one zero-order term in the expansion of the wave function into a Fourier series.

Thus, when one uses the approximation $a \gg 1$ (and a high field frequency ω) the energy levels are determined from the time-independent Schrödinger equation

$$[-(1/2)\Delta + \langle U(\mathbf{r}')\rangle]\Psi' = E\Psi' \tag{5}$$

(of course they differ greatly from the initial energy levels of the atom in the absence of a field).

Many calculations have been made using this method. An example is Ref. 8, in which an atom of hydrogen is examined in a superatomic linearly-polarized field ($I \sim 10^{17}$ W/cm^2, $F \sim 10^{10}$ V/cm, $\hbar\omega = 6.4$ eV). We note that these are completely realistic parameters for today's lasers. From the dependence of the energy of the ground state in the external field on the amplitude of the vibrations of the electron in the external field α, it follows that at $F > F_a$ the electron remains in the bound state in the atom, although the binding energy decreases continuously as a increases.

It is interesting to note that the calculation in Ref. 8 indicates the appearance the extension of the hydrogen atom along the vector of the electric field of the electromagnetic wave (when it is linearly polarized) and the so-called "dichotomy" phenomenon, the spatial localization of the wave function of the electron near two classical turning points in the superatomic field: $z = \pm a$. Here the Z axis is directed along the vector of the electric field. The electron cloud of the probability of finding the electron is shown qualitatively in Fig. 1.

In the report of K. Rurnett, V. C. Reed, and P. L. Knight, the Kramers-Henneberger method was used to study the generation of harmonics in a superatomic field using the example of a model two-dimensional atom. In M. Pont's report, this same method was used to determine the probability of multi-photon ionization of a hydrogen atom in a high-frequency electromagnetic field. The stabilization of the atom in a superatomic field is treated as the destructive interference of diverging electron waves.

Keldysh's approximation was used in H. R. Reiss' report to show that the stabilization of atoms in superatomic fields depends strongly on the polarization of radiation at a given intensity; moreover, as frequency decreases, the dynamic Stark shift of the continuum boundary begins to have an effect, improving the stabilization.

A similar conclusion regarding the role of the dynamic Stark effect was reached by Q. Su in his paper, but in the framework of the Kramers-Henneberger method, using the example of a long-range model potential of the atomic core.

Relativistic effects begin to have an effect in the superatomic field because the vibrational energy of the electron in the field becomes comparable with the rest energy of the electron. A general relativistic approach to the ionization of an atom in the framework of the Keldysh approximation was developed in Ref. 9. The conference report of P. S. Krstic was devoted to this subject. In the relativistic case one cannot be limited to a dipole approximation in the description of the interaction of an atom with an external electromagnetic field. Thus, the selection rule in atomic transitions is substantially changed. In particular, the aforementioned phenomenon of dichotomy disappears because the electron is substantially affected not only by the electric field, but also by the magnetic field of the electromagnetic wave.

Overall, one can make a confident conclusion about the stabilization of the ground states of atoms in superatomic fields ($a \gg 1$) at frequencies $\omega \gg 1$. A weaker stabilization follows from similar calculations at a radiation frequency ω less than the binding energy of the electron in the atom.

Studies in the framework of classical mechanics are in their initial stages. Only Refs. 10 and 11 are known, and they were done very recently.

Calculation in this case consists of the solution of a three-dimensional Newton equation

$$\ddot{\mathbf{r}} = (\mathbf{r}/r^3) + \mathbf{F} \cos(\omega t + \varphi), \tag{6}$$

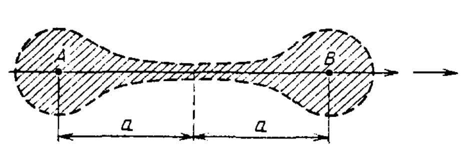

FIG. 1. Probability cloud in a superatomic field which is linearly polarized along the field axis. A and B are the classical turning points. a is the amplitude of oscillations of the electron in the field.

where **r** is the position vector which characterizes the position of the electron in the hydrogen atom for various values of parameters which characterize the superatomic electromagnetic field, and for various initial conditions, for example, the phase φ at the moment the external field is switched on. Results are obtained by a statistical analysis of a large number of classical trajectories of the electron.

At the conference, the Polish physicists M. Gaida, J. Grochmalicki, M. Lewenstein, and K. Rzazewski discussed the results of a calculation for the ground state of a hydrogen atom at $F = 2F_a$ and a field frequency which varied in the range $\omega = 1$–40 a.u. At $\omega = 40$ a.u. an atom stabilization effect was found: 100% of the trajectories were characterized by lifetimes $\tau > 0.5\tau_a$ (τ_a is the Kepler period of revolution of the electron around the nucleus).

The same range of issues was discussed in the report of A. L. Nefedov. It followed from Nefedov's report that in an *external oscillating field with frequency $\omega \gg 1$ stable trajec*tories arise only at high field strengths, when the amplitude a of electron oscillations is large. In contrast to quantum calculations, where stabilization takes place at $a \gg 1$, in the classical case the range $F^{-1/2} \ll a \ll 1$ was studied, where F is the amplitude of the electric field strength of radiation ($F \gg 1$ for a superatomic field). The quantity $F^{-1/2}$ is none other than the size of the region around the nucleus where the Coulomb field is greater than the external field, the only region where ionization can really occur. Since $a \ll 1$, the electron, on average, moves along a Kepler orbit with a "slight shiver" around it (Fig. 2). A more accurate condition for the field strength F has the form $F \gg \omega^{4/3}$ and follows from the inequality $a = F/\omega^2 \gg F^{-1/2}$.

Under such conditions the electron, in three-dimensional motion, traverses a Coulomb region around the nucleus of a size of the order of $F^{-1/2} \ll 1$, the only region where ionization can occur due to interaction of the electron with a third body, the nucleus (see Fig. 2). It has been found that more than 50% of the trajectories are characterized by lifetimes $\tau > 2\tau_a$, where τ_a is, as above, the Kepler period of revolution. In the report, there was a detailed classification of various modes of interaction of the atom with the external field (see also Ref. 11). This analysis shows that the main conclusions of Refs. 10 and 11 agree with each other. There is also agreement with the results of quantum calculations[12,13] in which analogous initial conditions are given.

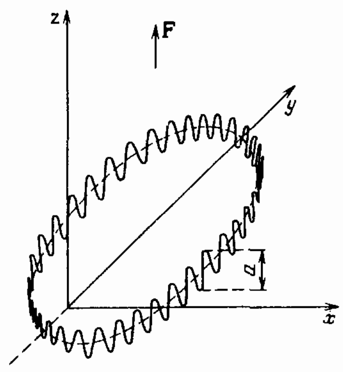

FIG. 2. Trajectory of the classical motion of an electron around the nucleus (at the origin of coordinates) in an oscillating field. a is the amplitude of electron oscillations in the field.

Thus, one can state that numerical calculations done in the framework of classical mechanics also predict that the atom is stabilized with regard to the ionization process in high-frequency superatomic fields.

Let us finally turn to Rydberg atoms. As in other cases, the Rydberg atom is a suitable object for the study of stabilization because one can use a quasiclassical approximation and obtain results in analytical form. We also note that in an experimental study of the ionization of Rydberg atoms one needs a field which is much weaker than in the case of atoms in the ground state. Actually, the atomic field for the Rydberg state of an atom with a principal quantum number n is of order of magnitude $F_a(n) = F_a n^{-4}$. For large values of n such fields are easily obtained even with "old" laser technology. However, when laser radiation is used, one is talking about relatively high frequencies of the external field ($\hbar\omega \gtrsim E_n$). Thus, the frequency of a CO_2 laser with the longest *wavelength ($\hbar\omega \approx 0.1$ eV) approximately corresponds to* the binding energy of a Rydberg atom with a principal quantum number $n = 12$. Radiation with a longer wavelength can be obtained, but only using the more complex technology of ultrahigh-frequency generators.

One can see that such experiments are realistic from the publications of the Koch group (see, for example, Ref. 14). Koch's report at the conference outlined the results of experiments on microwave ionization of a hydrogen atom in states with principal quantum numbers $n = 24$–90. The field strength was from 1 to 10^3 V/cm, and the frequency was from a few to several dozen gigahertz, that is, of the order of the Kepler frequency for these states. For specific values of the frequency (for example, 1.3 of the Kepler frequency) local stabilization of Rydberg states was experimentally detected. It was confirmed by theoretical calculations of the probability of ionization in fields of the indicated strength and frequency.

A theoretical study of the dynamics of the Rydberg atom for variations of the strength of the external electromagnetic field in the region near $F \sim F_a(n)$ was made in a number of publications. The most significant results were obtained in a series of publications by Fedorov *et al.*[16] An electron which has absorbed a photon with frequency $\omega > E_n/\hbar$, where E_n is the binding energy of the electron in a Rydberg atom, does not escape to infinity, but is compelled to emit a photon of the same frequency ω and return to the region of the spectrum of Rydberg states. This process of absorption and emission of photons occurs many times. The

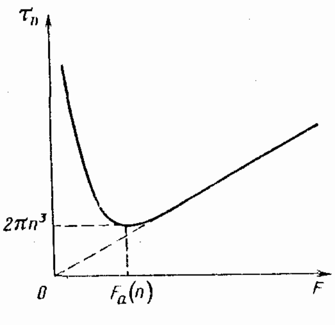

FIG. 3. Dependence of the lifetime τ_n of a Rydberg state with a principal quantum number n (in relation to the process of photo-ionization) on the strength of the external field F. $F_a(n)$ is the strength of the atomic field for a given state n.

total probability of this process is calculated taking into account the destructive interference of transition amplitudes. Thus, the total probability of ionization is much lower than the probability of the transition of an electron into the continuous spectrum (ionization) at $F < F_a(n)$. Thus, stabilization of the Rydberg atom arises at $F > F_a(n)$. Figure 3 shows the dependence of the lifetime τ_n of a Rydberg atom on the field strength F. This follows from the calculations in Ref. 15. At $F \gg F_a(n)$ the lifetime increases linearly as the strength F increases.

The report presented by M. V. Fedorov at the conference developed this model, using the language of wave packets. Attention was focused on the role of dynamic multiphoton resonances which arise between the ground and Rydberg states in a strong field due to the dynamic Stark effect, which is different at different points of the spatial-temporal distribution of intensity of radiation in the region of interaction with atoms.

The report of P. Bucksbaum and R. Jones was devoted to these same issues. Particular attention was devoted to the issue of the time at which $F = F_a(n)$ in the process of development of a laser pulse in time, because it is specifically at this time that the probability of ionization reaches its maximum value, a characteristic atomic quantity.

After the conference these same authors reported on the first experiment they had conducted[18] on the observation of stabilization of a barium atom in Rydberg states with principal quantum numbers $n \geqslant 25$ in a field of radiation of the third harmonic of a neodymium glass laser ($\lambda = 335$ nm). A beam of barium atoms in the ground state was irradiated by two dye lasers which put these atoms into Rydberg states. Then these atoms entered a region of space with a constant electric field with a strength of the order of several hundred V/cm. A linear Stark splitting of levels arose in this field. The amplitude of the field was sufficiently large for there to be quasi-intersections of Stark components of neighboring Rydberg levels. In the region of quasi-intersections the distance between these components was substantially less than the energy distance n^{-3} between unperturbed neighboring Rydberg levels, which facilitated their mixing through the continuum by the field of the third harmonic of the neodymium glass laser. An increase in the lifetimes of these Rydberg levels (a decrease in the yield of barium ions) was detected when the field strength of laser radiation increased above the atomic field strength $F_a(n)$.

Additional experiments were conducted which confirm the fact that the probability of one-photon ionization from the Rydberg states decreases when the field is stronger than the atomic field.

Thus, the results of this first experiment confirm the theoretical predictions of the interference stabilization of Rydberg states of atoms in a superatomic field of laser radiation.

Finally, among the issues examined was the problem of gigantic Stark shifts in an oscillating field. According to perturbation theory, at $\omega > E_n$ the shift of a level with a principal quantum number n is determined by the vibrational energy of the free electron in the field of a wave (assumed to be linearly polarized for definiteness):

$$E_{\text{osc}} = F^2/4\omega^2.$$

It is obvious that at large field strengths F and a small frequency ω the shift can be very large. In current experiments, shifts of excited atomic states of several electron volts are observed, which is comparable with the binding energy of these states in the absence of an external field (see, for example, Ref. 16). Taking into account the effect of stabilization of a Rydberg atom and larger Stark shifts in an oscillating field, recently it was found that it was possible for a new quasi-stable state of an atom to exist in an external oscillating field. The lifetime of this state is $\tau \gg \tau_n$ and the binding energy of the Rydberg states is[17] $E_n(F) \gg E_n$. Here $\tau_n = 2\pi n^3$ and $E_n = 1/2n^2$ (in atomic units). Such a state was called a "Stark atom."

In his report on the Stark atom N. B. Delone provided grounds for the criterion determining the greatest value of the perturbation which can be interpreted as a Stark shift of levels. It has the form $a < r_n$, where $a = F/\omega^2$ is the amplitude of oscillations of an electron in the field of an electromagnetic wave and $\mathbf{r}_n \sim n^2$ is the radius of an unperturbed Kepler orbit. From this criterion, given the frequency of the external field, one can obtain an estimate of the highest value of the field strength and of the shift of levels. Since it is assumed that the frequency of the external field $\omega \sim E_n/\hbar \ll E_1/\hbar$ where E_1 is the binding energy of the ground state, the perturbation in the external field of the ground and first excited states is very small. The broadening of Rydberg levels shifted by E_{osc} due to the presence of the stabilization effect is also small. Meanwhile, in the center of the spectrum there is always a region of n values for which the external field is equal to the atomic field ($F = F_a(n)$); consequently, their ionization broadening has the order of magnitude of the distance between levels, which is equivalent to the generation of a quasi-continuum in this region of the spectrum (Fig. 4).

Poster papers were also presented at the conference. It is impossible to comment on them here due to the size of the article. Among the poster papers we note the following. W. Becker, S. Long and J. McIver presented work on calcula-

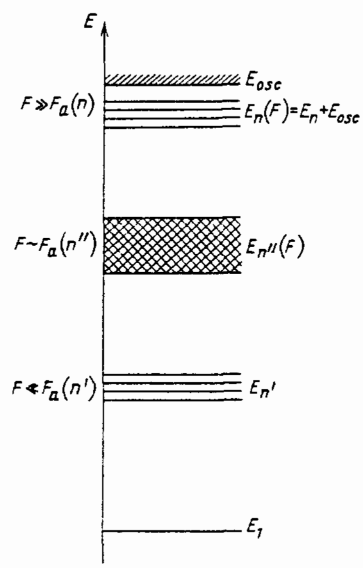

FIG. 4. Spectrum of a Stark atom in an external oscillating field. The hatched areas are Rydberg levels for which a quasi-continuum arises. E_1 is the energy of the ground state in an unperturbed atom (ionization potential).

tions of electron spectra accompanying detachment from a short-range potential by the superatomic field. The experimental group of C. Y. Tang presented work on multi-photon photo-detachment of an electron from a negative hydrogen ion. They observed a substantial deviation from the predictions of the multi-photon theory of perturbations due to the Stark increase in the threshold of ionization, which was discussed above. The theoretical work of V. P. Kraĭnov dealt with the behavior of a two-level system in a superatomic field including the phenomena of collapse and regeneration of the inversion of population density due to the quantized character of the electromagnetic field. A. Ritchie, C. Bowden, S. Pethel, and C. Sung compared calculations of the ionization of the ground state of a hydrogen atom using classical and quantum theory. It was shown that the stabilization effect is very sensitive to a change in the type of atomic potential. Numerical calculations of the ionization of Rydberg states of atoms were outlined in the work of D. D. Meyerhofer, S. Augst, M. V. Fedorov, and J. Peatross. They confirmed the aforementioned stabilization effect from analytical estimates. Finally, B. Piraux, E. Huens, and P. Knight showed that the stabilization of atoms may also be due to the formation of wave packets in the process of the excitation of atoms; these packets are located far from the atomic core, and this weakens the real absorption of photons of electromagnetic radiation.

Among the invited talks and poster papers were a number of reports on the interaction of an atom with an electromagnetic field at $F < F_a$. We will not comment on them here because we wish to concentrate the reader's attention on the problems of superatomic fields.

Thus, summarizing the work of recent years and more particularly, the discussions at this conference, one can conclude that contrary to the traditional point of view, there is a qualitative difference between an oscillating field and a constant electric field. In an oscillating electromagnetic field the presence of a frequency introduces a stabilizing feature. There is a wide range of conditions under which an atom in the ground or excited states can exist as a bound system for a period of time which substantially exceeds the atomic time at a field strength which exceeds the atomic field strength. As stated above, the first experiment with Rydberg atoms[18] shows that they are stabilized in a superatomic field. It is obvious that to study this effect in detail one must continue and further develop these experiments. On the other hand, the theoretical predictions about the stabilization of ground states in a superatomic field are based on another mechanism, which was discussed above. There is obvious interest in conducting experiments with atoms in the ground state as well.

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