Introduction to Simple Atoms

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1 Historical Remarks

It is really hard to overestimate the role which studies of hydrogen have played in establishing modern physics. Regularities in the spectrum of atomic hydrogen (known now as Lyman, Balmer, Paschen and Bracket series) inspired the appearance of Bohr's theory of the atom and the so-called *old quantum mechanics*. This model explained general features of hydrogen physics but not in full detail. A crucial success of the Schödinger theory was a calculation of the second- and the third-order terms of the perturbative expansion for the Stark effect in the hydrogen atom [1]. The non-relativistic theory was still not perfect and in particular it was not capable of dealing with the *fine structure* of hydrogenic lines. The problem was resolved with the discovery of the Dirac equation, which explained the fine structure and also a specific value for the spin component of the magnetic moment of the electron ($g = 2$). Some historical overview can be found in Ref. [2,3].

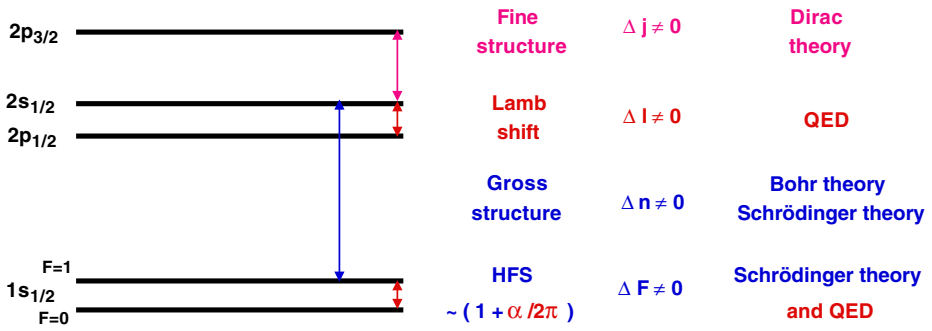

Fig. 1. Some low-lying levels in the hydrogen atom (not to scale)

Later, after experiments performed by Rabi, Lamb and Kusch and their colleagues, it was discovered that the actual hydrogen spectrum was in part in contradiction to Dirac theory (see Fig. 1). In particular, the theory predicted a value of hyperfine structure interval in the ground state of the hydrogen atom, different from the actual one by one part in 10^3, and no splitting between $2s_{1/2}$ and

$2p_{1/2}$ states, however the latter was observed. It was actually clear at that time that the theory was incomplete but there was no way to use any perturbation expansion because any *perturbative radiative corrections* contained numerous *divergencies*. A trial to resolve this discrepancy in the hydrogen spectrum led [4] to the introduction of the renormalization method and the method of Feynman diagrams, which are now an essential part of any quantum field theory. After a successful application of these and other methods, the problem was set and both the *Lamb shift* and the *anomalous magnetic moment* $(g-2)$ of the electron are now an usual part of any university courses in modern physics. The progress in quantum physics with respect to the hydrogen spectrum is summarized in Fig. 1.

2 Precision Physics of Simple Atoms

Simple atoms are a basic physical object and their simplicity has been a challenge for theory and experiment for some time. One could expect that a simple atom should be explained with a physically transparent and simple theory and studied with experiments based on simple ideas. At present-day the field is still attractive to physicists because of the clear physical nature of different phenomena and a possibility to perform both precise calculations and measurements. After a century of work in the physics of simple atoms, the list of such atoms available for study is quite long:

- *hydrogen*, and its isotopes: *deuterium* and tritium;
- pure leptonic atoms: *muonium* and *positronium*;
- *muonic atoms*;
- *the helium ion*;
- *highly-charged few-electron ions* at *medium* and *high* value of the nuclear charge Z;
- *exotic atoms*, *pionic atoms*, *antiprotonic atoms* etc;
- *antihydrogen*;
- *the neutral helium atom*;
- the Rydberg states *etc*;

where we use italic letters for atoms, presented in this edition (see *subject index* for detail).

The list of related studies of applications of simple atoms includes:

- *precision determination of fundamental constants*;
- *precise tests of QED* and *bound state QED*;
- study of proton structure and other particle properties;
- study of nuclear structure;
- *search for variation of fundamental contants*;
- *search for violation of fundamental symmetries*;
- *new frequency standards*;
- *advanced quantum mechanics of Coulomb systems*.

An introduction to the theory of simple atoms can be found in Refs. [1,2] and the state of the art work in this filed as it was twelve years ago in Refs. [3,5].

3 Studying the Simple Atoms

3.1 Hydrogen and deuterium (see [6,7] and Part VI)

Precision measurements of the hydrogen atom have played an important role in the development of frequency standards and for a long time the $1s$ hyperfine structure interval was the most accurately known physical quantity, and the hydrogen maser was a candidate for a primary frequency standard. The study of the hydrogen atom is now a way to determine the Rydberg constant (R_∞) and to develop a natural standard of the frequency, based on the value of R_∞. That became possible after the development of the Doppler-free two-photon spectroscopy methods [6][1]. The appearance of a new generation of frequency chains [8] and successful cooling of hydrogen atoms [7] offer us an opportunity for further progress in a way to a R_∞-based frequency standard. However, the possibility of reaching an even higher precision is limited by our knowledge of the Lamb shift. In the case of the latter the largest source of uncertainty are the effects due to the proton structure which are not known with a sufficient accuracy [9]. The proton structure effects also limit a possibility to precisely test bound state QED in the case of the hyperfine structure and the Lamb shift. The same problem arises with the deuterium atom and helium ion.

Indeed, since the atomic levels are affected by the nuclear structure, the study of the isotopic shift takes advantage of a significant cancellation of the QED uncertainty and offers an opportunity to study the nucleus. In particular, the study of the hydrogen [6] and the helium [10] isotope shift provides us with information about proton and two- and three-nucleon systems.

Perhaps a problem more important for applications is to eliminate the nuclear effects and to test the bound state QED precisely or use the bound state QED for the determination of some fundamental physical constants. There are a few ways to manage this problem [11] and to expand the accuracy of the tests of bound state QED beyond a level of our knowledge of the nuclear structure effects.

- The proton can be simply removed from the atom and substituted for a lepton, a particle which is not involved in strong interactions. Such atoms, muonium (μ^+e^-) [12] and positronium (e^+e^-) [13], were successfully studied for decades.
- One can study muonic atoms [14,15,16]. The muon orbit lies lower and much more close to the nucleus and its energy levels are much more affected by the strong interactions. However, to determine the nuclear contributions (for e. g. the one for the Lamb shift, which is completely determined by the nuclear charge radius) it is not necessary to know the QED part with an accuracy as high as in the case of the hydrogen atom. As a result, one can try to determine the parameters due to the nuclear structure and apply them afterwards to "normal" atoms.
- One more way is to try to study specific quantities which are only slightly affected by the nuclear structure. One example of which is the fine structure

[1] For detail see contributed papers (Part VI) in the attached CD.

of the p states, the wave function of which vanishes in the vicinity of the nucleus. Another example is a specific difference in the results for the $1s$ and $2s$ states.

3.2 Muonium and Positronium (see [12,13] and Part VII)

Both pure leptonic atoms, muonium and positronium, are not stable: the muon lives 2.2 μs and the positronium atom annihilates into photons in a much shorter time. However, they are compatible with the hydrogen atom as an object to test bound state QED.

The hyperfine structure interval in hydrogen is known experimentally on a level of accuracy of one part in 10^{12}, while the theory is of only the 10 ppm level [9]. In contrast to this, the muonium *hfs* interval [12] is measured and calculated for the ground state with about the same precision and the crucial comparison between theory and experiment is on a level of accuracy of few parts in 10^7. Recoil effects are more important in muonium (the electron to nucleus mass ratio m/M is about 1/200 in muonium, while it is 1/2000 in hydrogen) and they are clearly seen experimentally. A crucial experimental problem is an accurate determination of the muon mass (magnetic moment) [12], while the theoretical problem is a calculation of fourth order corrections $(\alpha(Z\alpha)^2 m/M$ and $(Z\alpha)^3 m/M)$ [11].

In the case of the positronium spectrum the accuracy is on the MHz-level for most of the studied transitions ($1s$ hyperfine splitting, $1s-2s$ interval, fine structure) [13] and the theory is slightly better than the experiment. The decay of positronium occurs as a result of the annihilation of the electron and the positron and its rate strongly depends on the properties of positronium as an atomic system and it also provides us with precise tests of bound state QED. Since the "nuclear" mass (of positronium) is the positron mass and $m_{e^+} = m_{e^-}$, such tests with the positronium spectrum and decay rates allow one to check a specific sector of bound state QED which is not available with any other atomic systems. A few years ago the theoretical uncertainties were high with respect to the experimental ones, but after attempts of several groups [17,18,19,20] the theory became more accurate than the experiment. It seems that the challenge has been undertaken on the experimental side [13].

3.3 Muonic Atoms and Nuclear Structure (see Part VIII)

The muon is about two hundred times heavier than the electron and its orbit lies 200 times closer to the nucleus. The nuclear structure effects scale with the mass of the orbiting particle as m^3R^2 (for the Lamb shift; R is a characteristic value of the nuclear size) and as m^2R^2 (for the hyperfine structure), while the linewidth is linear in m. That means, that from a purely atomic point of view the muonic atoms offer a way to measure the nuclear contribution with a higher accuracy than "normal" atoms. However, there are a number of problems with formation and thermalization of these atoms and with their collisions with the buffer gas.

3.4 Nuclear-Structure Independent Differences

The nuclear effects (both for the hyperfine structure and the Lamb shift) are a result of short-distance contributions and in the leading order are proportional to the Schrödinger-Coulomb wave function at the origin,

$$\Big(\varphi_{nl}(\mathbf{r}=0)\Big)^2 = \frac{1}{\pi\, a_0^3\, n^3}\,\delta_{l0}\ , \tag{1}$$

where a_0 is the Bohr radius. The value (1) vanishes for $l \neq 0$ states and for a specific difference

$$E(1s) - n^3 \cdot E(ns)\ . \tag{2}$$

A number of data are available for $1s$ and $2s$ *hfs* intervals in hydrogen, deuterium and the helium-3 ion. The potential of this difference for the *hfs* intervals in the helium-3 ion [21] with respect to testing bound state QED is compatible with the ground state *hfs* in muonium: both values are sensitive to fourth-order perturbative contributions. The difference of the Lamb shift plays an important role in the evaluation of optical data on the hydrogen and deuterium spectrum [22].

3.5 Fine Structure in Helium (see [23] and Part VI)

The fine structure in hydrogen cannot be measured precisely because of the natural radiative width of the $2p$ state, but it can be easily calculated. In contrast, while there was a problem with the accuracy of theoretical predictions, the helium fine structure has been measured precisely [23,24]. A higher experimental accuracy is possible because the helium triplet $2P$ states, 2^3P_J, have a lifetime about 60 times bigger than the $2p$ states in the hydrogen atom because of a forbidden (in the nonrelativistic approximation) $2^3P_J - 1S$ transition in helium. On the other hand, neutral helium, in contrast to the hydrogen atom, is a three-body system and even in the leading non-relativistic approximation, no exact solution is available, which causes troubles on the theoretical side. Fortunately, recently a significant progress in theory was obtained (see Ref. [23] and the references therein). Other options for the study of an interval which is not affected by the nuclear structure and can be measured accurately [25], are given by the hyperfine structure of $2S$ and $2P$ levels, caused by the spin-spin electron-electron interaction.

Helium is not the only three body system under study, but it is likely the most complicated one. The electron-electron interaction is comparable with the electron-nucleus interaction and cannot be considered as a perturbation. The situation is different with helium-like (and lithium-like) ions, where the electron-electron interaction is as small as $1/Z$ with respect to the interaction of an electron and the nucleus.

3.6 Few-Electron Ions (see [26,27] and Part XI)

A few-electron ion at moderate or high Z is a good example of a simple atom which is actually more simple than the neutral helium or lithium. The nuclear charge is large $Z \gg N$ (N is the number of electrons, $N = 1$–3) and all electrons are essentially hydrogen-like ones and that differs significantly from neutral helium and lithium. The electron-electron interaction is a small perturbation of the same order as the radiative corrections. It is sometimes not even possible to split a calculation of radiative corrections (e. g. the self energy of an electron) and electron-electron interactions (the exchange-photon contribution). The problem is that the few-electron wave function is an asymmetrical combination of products of the single-electron wave functions and the two-electron Green function contains the electron-exchange diagram. The gauge invariant set must include interactions of any electron in the initial state with every electron in the final state (see e.g. Fig. 2).

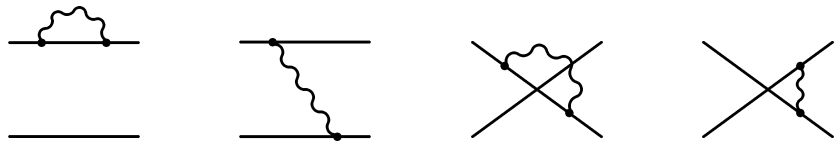

Fig. 2. Correction in linear order of α to the two-electron Green function

Recently, in addition to the Lamb shift [26] and hyperfine structure, one more value was measured with a high accuracy – the g factor of an electron bound in a hydrogen-like ion [27].

Recent progress in the study of high- and medium-Z ions [26,27] make calculations of two-loop corrections an important problem and that involves more QED effects in the study and now the status of high-Z and low-Z physics is very similar: both need to take into account α^2 terms and both cannot only apply an expansion in $Z\alpha$.

3.7 Medium-Z Physics (see [26,27] and Part XI)

A special case of few-electron ions is the medium-Z case, when

$$Z\alpha \ll 1 \quad \text{and} \quad Z \gg N.$$

One can hope that both technics, $1/Z$-expansion (high-Z technics) and $Z\alpha$-expansion (low-Z technics), can be applied. At medium Z one can try to provide a cross check of both theoretical approaches. Both use some expansion and that means that both are incomplete. It is necessary to somehow estimate the higher-order corrections which cannot be calculated now. The estimation of such corrections is a kind of art and it is very helpful [11] if we can try to verify these estimates in the case of medium Z.

3.8 Higher-Order Corrections

Recently, a problem of one- [28] and three-loop [29] corrections at low Z was resolved with sufficient accuracy, while the two-loop effects are known only in part [30,32] (for detail on theoretical calculation see a review [31]). After the first calculation of some $\alpha^2(Z\alpha)^6 m$ terms [32] there were few medium-Z calculations [33] which contradicted each other. They have showed that the $\alpha^2(Z\alpha)^6 m$ term is expected to be large.

There are two kinds of higher-order corrections that now limit the accuracy of theoretical calculations [11]:

- two-loop corrections in order $\alpha^2(Z\alpha)^6 mc^2$;
- radiative-recoil corrections in order $\alpha(Z\alpha)^6 m^2c^2/M^3$ and pure recoil terms in order $(Z\alpha)^7 m^2c^2/M^3$.

The latter presents the largest sources of uncertainty in the theory of the muonium *hfs* interval, positronium energy spectrum and the specific nuclear-structure-independent difference for the *hfs* in the helium ion. The former are crucially important for the theory of the Lamb shift in hydrogen and medium-Z ions, for the difference in Eq. (2) applied to the Lamb shift and hyperfine structure in hydrogen and helium ion, and for the bound electron g-factor. In the case of high-Z, the Lamb shift, g-factor and hyperfine structure require an exact treatment of the two-loop correction.

3.9 Bound State QED

The higher-order two-loop corrections are to be calculated within the so-called *external filed approximation* (i. e. neglecting by the nuclear motion), while the recoil effects require an essential two-body treatment. There are a few approaches to solve the two-body problem (see e.g. [31]). Most start with the Green function of the two-body system which has to have a pole at the energy of the bound state

$$G(E \to E_n) \sim \frac{|n\rangle \langle n|}{E - E_n} \ . \tag{3}$$

The theory is needed to construct a perturbative approach to find a position of this pole.

Bethe-Salpeter Equation

The most straightforward way refers to *the Bethe-Salpeter equation*, i.e. an equation for the two-body Green function. It may be solved for the Coulomb potential and a two-body perturbative theory can be developed starting from this solution. This method was rarely used in the bound state QED calculations, being very complicated.

Effective Dirac Equation

An obvious disadvantage of this approach is a complicated two-body perturbation theory. Actually, if one studies the Green function with some particular kinematics (i.e. with the nucleus in the rest, or with the nucleus on the mass shell) the Green function still has a pole. We can study equations for this Green function with reduced kinematics. Since the nuclear degrees of freedom are strongly reduced, it is possible to find an effective single-particle equation. The price of this reduction is the appearance of new diagrams for interaction. This approach was applied numerous times to hydrogen and muonium. It is a single body perturbation theory – the wave functions and the Green function are essentially the single-particle ones. Any two-body effects (beyond a kind of reduced mass effects) are put into a perturbative Hamiltonian. While nucleus is a real particle and often treated non-relativisticly, the electron is a relativistic one and can be real (on the mass shell) or virtual (off the mass shell). It is described with the help of an *effective Dirac equation* which allows for the easy solution of the "unperturbed problem" with the Coulomb interaction.

Effective Schrödinger Equation

Reducing the degrees of freedom of the only nucleus is fruitful in the case of a heavy nucleus. In the positronium atom the nucleus has the same mass as the electron and it is useful to treat both particles symmetrically. It is well known that the $\alpha^4 m$ terms originate not only from relativistic effects, but also from annihilation contributions and the Fermi interaction. Due to that, the most useful approximation is a non-relativistic one and the final single-body equation is an *effective Schrödinger equation* with Coulomb interaction. This approach, based on an effective equation, was also developed for the few-body problem in nucleus physics.

Effective Non-Relativistic Hamiltonian

An alternative method was developed starting in the thirties. It was an approach with an effective non-relativistic Hamiltonian. The clear advantage is that if theory can be described with the help of a non-relativistic Hamiltonian, the two-body problem is not a problem at all. It is just a question of the introduction of a reduced mass. One of the equations of this kind is know as a *Breit equation*. One of the problems of any non-relativistic approaches is a divergency due to short-distance contributions. That is not a divergency which leads to renormalization of mass and charge. It has a different nature – any non-relativistic expansion is incomplete, because corrections become large with high momentum and some integrals are needed to be cut at relativistic momenta. An example of such a cut-off is a well-known calculation by Bethe of the Lamb shift, where the contributions of high and low energy were separated.

Different non-relativistic approaches developing these ideas were introduced. The most effective one, used successfully in positronium and muonium calculations was introduced by Caswell and Lepage and is known as *NRQED* (Non-Relativistic QED) [34]. Some applications to positronium are presented in this edition in Refs. [17,20].

A similar approach (NRQCD) is applied to some quark-antiquark system. The idea of this approach is close to the so-called *operator approach* in particle physics. A cut-off is introduced everywhere to split distance/momentum/energy into two parts. The one uses perturbative physics and the other cannot. In the case of NRQED the perturbative effects are non-relativistic and they deal with the Schrödinger wave function and Green function. The non-perturbative part comes from relativistic contributions to effective operators and has to be determined beyond the non-relativistic expansion within NRQED. The relativistic operators are usually found by calculating relativistic scattering amplitudes and matching them with a phenomenological non-relativistic hamiltonian.

3.10 Exotic Atoms (see [35,36] and Part IX)

The situation is similar to when one used to deal with an object of a simple structure of the states, but a complecated nature. There are a number of examples of such objects in atomic, nuclear and particle physics. An effective hamiltonian, described with a few parameters, is usually introduced and the parameters must be determined experimentally. A well-known example is the nuclear contributions to the atomic energy levels in the hydrogen-like atoms

$$\Delta E(nl) = \frac{2}{3}\,\frac{(Z\alpha)^4 mc^2}{n^3}\,\left(\frac{mcR}{\hbar}\right)^2 \delta_{l0}\ . \tag{4}$$

We cannot calculate the nuclear structure but we can describe the leading correction to the Lamb shift with the help of a simple delta-like potential, which depends on a single parameter, the nuclear charge radius R, calculated as $\sqrt{\langle R^2\rangle}$. The parameter must be found experimentally. Usually this contribution is small enough and if necessary some corrections can be calculated.

There is a kind of atom where the nuclear effects are very large – exotic atoms, containing hadrons, i.e. particles that can interact strongly: pions, antiprotons, kaons etc. In such atoms any advanced high-accurate QED theory is not necessary and a goal to study such atoms is to measure these nuclear parameters. An important feature of any spectroscopic measurement is its high accuracy in respect to non-spectroscopic methods. That is very important for exotic atoms, because some, like e.g. pionium ($\pi^+\pi^-$-system or bound $\pi\mu$-system), are available in very small quantities (a few hundreds) [35].

Pionic Atoms and Antiprotonic Atoms

Recently, serious progress was made in pionic and antiprotonic atoms and that gave new results about scattering lengths and the pion mass. The work with

these atoms is limited by the their lifetime because of the unstability of the pion and the annihilation of the antiproton with the nucleus. However, it was found that some atomic states in antiprotonic helium can have a long life time, because of a high value of the orbital momentum and, thus, a low annihilation rate of the orbiting antiproton and nuclear proton [36]. For such an atom we can expect some really precise measurements which can provide us with e.g. an accurate value of the (anti)proton mass.

3.11 Antihydrogen and CPT Violation (Part IX)

There is an atom which contains an antiproton and nevertheless it is stable. That is *anti*hydrogen[2]. Its spectrum must be the same as the hydrogen spectrum, it is questionable if it really is the same. A goal of two large international collaborations projects running at CERN is the production and spectroscopic study of slow (trapped) antihydrogen atom in order to test CPT invariance, which implies the same mass, charge, magnetic moment etc of particles and their antiparticles.

3.12 Exotic Events

While experiments with an antihydrogen atom (after experimental success in its trapping, cooling and keeping for a while in the trap) look like routine measurements (but an extremely accurate one), another kind of search for new physics is a search for exotic events which are forbidden within the Standard model but can nevertheless occur within its extensions. A few of them deal with simple atoms.

One is based on a study of the possibility of the conversion of muonium (μ^+e^--system) to antimuonium (μ^-e^+-system) [12]. This is possible in the case of non-conservation of electronic charge (i.e. the number of electrons and electronic neutrinos minus the number of positrons and antineutrinos) and muonic charge (i.e. the number of muons and muonic neutrinos minus the number of their antiparticles). Both must be conserved separately with the Standard Model.

Another example is dealing with the search for different exotic modes in the decay of positronium [13]. Some of them involve no new particles but violates C and P symmetry, the others are supposed to produce new neutral particles.

3.13 Variation of Constants (Part X)

In contrast to the search for exotic events with a low probability, one can try to learn new physics with the help of high accuracy. The most promising way now is likely to look for a variation of results due to different circumstances. One possibility is a variation of fundamental constants with time. Some of these comparisons can be done over an astronomical time [37].

[2] The couple atom-*anti*atom produced for the first time, was actually an exotic systems: $\pi^+\mu^-$ and $\mu^+\pi^-$ (see [35] for detail). However, only in the case of antihydrogen some precision study can be possible.

3.14 Precision Frequency Metrology ([38] and Part X)

Precision frequency metrology is now compatible for the search of a variation of the constants [38]. A new generation of frequency chains [8] allows to easily do two kind of frequency measurements which were hardly available previously:

- the comparison between two arbitrary optical lines;
- the comparison between an optical line and a microwave signal.

Recent progress in the development of the chain was inspired by the study of the $1s - 2s$ transition at MPQ [6].

3.15 Determination of Fundamental Constants ([39,40] and Part X)

Another metrological application of simple atoms is the determination of values of the fundamental physical constants. In particular, the use of the new frequency chain for the hydrogen and deuterium lines [6] provided an improvement of a value of the Rydberg constant (R_∞). But that is not the only the constant determined with help of simple atoms. A recent experiment on g factor of a bound electron [27,11] has given a value of the proton-to-electron mass ratio. This value now becomes very important because of the use of photon-recoil spectroscopy for the determination of the fine structure constant [41] (see also [8]).

The fine structure constant α can be determined with the help of several methods. The most accurate test of QED involves the anomalous magnetic moment of the electron [40] and provides the most accurate way to determine a value for the fine structure constant. Recent progress in calculations of the helium fine structure has allowed one to expect that the comparison of experiment [23,24] and ongoing theoretical prediction [23] will provide us with a precise value of α. Since the values of the fundamental constants and, in particular, of the fine structure constant, can be reached in a number of different ways it is necessary to compare them. Some experiments can be correlated and the comparison is not trivial. A procedure to find the most precise value is called the *adjustment of fundamental constants* [39]. A more important target of the adjustment is to check the consistency of different precision experiments and to check if e.g. the bound state QED agrees with the electrical standards and solid state physics.

Fundamental physical constants are universal and their values are needed for different problems of physics and metrology, far beyond the study of simple atoms. That makes the precision physics of simple atoms a subject of a general physical interest. The determination of constants is a necessary and important part of most of the so-called *precision test* of the QED and bound state QED and that makes the precision physics of simple atoms an important field of a general interest.

4 About This Publication

Precision physics of simple atoms offers the opportunity of interdisciplinary exchange between atomic spectroscopy, nuclear and particle physics and quantum

field theory. Our publication is devoted to the following main topics: the hydrogen atom, muonium and positronium, the neutral helium atom and helium ion, few-electron highly-charged ions at medium and high Z, muonic and exotic atoms, and the determination and variation of fundamental physical constants. This publication is based on oral and poster presentations from the *Hydrogen Atom 2* meeting, which took place in Castiglione della Pescaia (May, 31–June, 3, 2000). The *Hydrogen Atom 2: Precise Physics of Simple Atomic Systems* was the second conference, following the initial *Hydrogen Atom* meeting in 1988. This publication consists of a book and a CD with reviews and contributed papers to both *Hydrogen Atom* meetings.

The review contributions of the more recent meeting, *Hydrogen Atom 2*, form the book, which presents the state of the art in

- high-resolution spectroscopy of hydrogen and helium;
- the study of muonium and positronium;
- precision spectroscopy and the determination of the fundamental constants;
- spectroscopy of highly-charged ions;
- the formation and spectroscopy of exotic atoms.

The consideration of the basic problems and recent progress in the field is continued in an electronic book of contributed papers, which is on the CD. To simplify the use of the books we also put onto the CD the book of reviews.

The *Hydrogen Atom 2* meeting covers advances in the physics of simple atoms made over more than a decade since the first meeting *the Hydrogen Atom*, which took place in Pisa in June, 30–July 2, 1988. The proceedings of this meeting [5] were published by the chairmen, G. F. Bassani, M. Inguscio and T. W. Hänsch, and their scanned content is also included on the CD.

Thus, this publication consists of:

- The book *The Hydrogen Atom: Precision Physics of Simple Atomic Systems*, edited by S. G. Karshenboim, F. S. Pavone, G. F. Bassani, M. Inguscio and T. W. Hänsch (XXIII, 293 pages);
- The CD which contains, in pdf form,
  - The contents of the above book;
  - *The Hydrogen Atom: Precision Physics of Simple Atomic Systems. Contributed papers*, edited by S. G. Karshenboim, F. S. Pavone (509 pages) as a pdf file;
  - A scanned copy of the book *The Hydrogen Atom* of 1989, edited by G. F. Bassani, M. Inguscio and T. W. Hänsch (351 pages).

The book contains the author and subject indexes for the whole publication.

Acknowledgements

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- the MPQ staff and especially Mrs. R. Lechner for her heroic work during the conference and the Mrs. C. Thomas-Varcoe for ediditig some sections of this book;
- the LENS staff and especially M. Giuntini for preparing the conference website [42];
- the VNIIM staff and especially Oleg Rybkin and Ivan Schelkunov for their help in preparing two permanent websites for the meetings on Precision physics of simple atoms [43,44].

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