

Section.1 : Fundamental interactions

The investigation of nuclear properties played an important role in further developing the understanding of fundamental interactions. This statement is perhaps best illustrated by the original Lamb shift experiment where RF techniques originally developed for measuring nuclear ground state properties have been used to determine a small deviation from the Dirac values indicating the need to reformulate the interaction of light with matter. One could state equally well that the invention and use of accelerators in the field of nuclear physics laid the foundation for the present understanding of nuclear and high energy physics. Nuclei or nucleons being subject to all kinds of interactions beyond strong interaction continue to contribute to a deeper understanding of the laws of nature. This extends from strong interaction proper to increasingly precise tests of the structure of electroweak interactions.

Even with the Standard Model (SM) now widely accepted, high precision studies are still necessary to refine theoretical tools for detailed calculations of higher order phenomena inside the SM. Expressed differently it is not sufficient to know the structure of an interaction *in principle*, but the theoretical tools should be confronted with experiments at the highest precision. As an illustrative example the high precision measurements of QED in bound states of high Z hydrogen-like atoms (Lamb shift and g -factor measurements) are mentioned here. A second example is the investigation of strong interaction phenomena in elementary hadronic atoms like ponium or pionic as well as kaonic hydrogen. Both experimental programs have in common that they are conducted with two body systems thus avoiding many body effects which would render high precision experiments impossible.

As it is also widely accepted that the SM will not be the final theory any effort should be undertaken to find hints for new physics. Again only simple systems with well controlled properties (both experimentally and theoretically) can be used for a search of physics beyond the SM. Such systems are also available outside high energy physics as are bare nucleons or nuclei at rest. Good examples for modern experiments are the search for the EDM of the neutron or correlation experiments with neutrons or trapped atoms. Also the use of nuclear physics techniques for the study of highly ionized atoms or exotic atoms opens many possibilities for high precision experiments also beyond the standard model. Examples are the search for right-handed currents in weak decays or the search for violation of conservation laws like CP or CPT.

1.1 Within the standard model

1.1.1 QED

QED is the basis and cornerstone of all present field theories. It is the best-confirmed theory in physics. The more it is important to investigate QED predictions under as many different circumstances as possible and especially at extreme conditions. Atomic systems permit a study of bound state QED at higher order of the perturbation series expansion and additionally for high values of the electric field. Exotic atoms provide in addition a means to test few body Coulomb calculations with extremely high accuracy.

1.1.1.1 Higher order corrections

Despite the enormous success of QED in predicting the properties of electrons in weak fields, a precise test is still pending for the strong field limit where new phenomena might show up. Thus, a primary goal is to explore the behaviour of electrons in the strongest

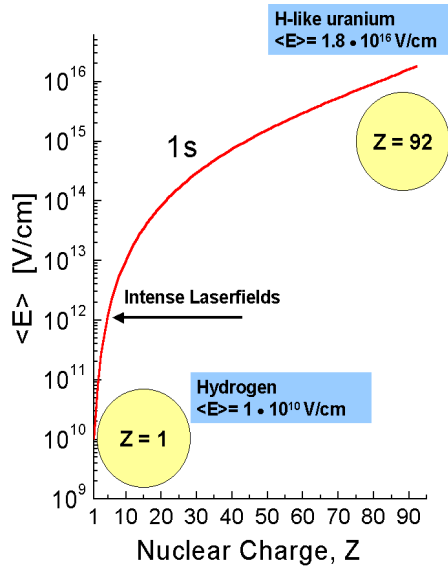


Fig. 1.1.1 : Expectation value of the electric field strength for a K-shell electron as function of the nuclear charge number [1].

keV, a stringent test of QED requires an absolute experimental accuracy of about ± 1 eV which represents the accuracy theoreticians claim presently. For such studies the storage and cooler ring ESR at GSI-Darmstadt provides favourable conditions where intense beams of high-Z ions up to bare uranium are available for experiments. This has been demonstrated within the first series of experiments performed at the ESR gas jet target as well as at the electron cooler device. For the case of the 1s-Lamb shift in hydrogen-like uranium, the achieved accuracy of ± 13 eV [2] is already a substantial improvement by almost one order of magnitude compared to a former experiment conducted at the BEVALAC accelerator. The result obtained gives the most precise test of QED for a single electron system in the strong field region and is now at the threshold of a real test of higher-order QED contributions. A prerequisite for the currently reached precision is the capability of the ESR to decelerate high-Z ions in order to reduce systematic uncertainties associated with the Doppler effect. By using decelerated beams, further progress towards an absolute accuracy of 1 eV can be anticipated. The deceleration mode not only reduces the uncertainties in the Doppler corrections but in particular, it

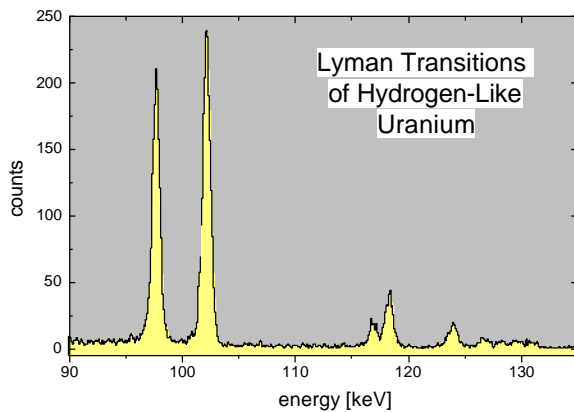


Fig. 1.1.2: X-ray spectrum measured at the ESR/GSI associated with Lyman transitions in hydrogen-like uranium [2].

electromagnetic fields accessible to experimental investigation (see Fig. 1.1.1). Here precision measurements of electron binding energies are best suited to deduce characteristic QED phenomena. Therefore, the comparison of predicted and experimentally determined energy levels of strongly bound electrons provides a critical test of QED in strong fields.

Whereas low-Z ions are primarily sensitive to the lowest-order self-energy corrections, the study of the higher-order self-energy and vacuum polarisation contributions requires the heaviest ions available. Here, the goal of the experiments is to probe higher-order QED contributions, which correspond to Feynman diagrams such as the two-photon exchange diagrams. For the case of uranium, where the total 1s Lamb shift contributes 465.8 eV [1] to the total ground state binding energy of 131.814

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Beside the precision measurements of binding energies (Lamb shift), the measurements of the magnetic moment anomaly (g-factor) of the bound electron in highly charged ions provide important tests of bound-state QED calculations. The experimental determination of the g-factor of the free electron to a few parts in 10^{-12} , $g_{\text{free}} = 2,002\,319$

304 377(9), performed by Dehmelt and coworkers on a single electron in a Penning trap, is by far the most precise test of the theory of Quantum Electrodynamics for free particles. However, information on the g -factor of the bound electron in hydrogen-like ions was until recently available only for the hydrogen atom and the ${}^4\text{He}^+$ -ion. For the determination of the g -factor of the bound electron in highly charged ions as a test of bound-state QED a precision Penning trap has been developed in a joint effort of the University of Mainz and GSI-Darmstadt. The g -factor of the bound electron is determined from the Larmor precession frequency of the bound electron and the cyclotron frequency of the hydrogen-like ion stored in the Penning trap. The recent measurements of the g -Factor Collaboration yielded the g -factor of the bound electron in hydrogen-like carbon ${}^{12}\text{C}^{5+}$ with an accuracy of a few ppb, $g_e^{\text{exp}}(\text{C}^{5+})=2.001\,041\,596\,(5)$, in excellent agreement with the theoretical value of $g_e^{\text{th}}(\text{C}^{5+})=2.001\,041\,591\,(7)$. This is one of the most stringent tests of bound-state QED. In the future, the g -Factor Collaboration will extend the g -factor measurements up to hydrogen-like uranium U^{91+} (HITRAP Project) [3]. This will provide a crucial test of QED calculations in extreme electromagnetic fields.

In addition, the development and understanding of QED in strong fields can be improved significantly for many body systems by measuring, e.g., the $2s_{1/2}-2p_{1/2}$ (≈ 280 eV) or the $2s_{1/2}-2p_{3/2}$ (≈ 4.5 keV) splitting in Li-like uranium to an accuracy of 10^{-2} eV. Lithium-like ions are in particular suited since they represent a good compromise between the request for reliable calculations of the electronic factor and low atomic excitation energy. Consequently the most precise experiments were conducted for Li-like high- Z ions at the Super-EBIT and at an accelerator [4, 5]. For the goal of an accuracy of 10^{-2} eV, laser based techniques appear to be most promising. At the ESR photon energies in the laboratory frame of around 110 eV would be sufficient to induce the 280 eV $2s_{1/2}-2p_{1/2}$ transition in uranium when the laser light is counter propagating with respect to the ions. Such a photon source could be provided by an X-ray laser pumped by multi-terawatt pulses from the 10 J front-end of the laser system PHELIX presently under construction at GSI [6]. The experimental procedure will be similar to the established scheme used for laser spectroscopy of the ground state hyperfine splitting in hydrogen-like ions. For low- and medium- Z ions, high-precision spectroscopy experiments can also be anticipated for investigations at EBIT devices.

In contrast to electronic atoms where the self-energy graph contributes mostly to the QED correction of binding energies, exotic atoms probe a region at even higher electric field and are mostly sensitive to the vacuum polarisation term. The presently reached accuracy of about 900 ppm [7] is limited by the fact that the unknown occupation of the electron shell around the exotic atom leads to uncontrollable shifts of the measured energies. Modern experiments can be conducted with a fully ionised electron shell or under circumstances where the assumption on the status of the electron shell can be checked. High resolution bent crystal Bragg spectroscopy offers many possibilities for a better determination of the vacuum polarisation term both in muonic and pionic atoms. This opens the way to test the higher order QED contributions to third order in the fine structure constant [8].

An important contribution to the test of QED predictions in electronic hydrogen to be mentioned later (see [34] in section 1.2.4) is the proposed determination of the proton charge radius by a determination of the $2s-2p$ energy difference in muonic hydrogen with a Lamb shift type experiment. An increase in accuracy of a factor of 20 is envisaged for the first step of an experimental series including in future muonic deuterium and He- isotopes [9].

1.1.1.2 Experiments with antiprotons: antiprotonic atoms and collision studies.

Present and future experiments with antiprotonic atoms focus on a high-resolution laser spectroscopy of antiprotonic helium and hydrogen atoms. The applications in terms of fundamental questions range from the test of conservation laws or fundamental principles to the calculation of few body Coulomb problem.

In past the theory of the pure Coulomb few body quantum problem was checked in atomic systems like the He atom, and further developed in muonic molecular ions during the investigation of muon catalysed fusion. It is extended today to calculations of binding energies of "atomcules" formed by an He nucleus plus an antiproton and an electron. The corresponding experiments have been very successfully executed at CERN/LEAR and will be exploited further in the AD period in the ASACUSA experiment [10]. They are based on the discovery of metastable states with lifetimes of the order of μs , which allows Laser and HF excitation. At present, a complete picture of the atomcule states is emerging with about 20 different transitions found for the two He isotopes (three recently at the AD machine). In parallel to the highly developed experimental technique, the three-body calculations have reached a high level of sophistication, which includes relativistic effects and QED corrections like the Lamb shift [11]. Accuracy on the 0.1 ppm level is achieved at present with prospects to increase these still further into the region of several ppb, which requires higher order QED calculations in a system different from the usual central potential systems, which is of interest in itself.

Future experiments require dedicated Laser equipment and the ability to stop enough antiprotons at low pressures in order to minimize pressure broadening. In the ASACUSA experiment a RFQ will be used to decelerate the antiprotons from the 5.3 MeV delivered by AD to energies in the region of about 100 keV and to collect them in an electromagnetic trap.

In addition the high precision study of the atomcules delivers information on intrinsic properties of the antiproton like its charge, mass and magnetic moment which leads in comparison with the equivalent numbers for protons to a test of CPT violation which is also planned for the antihydrogen measurements to be discussed below [12].

With well developed Laser and stopping techniques, it is also planned to do a spectroscopy of high lying levels (n between 40 and 50) of the protonium atom. Narrow line widths can be achieved using a two-photon excitation with a subsequent ionisation step in order to provide a signal. In case of success, a value for the antiprotonic Rydberg energy of unprecedented accuracy would be achieved.

Based on the RFQ deceleration technique collision experiments will be performed extending the earlier experiments on ionisation cross sections at LEAR [13]. Cooled antiprotons will be extracted again from the electromagnetic trap for *e.g.* experiments on the energy loss of antiprotons in hydrogen gas. With the stable antiprotons the present knowledge about the ionisation processes of negatively charged particles and the formation of exotic hydrogen atoms can be considerably developed further. With a source of low energy antiprotons at hand also a new version of protonium and antiprotonic deuterium spectroscopy with a fast CCD detector can be undertaken resolving the puzzling situation left behind after the LEAR experiments [14].

1.1.2 QCD.

Recently much theoretical effort went into the development of perturbation theories of strong interaction in the confinement regime based on the concept of chiral perturbation symmetry, which was also extended to include baryons in the Heavy Baryon Chiral Perturbation Theory (HBChPT). The study of the $\pi^+\pi^-$ (pionium) system with the DIRAC experiment at CERN, provides a direct insight into the mechanism of chiral symmetry breaking. The high precision measurement of the ground state shift and width of pionic hydrogen tests the heavy baryon chiral perturbation theory to 4-th order. Experiments with kaonic hydrogen will extend this kind of experiments to strange quarks.

1.1.2.1 Pionium.

A system consisting out of two pions is conceptually the simplest system to study strong interaction effects. In an ongoing experiment at the CERN Proton Synchrotron it is planned to measure the lifetime of the ground state of the pionium atom with an accuracy of 10% [15]. As the strong interaction width of the ground state is proportional to $|a_0 - a_2|^2$ (a_0 and a_2 are the isoscalar and isotensor scattering lengths), the measurement directly determines a combination of two isospin separated scattering lengths with a 5% accuracy. Chiral perturbation theory predictions are on the same level of precision. Further developments are under study to also measure the QCD Lamb shift and extend the experiment to a study of the electromagnetically bound πK system which would allow to study the mechanism of chiral $SU(3)_L \times SU(3)_R$ symmetry breaking.

1.1.2.2 Pionic hydrogen.

The linear combinations of the isospin separated scattering lengths a^+ and a^- of the pion-nucleon system can be determined from measurement of the strong interaction shift ($\propto a^+ + a^-$) and width ($\propto (a^-)^2$) of the ground state of pionic hydrogen. This provides a stringent test of predictions from HBChPT. Moreover, the width (a^-) value alone allows the determination of the πNN coupling constant via the GMO sum rule. At present, an extraction of both scattering lengths with equivalent precision pionic hydrogen alone is hampered by a relatively bad determination of the width and relies on a separate measurement of the shift in pionic deuterium [16]. A determination from pionic hydrogen alone would not only provide a guide line for the further development of the HBChPT higher than 4-th order together with an unprecedented accuracy of the πNN coupling constant but would also allow to test the understanding of the pionic deuterium system [17]. Future experiments will profit from a much improved peak/background ratio compared to earlier experiments together with a substantially enhanced statistics.

1.1.2.3 Kaonic hydrogen.

The investigation of the kaon-nucleon system aims at the understanding of SU3 chiral symmetry breaking. Measurements of the ground state level shift are planned for kaonic hydrogen and deuterium atoms. First measurements have been performed at KEK where the Lyman series of Kaonic hydrogen has been discovered [18]. A dedicated set-up at the storage ring DAΦNE at Frascati will perform a 1% measurement of the isospin separated scattering lengths in near future [19]. Such a precision implies a determination of the KN sigma term, which is also a sensitive and direct measurement of the strangeness content of the proton.

1.2 Beyond the standard model.

1.2.1 *Electric dipole moments of particles nuclei and atoms.*

The discovery of a particle or nuclear electric dipole moments (EDM) implies a violation of both parity and CP reversal invariance. It would shed some light at the stage in the development of the universe when these symmetries have been broken. Depending on time and energy of this event accelerator experiments would eventually never reach the corresponding energies. High precision experiments are in this respect complementary. Especially experiments on the EDM of the neutron have played an important role in non-accelerator particle physics and have reached a record in discarding theoretical models. The standard model (SM) prediction of about 10^{-32} e cm for a neutron EDM is still very much below the present experimental upper limit (at 90% confidence level) of 6.3×10^{-26} e cm as published in 1999 [20] and quoted in the compilation of the Particle Data Group. It may be argued at this stage that EDM experiments are therefore not able to answer fundamental questions. The contrary is true, as they are extremely sensitive to possible new physics beyond the standard model and because a positive result would shed light on the reason for the observed baryon-antibaryon asymmetry [21]. Recent developments in gauge theories with spontaneously broken symmetries have rendered different models for the description of CP violation [22, 23]. Supersymmetric (SUSY) models, two and multi-Higgs doublet models extend the SM and predict neutron EDM to be allowed to first order in weak interaction, which should be on the level of about 10^{-26} to 10^{-28} e cm.

Most experiments exploit the Ramsey separated field technique of magnetic resonance with a superimposed electric field. An experimental breakthrough was achieved by using ultracold neutrons (UCN). UCN are easily polarised and may be stored for a long time in a material trap (neutron bottle) which drastically increases the resolution of the experiment. Multi-cell arrangements are considered in order to suppress systematic errors as much as possible. Also the low velocity of the UCN is decisive in reducing systematic errors caused by motional fields. A very delicate part in the technical development is a proper design of magnetometers, which map the magnetic field distribution. New approaches to use solid deuterium to increase the flux density of UCN are presently being developed with promising results. The technical realisation is being considered at Los Alamos and in different European institutions as well (Munich (Mainz) or PSI).

A completely different experimental method, using superfluid He with ^3He as polariser and analyser with a ^3He magnetometer, is presently investigated at Los Alamos. The goal envisaged is to reach a sensitivity of 10^{-29} e cm [24].

Also experiments (discussed below) concentrating on the high precision measurement of neutron decay parameters in searching for effects beyond the SM profit as well from the development of high intensity UCN sources.

Complementary to the experimental efforts with neutrons also a search for electron EDM has been conducted in atomic physics experiments. Here a drastic enhancement is calculated for the measurement of electron EDM in heavy atoms [25, 26]. Not being subject to strong interaction, electron EDM experiments test theories different from neutron EDM studies. In table 1.2.1, table below, also a value for the muon EDM is included which originates from the CERN g-2 set-up. At present, there are plans or proposals for a drastic increase in sensitivity for all three particles.

particle	experimental limit	SM prediction
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	[e cm]	[e cm]
n	6.3×10^{-26}	10^{-32}
e	4×10^{-27}	10^{-40}
μ	1×10^{-18}	10^{-38}

Table 1.2.1 : The experimental limits of EDM experiments are shown together with standard model expectations for different particles.

The best EDM limit for an object was obtained for the ^{199}Hg atom with an upper limit of 9×10^{-28} . Interpreted in terms of nuclear EDM this value delivers a result that is still about 6 orders of magnitude above the SM prediction, which is a situation similar to the neutron EDM measurements.

The μ EDM is presently under consideration for an experiment at the g-2 storage at Brookhaven. Using a remarkable idea to compensate for the precession in the magnetic field by using a suitable radial electric field, a sensitivity of 10^{-24} e cm is expected [27]. Based on this idea there are approaches for the measurement of nuclear EDM at cooled storage rings. An EDM should show up in the built up of a polarisation perpendicular to the accelerator plane. Such a polarisation could be measured by using β decay of radioactive nuclei or by using polarisation scattering after extracting the beam.

1.2.2 Weak interaction decays.

Weak interaction decays permit a sensitive test of the validity of the standard model from the measurement of small effects in different decay parameters. The relevant terms in the formula for the decay rate W for a semileptonic transition from an oriented sample of nuclei or particles with vector polarisation \mathbf{J} , spin \mathbf{s} and momentum \mathbf{p} of the detected lepton and \mathbf{q} being the momentum of the unobserved neutrino are given by:

$$W \propto [1 + A (\mathbf{J}\mathbf{p})/E + B (\mathbf{J}\mathbf{q})/E_{\nu} + D \mathbf{J}(\mathbf{p} \cdot \mathbf{q})/E E_{\nu} + R \mathbf{J}(\mathbf{p} \cdot \mathbf{s})/E + \dots],$$

E, E_{ν} are the total energies of the emitted leptons. A and B are the usual decay asymmetry parameters arising from parity violation, the D and R parameters are different from zero only if time reversal and/or parity violation is taken into account.

1.2.2.1 Neutron \mathbf{b} -decay.

The SM restricts the weak interaction Hamiltonian to two types of interaction, vector and axial vector, which form left-handed hadron and lepton currents. Many experiments are carried out inside the framework of the SM in order to determine different parameters with ever increasing accuracy as the lifetime of the free neutron or different correlation parameters from observables in the neutron decay.

A sensitive search for a deviation from the SM can be carried out by measuring *e.g.* the B -coefficient providing a new limit for the mass of a right handed boson $M_{WR} > 302 \text{ GeV}/c^2$ [28].

One illuminating example for the impact of neutron decay studies is the recently observed evidence for a deviation from unitarity of the first row of the CKM matrix as obtained at ILL with the PERKEOII experiment [29].

An experiment to search for a T-odd, P-odd observable has been set up at a polarised neutron beam line at PSI [30]. It is sensitive to the R-parameter, and will result in vastly improved limits for Scalar and Tensor contributions to the V-A interaction.

1.2.2.2 Nuclear β -decay.

In the last years various facilities in Europe have developed techniques to produce radioactive nuclides which otherwise only exist transiently during astrophysical processes like supernova explosions. Together with atom- and ion-trapping techniques developed in the atomic physics community, this has created new possibilities to study basic laws of nature and to detect possible insufficiencies of today's theoretical models. A promising means to observe phenomena in disagreement with the Standard Model is a study of processes governed by the weak interaction. As an example, we discuss the β -decay of a nucleus, when a neutron changes to proton or vice-versa. Measuring the details of the decay reveals the structure of the interaction.

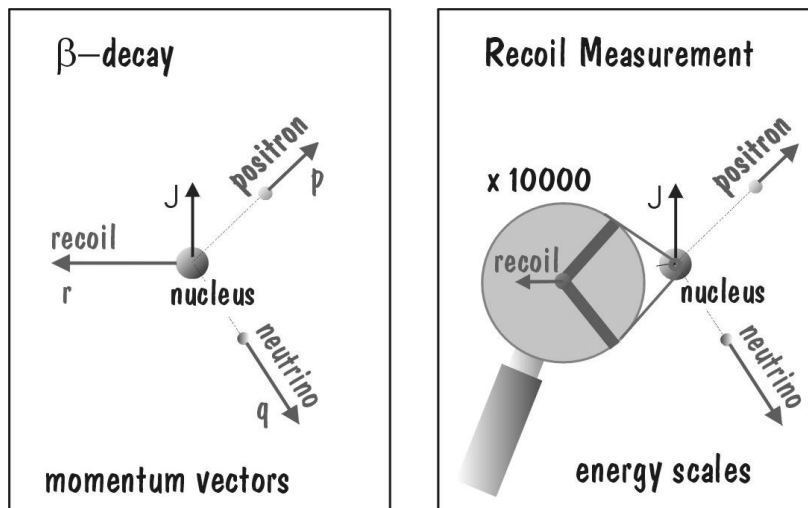


Figure 1.2.1: β -decay parameters in terms of momentum (left) and energy (right). \vec{p} , \vec{q} and \vec{r} indicate the momenta of the positron, neutrino and recoiling nucleus, respectively. Also, the direction of the spin \vec{J} of the parent nucleus is indicated. The electron and neutrino have typical energies of about an MeV. The electron can be measured by standard techniques. However, the neutrino can, of course, not be measured here. Therefore, accurate detection of the recoiling nucleus is essential for recovery of the neutrino momentum \vec{q} . Due to its large mass the energy of the recoiling nucleus is only a fraction $\sim 10^{-4}$ of the decay energy and is at most about 100 eV. With such low energies it will stop immediately in any supporting material. Therefore, the trap environment is ideal for such measurements: The radioactive sample can be collected and held at a well-defined position without supporting material, while its spin direction may be manipulated.

The corresponding 'ideal' experiment is conceptually as simple as it is difficult in practice: by optical pumping, selected radioactive isotopes can be polarised while their thermal motion can be minimised. Observing the β -particle (electron or positron) and the recoiling nucleus in coincidence, the full kinematics of the event including that of the unobserved neutrino can be established in detail, as shown schematically in figure 1.2.1. Such ideal measurements give immediate access to observables that test the Standard Model in detail. The correlation $J(\mathbf{p} \cdot \mathbf{q})$ is e.g. an observable which is odd under time reversal and, therefore, any *measurable* deviation of its expectation value from zero would be inconsistent with the Standard Model. The energy of the recoiling nucleus ($<100\text{eV}$) is extremely small for nuclear physics standards and requires the use of atomic physics detection techniques. This requirement combined with the possibility to manipulate the spin direction makes traps the ideal apparatus for this research. To solve the practical problems many technical and scientific innovations will be necessary. For an observation of deviations from the Standard model e.g. high loading densities of short-lived nuclides are necessary, independent of the specific type of trap that will be used. New know-how and skills of scientific and technical staff will be developed.

1.2.2.3 Perspectives.

The neutron decay experiments will profit considerably from the advent of intensity-enhanced ultraslow neutron beams available in near future at different reactor- and accelerator centers. Experiments using atomic traps are presently being prepared at various places in Europe, e.g. at the Nuclear Accelerator Institute KVI in Groningen/Netherlands, in Leuven/Belgium and at Legnaro/Italy. It can be expected that the joint efforts of atomic and nuclear physicists from various countries - possibly with support from the European Union - will lead to exciting results during the next few years.

1.2.3 Neutrino masses.

The recent results at SuperKamiokande [31] claim for neutrino oscillation, muon neutrinos oscillating to tau neutrinos. The combination of the high precision elastic scattering data of this experiment with the solar neutrino data from the Sudbury Neutrino Observatory [32] provides a strong evidence for neutrino oscillations and therefore indicates the existence of massive neutrinos. This is presently the strongest hint for physics beyond the minimal Standard Model.

A direct search for the existence of massive electron neutrinos is being conducted with nuclear physics methods. The most stringent upper limits for the electron (anti)neutrino are about $2.5 \text{ eV}/c^2$ from two experiments using the MAC-E-Filter technique used both in Troitsk and Mainz. [33,34]. The end point of the electron spectrum from Tritium decay has been chosen as the most promising case. Here the end point is at a relatively low energy, the atoms involved are the most simple ones and the tritium β decay is a super-allowed nuclear transition almost free from nuclear matrix elements corrections.

The best upper limit for an effective neutrino mass which also implies a determination of the character of the neutrinos (Dirac or Majorana particle) comes from double β -decay experiments. The sensitivity presently reached is an order of magnitude better than in the kinematics experiments [35]. Its interpretation, however, is nuclear model dependent and may be subject to cancellation.

Both experimental efforts should be continued. In the kinematics experiment a much improved technique will allow an extension of the sensitivity to the sub-eV level. The present second generation of double β -decay experiments with a sensitivity to half-lives of 10^{28} years will probe effective Majorana neutrino masses down to 10^{-2} eV. In addition these experiments will have huge implications to other fields of physics beyond standard model like dark matter search.

1.2.4 Experiments with antihydrogen.

The production of antihydrogen atoms "at rest" belongs to the most challenging projects of atomic physics at accelerators. A sufficient quantity of these objects given would permit a comparison with the highly developed precision spectroscopy of hydrogen atoms. A two-photon spectroscopy of the energy difference of the 2s-1s states in both the hydrogen and the antihydrogen system profits from the its narrow relative line width. With an anticipated good knowledge of the line shape an extraction of the energy interval with an accuracy of 10^{-18} can be envisaged. The accuracy achieved presently is better than 10^{-13} and is the result of an impressive development with a gain of about one order of magnitude per year over the last decade [36]. Finally a comparison of the frequencies of the hydrogen with the antihydrogen atom would permit a CPT test on the level of accuracy as it is established from the Kaon system [37]. Such a determination is planned by two extremely challenging experiments at CERN/AD [38, 39].

Once the frequency is measurable, a test for the validity of the weak equivalence principle (WEP) can be performed for antimatter. It will be tested whether the 2s-1s frequency measured in an antimatter system depends in the same way on the change in the gravitational potential as for matter. The measurement of the transition frequency will be done for values of the gravitational potential on the way of the earth on its elliptic orbit around the sun. With a 10^{-18} frequency resolution, a test of a violation of the WEP on the level of the original Eötvös experiment could be performed.

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