Precision spectroscopy of Helium

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Abstract. Accurate Quantum-Electrodynamics (QED) tests of the simplest bound three body atomic system are performed by precise laser spectroscopic measurements in atomic Helium. In this paper, we present a review of measurements between triplet states at 1083 nm (2^3S-2^3P) and at 389 nm (2^3S-3^3P). In 4He, such data have been used to measure the fine structure of the triplet P levels and, then, to determine the fine structure constant when compared with equally accurate theoretical calculations. Moreover, the absolute frequencies of the optical transitions have been used for Lamb-shift determinations of the levels involved with unprecedented accuracy. Finally, determination of the He isotopes nuclear structure and, in particular, a measurement of the nuclear charge radius, are performed by using hyperfine structure and isotope-shift measurements.

Keywords: helium neutral atoms, quantum electrodynamics, measurement by laser beam

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INTRODUCTION

Precision spectroscopy in simple atomic systems is a powerful tool for the determination of fundamental physics quantities and for testing Quantum Electrodynamics (QED), perhaps the most accurate theory of physics [1]. In this frame, spectroscopic measurements in Helium atom have been used, for more than four decades, as an accurate test of the QED theory for the simplest three-body bound system. A particular improvement in terms of high precision has been achieved for measurements of He transitions from triplet states. The long lifetime of the lowest triplet state 2^3S, which can be considered as a fundamental He state, makes these precise measurements accessible to the well established laser spectroscopy techniques. In this paper we report a review of these measurements, in particular those related with the transitions between 2^3S-2^3P states at 1083 nm, and 2^3S-3^3P states at 389 nm, as well as their significance for physics when compared with theoretical determinations. Measurements [2, 3, 4, 5, 6, 7, 8] and determinations [9, 10] of the 2^3P fine structure (FS) splittings in 4He have reached the sub-kHz accuracy level. A comparison between them can set a new value of the FS constant α, with an accuracy comparable with determinations of this constant from other physical systems [11]. Furthermore, absolute frequency measurements of the optical He transitions with an accuracy of few parts in 10^-12 or even better can be now performed thanks
to the development of the optical frequency synthesizers (OFS) [12]. From these measurements Lamb-shift values of the involved states can be determined, as we have done recently for the $^{23}\text{S} \rightarrow ^{23}\text{P}$ transition [13]. Precise determinations of the nuclear charge radius of $^3\text{He}$ isotope with respect to the $\alpha$-particle one have been obtained from precise isotope-shift (IS) and hyperfine structure (HS) measurements [14, 15, 16]. This spectroscopic technique for relative determination of nuclear charge radii has proved to be competitive with other nuclear physics techniques, and now it is used for measurements in exotic nuclei of radiative He isotopes such as $^6\text{He}$ [17] and $^8\text{He}$.

**$\alpha$ Determination from $^4\text{He}\ 2^3\text{P}$ Fine Structure Splittings**

The energy of the He states (and hence the energy differences) can be calculated in terms of a power series of the $\alpha$ constant, by using QED theory. The large separation (about 30 GHz) (see fourth section) and short lifetime (about 98 ns) of the $^{23}\text{P}_J$ manifold of states, as well as the cancellation of several QED contributions when calculating the energy difference among them, can potentially provide an accurate determination of $\alpha$ by comparison between theory and measurements for these FS splittings [18]. In fact, the theoretical [19] and experimental [20] efforts during the 70’s and 80’s gave an $\alpha$ value from He FS with an accuracy of 900 parts per billion (ppb) although laser spectroscopy and modern computational techniques had not yet fully developed. Today, the accuracy goal is given by the uncertainty with which $\alpha$ is known. In the last CODATA adjustment of the physical constants [11], $\alpha$ is given with an accuracy of 3.3 ppb, mainly determined by the anomalous magnetic moment ($g - 2$) of the electron, as shown in Figure 1. Apart from the $\alpha$ value from the ratio $\hbar/m_{\text{Cs}}$, $\alpha$ determinations from other physical systems are accurate at the level of tens of ppb, and discrepancies among them are of similar magnitude. Therefore, an $\alpha$ value from He with 8 ppb uncertainty can help to get a more consistent determination of this constant. Due to the fact that FS energies are mainly determined by the leading $\alpha^2$ term, theory and experiment of FS splittings must achieve an accuracy of the order of 16 ppb (or $1.6 \times 10^{-8}$) to be competitive for $\alpha$ determinations. This new $\alpha$ determination by a different method, i.e. a spectroscopic technique, can be a sensitive test of the consistency of physics across a range of energy scales and physical phenomena.

**Experiments**

*The wavelength measurements at Yale University*

FS measurements, until the end of the 80’s were performed by magnetic microwave spectroscopy in the $^{23}\text{P}$ manifold [20]. A completely different approach was taken in an experiment completed in 1995 at Yale University [2]. The development of laser spectroscopy made advantageous to perform FS measurements in the optical domain, i.e. by measuring frequency differences of optical transitions. Shiner and coworkers
measured the wavelength of the different fine structure components of the 1083 nm $^2\!^3S_1 \rightarrow ^2\!^3P_J$ transitions. The detection scheme was again based on a double Stern-Gerlach apparatus, but the demagnetization was caused by the laser beams. The final accuracies were 436 ppb for $^2\!^3P_1-^2\!^3P_2 (\nu_{12})$ and 101 ppb for $^2\!^3P_0-^2\!^3P_1 (\nu_{01})$. The main source of uncertainty was attributed to the interferometric technique used to measure the laser wavelength. To overcome this problem, in the year 2000, this group has improved this experimental apparatus by using sideband modulation spectroscopy to directly measure the $\nu_{12}$ FS frequency [3], similarly to the experimental approach we use in Florence. In this way, they improved by a factor 3 the accuracy for this interval, which is the most accurate result for $\nu_{12}$, to date.

The microwave measurements at York University

At York University, Toronto, microwave measurements have been revived by Hessels and coworkers in a series of experiments begun at the end of 90’s [4, 5]. They could benefit of lasers to prepare He atoms in the $^2\!^3S$ level, to excite the $^2\!^3P$ level and to detect 1083 nm fluorescence after microwave interaction. In this way, systematics effects due to the strong magnetic fields of Hughes experiments were minimized. In fact, they measured with 436 ppb accuracy the $\nu_{12}$ interval, and with sub-kHz accuracy (30 ppb) the largest interval $\nu_{01}$, which is still the most accurate result.

The frequency measurements at Florence

In Florence we have chosen an approach that combines laser spectroscopy with the direct frequency measurements of the microwave experiments. The $^2\!^3P$ FS frequencies
are measured by frequency difference of the $2^3S_1 \rightarrow 2^3P_J$ ($J = 0, 1, 2$) transitions at 1083 nm [6, 7, 8]. We take advantage of the obvious consideration that to obtain the fine structure separations there is no need to precisely know the optical transitions frequencies but just their differences. Thus, if we dispose of two laser frequencies whose difference can be accurately controlled, we may use one as a fixed reference (master laser) and tune the second (slave laser) across the atomic resonances. In fact, our approach reverts to an heterodyne technique, where all the transitions are measured with respect to the same frequency reference, that can take any arbitrary but stable value. In the experimental realization, we obtain the two frequencies by phase-locking two DBR diode lasers at 1083 nm (master and slave), i.e. phase-locking their beat note to a microwave oscillator [21], as shown in figure 2.

Fluorescence saturation spectroscopy in an atomic beam of metastable He was used to detect natural-linewidth (1.6 MHz) limited signals resonant with the slave-laser light, as shown in Figure 3. A detailed description of this experimental set-up can be found elsewhere [6, 7, 8]. Here we just report, perhaps, the most significant difference with respect to other experiments: in our measurements no biasing magnetic field is present. Although, in principle, the first-order Zeeman effect is eliminated by selecting transitions connecting $m = 0$ states, at the kHz level of accuracy even the second-order effect is relevant. As a consequence, we chose to work with zero magnetic field. A cylinder of high-magnetic-permittivity metal ($\mu$-metal) embeds the interaction region to shield it against dc and ac magnetic fields while a pair of Helmholtz coils inserted therein allows for the fine cancellation.

In the last years, these FS intervals were measured by using different experimental setups in order to get better master frequency stability, to increase the S/N of the fluorescence dips, and to control better the experimental parameters affecting the systematic uncertainties. The results are listed in Table 1. The frequency values shown in this table are determined by averaging hundreds of measurements of each interval taken over different days, and by correcting the resulting mean value with the contribution of the
TABLE 1. Fine structure splittings of the $^2P_J$ Helium levels measured in Florence.

<table>
<thead>
<tr>
<th>FS interval$^1$</th>
<th>1998$^2$ (kHz)</th>
<th>2004$^3$ (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_{01}$</td>
<td>29616950.0(2.0)</td>
<td>29616952.7(1.0)</td>
</tr>
<tr>
<td>$\nu_{12}$</td>
<td>2291167.2(15.0)</td>
<td>2291167.7(11.00)</td>
</tr>
</tbody>
</table>

$^1$Uncertainties are given in parentheses.

$^2$From references [6, 7].

$^3$From reference [8].

Systematic effects. In the same way, their uncertainties are given by the quadratic addition of the uncertainties due to the statistical average and to the systematic effects. The main difference between the 1998 results [6, 7] and the 2004 ones [8] is the different frequency reference used to lock the master frequency. In fact, in the 1998 measurements, saturated absorption dips of He at 1083 nm observed in a discharge cell were used as a master frequency reference. As indicated in [6], the master stability (7 kHz in 1s) achieved with this reference and the long-term drifts due to pressure variations in the cell were a limiting factor to get a statistical uncertainty better than 2 kHz. To overcome this problem, we decided to improve the master frequency stability by changing the frequency reference: the hyperfine components of electronic transitions of the iodine molecule at the double frequency (541 nm). To achieve the iodine lock, we developed a new coherent source at 541 nm [22], based on amplification of the master radiation up to 1 W by an Yb-doped fiber amplifier and a single-pass frequency doubling in a periodically-poled KTP non linear crystal. The generated green power is used to perform FM saturation spectroscopy of hyperfine transitions of I$_2$ at 541 nm. We have compared the master stability with this new reference with respect to the He reference used in the 1998 measurements [23], obtaining a stability improvement of about one order of magnitude at short time scales (0.5 kHz in 1s) and cancellation of long-term frequency drifts. As a consequence, the statistical uncertainty was improved, giving a final uncertainty of the 2004 $\nu_{01}$ value that is two times better than the 1998 $\nu_{01}$ uncertainty.

Instead, this improvement was prevented, for the $\nu_{12}$ interval, by the uncertainty of systematic corrections. When the contribution of the Zeeman shift is reduced below 0.1 kHz$^1$, the main systematic correction to our measurements is given by the recoil shift (RS) accumulated by the atoms in the several absorption-spontaneous emission cycles during the interaction time. A detailed description of this systematic effect, lying outside the scope of this paper, can be found in Refs. [6, 24]: we just report that, due to the different absorption-spontaneous emission nature of the 1083 nm transitions in our experimental conditions, the RS is different for all three transitions. Therefore, it does not cancel in the frequency difference, giving a residual correction of about 12 kHz for $\nu_{12}$.
FIGURE 3. Third-derivative signal of the saturated-fluorescence dip for the $^{2}3S_{1} \rightarrow ^{2}3P_{1}$ transition recorded by means of frequency modulation of the slave-laser light. This technique is used to increase the signal-to-noise ratio and to eliminate the residual Doppler fluorescence background. The solid line is the fit to the expected function used to measure the line-center frequency with respect to the master frequency. Residuals of this fit are also shown.

The $\nu_{01}$ interval, which contains the two "open"$^{2}$ transitions $^{2}3S_{1} \rightarrow ^{2}3P_{0,1}$, and of about 190 kHz for the $\nu_{12}$ interval, which contains one "open" and one "closed" transition ($^{2}3S_{1} \rightarrow ^{2}3P_{2}$). More important for our purposes, RS is more sensitive to interaction time (i.e. variations of longitudinal atomic velocity and interacting beam waist) for "closed" transitions than the "open" ones. For this reason, the RS for the $^{2}3S_{1} \rightarrow ^{2}3P_{2}$ transition cannot be determined with an uncertainty better than 15 kHz. Therefore, this error is propagated to the $\nu_{12}$ difference, as shown in Table 1.

As a conclusion of our $^{2}3P$ FS measurements, we notice the agreement between the 2004 and the 1998 results within their combined standard deviation, even in the case of less accurate measurements for the $\nu_{12}$ interval.

The state of the art of the theory

At present, two theoretical groups are working at the QED theory for Helium: one in Windsor University (Canada) [9] and the other in Warsaw University (Poland) [10]. Basically, the idea of both groups is to get a basis of wavefunctions solving the non-relativistic Schrödinger equation for a system of two electrons. Then, the relativistic and QED operators in terms of a power series of $\alpha$ are individuated and their contribution to the energy, by using a perturbative approach. Although each group uses a different strategy to solve the problem, it includes in its calculation terms and operators already

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$^{2}$ Transitions for which the selection rules make at least one of the Zeeman $^{2}S_{1}$ sub-levels uncoupled to the laser light ("dark" levels).
considered by the other, sometimes controlled and corrected with its own theory. Therefore, we have considered the FS theory reported in [9] as the most updated theoretical determination for the $^{233}$P FS energies. This calculation contains all terms up to $\alpha^5$. The final uncertainty for these determinations was 7 ppb for $\nu_{01}$ and 131 ppb for $\nu_{12}$, limited by the uncalculated $\alpha^6$ corrections and by the computational error.

**Discussion**

We show in Table 2 the present situation for measurements and theory of the $^{233}$P FS splittings. Regarding measurements, we notice that there is an agreement between values, at the level of a few kHz accuracy, for both intervals. Due to the different experimental approaches and to the different systematics that affect these measurements, we can conclude that the experimental values of the $^{233}$P FS frequencies are now well determined at this level of accuracy. Therefore, we have calculated a weighted-mean value for these separations, taking into account only measurements with an accuracy better than 3 kHz:

$\nu_{12} = 2291175.3(8) \text{ kHz (350 ppb)}$

$\nu_{01} = 29616951.8(6) \text{ kHz (20 ppb)}$

They must be considered as the most accurate experimental values of the He FS splittings so far.

**TABLE 2.** Summary of the different $^{233}$P FS measurements and calculations.

<table>
<thead>
<tr>
<th>Reference</th>
<th>$\nu_{01}$</th>
<th>$\nu_{01} - \overline{\nu}_{01}$</th>
<th>$\nu_{12}$</th>
<th>$\nu_{12} - \overline{\nu}_{12}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(kHz)</td>
<td>(kHz) ($\sigma$)</td>
<td>(kHz)</td>
<td>(kHz) ($\sigma$)</td>
</tr>
<tr>
<td>Measurements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minardi et al.[6, 7]</td>
<td>29616950.0(2.0)</td>
<td>-3.5</td>
<td>2291167.2(15.0)</td>
<td>-10.4</td>
</tr>
<tr>
<td>Shiner et al.[2, 3]</td>
<td>29616959.0(3.0)</td>
<td>12.0</td>
<td>2291175.9(1.0)</td>
<td>0.7</td>
</tr>
<tr>
<td>Hessels et al.[4, 5]</td>
<td>29616950.9(0.9)</td>
<td>-1.5</td>
<td>2291174.0(1.4)</td>
<td>-1.6</td>
</tr>
<tr>
<td>Giusfredi et al.[8]</td>
<td>29616952.7(1.0)</td>
<td>1.5</td>
<td>2291167.7(11.0)</td>
<td>-9.5</td>
</tr>
<tr>
<td>Calculations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drake et al.[9]</td>
<td>29616946.4(0.2)</td>
<td>-9.0</td>
<td>2291154.6(0.3)</td>
<td>-25.9</td>
</tr>
</tbody>
</table>

1. $\overline{\nu}_{01} = 29616951.8$ kHz, $\sigma_{01} = 0.6$ kHz
2. $\overline{\nu}_{12} = 2291175.3$ kHz, $\sigma_{12} = 0.8$ kHz

Whereas the smallest interval $\nu_{12}$ is used as a test of the theory, measurements and calculations of the largest one $\nu_{01}$ are used for $\alpha$ determination. Pachucki [10] gives a simple formula to get this determination, by considering all QED and relativistic corrections of the order $\alpha^3$ up to $\alpha^5$ as an $\alpha$-independent correction $\delta \nu_{01}$ of the measured value $\nu_{01}$:

$$\nu_{01} - \delta \nu_{01} = \alpha^2 \times 556200289.5(1) \text{ MHz}$$
From [9], we have calculated a frequency correction \( \delta \nu_{01} = -1472.13(50) \) kHz. If we use the simple formula above, we obtain:

\[
\alpha^{-1} = 137.0359872(18) \quad (13 \text{ ppb})
\]

In Figure 1, we have plotted this value with others coming from other physical systems. The \( \alpha \) value from He is the third most accurate determination, but there is a discrepancy of more than 7 standard deviations between this value and the present CODATA recommended value. Such discrepancy implies that this determination is not statistically compatible with the others, following the CODATA criteria [11], although, as we can see in the figure, there is an agreement with some other determinations (e.g. the ac-Josephson effect). The origin of this difference can be attributed to the poor agreement between measurements and theoretical determinations of the FS intervals, as shown in Table 2. This disagreement for the \( \nu_{01} \) interval is about 9 times larger than their combined standard deviations. A larger discrepancy, about 26 combined standard deviations, is found for the smallest interval \( \nu_{12} \). The measured values are well established at the kHz level, as indicated above, and the contribution from uncalculated \( \alpha^6 \) and higher order QED corrections has been estimated to be of the order of about 1 kHz. Therefore we conclude that the discrepancies can be explained with some QED contribution that has not been well evaluated or has not yet been taken into account. With respect to the former cause, Drake and coworkers are controlling some high-order recoil corrections to the \( 2^3 \)P FS, calculated by Pachucki et al. [10]. However this discrepancy could also be due to an additional spin-dependent contribution that has not yet been taken into account, as pointed out by Drake [9].

**ABSOLUTE FREQUENCY MEASUREMENTS OF \( 2^3 \)S\( \rightarrow \)\( 2^3 \)P HE TRANSITIONS AROUND 1083 NM. LAMB-SHIFT DETERMINATIONS**

A larger number of one and two-photon transitions of He lies in the visible and near-UV regions, as shown in Figure 4. Till the end of the last century, the frequency of most of them could not be directly measured against the primary frequency standard. Wavelength measurements were performed [2, 25], except for the \( 2^3 \)S\( \rightarrow \)\( 3^1 \)P transition at 389 nm [26], thanks to the coincidence that such frequency is nearly twice the frequency of the Rb two-photon transition at 778 nm. Now, with the development of the OFS, high-accuracy absolute frequency measurements of optical transitions are possible.

The OFS is like a frequency ruler where each tick is determined by two microwave-RF frequencies: the repetition rate \( \nu_r \) and the carrier-envelope offset frequency \( \nu_0 \), which are directly traceable with respect to the primary frequency standard [12]. A frequency falling in the OFS coverage range can be easily measured by knowing the order number of the nearest tooth of the comb and by counting the RF beat-note frequency between these two frequencies. We have applied this approach to measure the absolute frequencies of the \( 2^3 \)S\( _1 \)\( \rightarrow \)\( 2^3 \)P\( _{0,1,2} \) \( ^4 \)He transitions at 1083 nm [13]. The apparatus used was the same described above for the FS measurements, but we measured the absolute frequency of the \( \text{I}_2 \)-locked master laser with the OFS, while simultaneously
recording the He spectra with the slave laser (see Figure 2). As in the FS measurements, the final frequency values are given by the average of measurements performed in different days, corrected for systematics. Also in this case the main systematic effect is due to RS, so that the $^2\!^3S_1 \rightarrow ^2\!^3P_2$ closed-transition cannot be measured with an accuracy better than $5 \times 10^{-11}$. Instead, accuracies of the order of $7 \times 10^{-12}$ were achieved for the open-ones. By using our value for the $^2\!^3S_1 \rightarrow ^2\!^3P_1$ transition and the mean values of the FS splittings, we have calculated the centroid frequency of the $^2\!^3S \rightarrow ^2\!^3P$ transition of:

$$\nu_c = 276\,736\,495\,650.6(2.4) \text{ kHz} \quad (9 \times 10^{-12})$$

This value is in agreement with a previous measurement [2], but 30 times more accurate. Thanks to the OFS coverage, this result shows the potentiality of our system to measure other He transitions accessible to visible lasers with similar or even better uncertainty.

The centroid frequency was used to calculate the Lamb-shift contribution to the $^2\!^3S$-$^2\!^3P$ energy, by taking the difference between our measurement and the calculated non-relativistic energy. The result is, to our knowledge, the most precise Lamb-shift measurement in a calculable atomic system. These Lamb-shift determinations can be used as a challenge of the QED-multielectronic system theory.

**ISOTOPE SHIFT MEASUREMENTS. DETERMINATION OF NUCLEUS CHARGE RADII OF HE ISOTOPES.**

Measurements of two basic observables in an atomic nucleus, mass and size, can be used to test the standard nuclear structure models. A detailed knowledge about the charge radius of simple nuclei, such as $^3\text{He}$, could help for a better understanding of a number of important issues, including the role of three nucleon forces, relativistic effects and the

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3 The non-relativistic ionization energies of the He states are known with an accuracy better than $10^{-22}$. 

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role of local/nonlocal potentials. The spectroscopic method described here, to measure nuclear radii, has been demonstrated as an alternative powerful tool to conventional scattering methods of nuclear physics [16]. Basically, the energy difference between the transitions involving the same levels in two different isotopes of an atom (i.e. isotope shift) is given by the difference of the finite nuclear volume QED contribution of each isotope, since the other energy contribution cancels in the difference:

\[ \nu_{IS}(\nu) = \nu_{IS}(M_1, M_2, \nu) + c(\nu) \times (r_1^2 - r_2^2) \quad (\text{MHz}) \quad (1) \]

with \( M_1 \) and \( M_2 \) the masses of nuclei, \( r_1^2 - r_2^2 \) is the difference between the mean square charge radii (in \( \text{fm}^2 \)), and \( \nu \) the frequency of the atomic transition. In Helium, the first term of Eq. 1 is a big contribution to the isotope shift of the order of tens of GHz depending on the isotope masses and on the transition considered. The second term, that contains the nucleus size effect, is a small contribution of the order of a few MHz, depending of the constant \( c(\nu) \). If we measure the isotope shift frequency and \( \nu_{IS}(M_1, M_2, \nu) \) and \( c(\nu) \) are calculated by using the He QED theory, we can use Eq. 1 to calculate the relative nuclear radius difference. If the radius of one He isotope is well known, the measurement of the isotope shift essentially yields the radius of the other nucleus. In fact, this technique was used successfully, for the first time, to measure the \(^3\text{He}\) nuclear charge radius by an isotope shift measurement at 389 nm [14]. A more accurate value of this radius, in agreement with the previous one, was obtained by measuring the \(^3\text{He}-^4\text{He}\) isotope shift at 1083 nm [15]. A diagram of the levels and transitions involved in this experiment is shown in Figure 5.

As we can see, in the case of \(^3\text{He}\), the isotope shift method can be used after correction of the hyperfine structure contribution to the energy levels, due to the non-zero nuclear spin of this atom. Therefore, accurate HS measurements and calculations are required to get the \(^3\text{He}\) nuclear charge radius from IS measurements. A “revival” of this spectroscopic method allowed last year to measure the nuclear radii of short-lived neutron-rich isotopes, such as \(^6\text{He}\) [17]. Knowledge of the nucleus size of this exotic isotope is of par-
particular interest because the excess neutrons are loosely bound and form a "halo" around a stable $\alpha$-particle core. The low abundance and short lifetime of this isotope make the IS method a unique technique to measure the nuclear radius with high precision.

**FINAL REMARKS AND PERSPECTIVES**

A summary review of precise spectroscopic measurements of Helium triplet transitions has been reported. In particular, we have reviewed FS and HS measurements of the $2^3P$ manifold of states in $^4$He and $^3$He, respectively, as well as IS measurements between both isotopes. Their implication in accurate determinations of $\alpha$ and nuclear charge radii, and as a testing ground of He QED theory has been also discussed. Moreover, accurate Lamb-shift determinations of the most QED-affected triplet levels are now possible by using precise absolute frequency measurements of He transitions in the visible near-UV range, thanks to the OFS. Although these Lamb-shifts can be used as a challenge of the high-order QED contributions to levels energy, new accurate FS and HS measurements are, at present, preferred by theoreticians, because they might help to understand better the He finite nuclear size and nuclear structure, removing other contributions. To this goal, in Florence we are performing $^3$He HS and $^3$He-$^4$He IS measurements at 1083 nm. A new improvement has been implemented in the experimental apparatus in order to perform these relative frequency measurements: now we phase-lock the master-laser frequency to the nearest tooth of the OFS. In this way, not only a better frequency stability than with the iodine lock is achieved, but we also get absolute frequency control of the master, and hence absolute frequency measurements of the 1083 nm transitions. Moreover, the possibility to simultaneously lock two 1083 nm lasers, resonant with two different He transitions, to two OFS teeth [27], will allow us to measure directly FS, HS and IS in Helium, cancelling common systematic errors and improving the final accuracy.

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